INTEGRATED MASS, SOLUTE, ISOTOPIC AND THERMAL BALANCES OF A COASTAL WETLAND

J. F. Rich	BSc (Geology)	Western Ontario
	Diploma Environmental Impact Assessment	Murdoch

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Twixt Coast and City

F. W. Ramage 1913
Oil on canvas, 29.2 x 39.6 cm
View towards Perth and the old homestead at Perry's Swamps
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ABSTRACT

Mass, solute (chloride), isotope (deuterium) and thermal balances were completed at Perry Lakes, two semi-permanent 'water table' lakes near Perth, Western Australia. All balance components except groundwater discharge/recharge were measured independently. These difficult to measure groundwater components of lake-aquifer interaction were estimated by integrating mass, solute and chloride data in sequential 4 day balances spanning two years. Before urbanisation, such wetlands functioned predominantly as flow-through lakes. Now, large winter storm water inputs (and summer artificial level maintenance pumped locally from groundwater) dominate. In East Lake these inputs together comprise 42% of the annual water budget; groundwater discharge is reduced to just 2%. Even under flow-through conditions, these 'non natural' inputs are so large East Lake always tends towards a recharge state and commonly becomes a local groundwater mound. Flow-through is established in both lakes over winter. Initially each lake functions separately however as winter progresses shared capture and release zones are established. Maintenance of lake levels in early summer forces East Lake back to recharge status.

Sediment heat flux (Qse) is significant in these very shallow lakes. Over summer Qse was negative, with a net movement of heat from the water into the sediments which act as a seasonal heat sink. In winter Qse was positive and stored summer heat was returned to the water column. This flux at times exceeded 40 W m^{-2}. Evaporation was determined independently by floating pan, leaving Qse as the thermal balance residual. Ignoring Qse, annual evaporation determined by thermal balance was over estimated by 7%. Over and under estimates of individual 12 day balance period evaporation exceeded 50%.

Monthly Class A (Perth airport) pan coefficients varied from 0.54 (January) to 0.86 (September). Ten empirical equations for evaporation were calibrated and compared with the East Lake floating pan. Best performer was the Makkink which tracked the floating pan closely throughout all seasons. Poorest were the Penman, DeBruin-Keijman, Priestly-Taylor and Brutsaert-Stricker which grossly over estimated late winter evaporation. Transpiration from *Typha orientalis*, estimated using hydrograph techniques was 43% of open water evaporation in summer and 28% annually. Temperature controlled evaporation pans (tracking lake temperature) experimentally determined the local deuterium content of lake evaporate δ_E, required for isotopic balances. Techniques employing pans evaporated to dryness and pans evaporated at constant volume were run in tandem continuously for two years.

This study singularly integrates mass, solute and isotope balances thereby allowing groundwater components to be accurately quantified. The isotope balances are unique, being the only such balances incorporating experimentally derived local deuterium values of lake evaporate. This study represents the only thermal balance, the only accurate determination of pan-lake coefficients and the first calibration of commonly used empirical evaporation equations for Swan Coastal Plain wetlands.

Groundwater levels in the western suburbs of Perth have declined over 40 years and a disproportionate larger decline now seriously threatens Perry Lakes. Modelling suggests regional groundwater extraction exceeds recharge. Wetland managers can no longer maintain East Lake via local groundwater extraction. Artificial recharge using imported surface and waste water are possible future management options.

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The Town of Cambridge gave me unfettered access to Perry Lakes and records inherited from the Perth City Council (PCC) and assisted with the installation of the top up flow meters. Particular thanks to Ross Farlekas and Ross Bowman and head groundsman Ken Turner.

Piecing together the early history of the lakes and their modifications in the late 1950's relied mostly on oral history and recollections of those who lived in the area. Thanks to Joy Black who assembled much on the early history of the area, former PCC engineer E. P. 'Penn' Smith, former PCC Manager of Parks and Gardens Warren Somerford and surveyor Gordon Laffer. Nancy Phillious who grew up in the ranger's house at Perry Lakes was an invaluable source of anecdotal information on the lakes as they were in the 1950's. Verity James and ABC Radio Perth were instrumental in tracking down the whereabouts of the Ramage painting. Thanks to the Royal Western Australian Historical Society for permission and assistance to have it professionally photographed and Barbara Knott for assistance with its botanical interpretation. Particular thanks go to Ian Lantzke for providing early water chemistry and biological data and the Western Australian herbarium and Jannette Nowell for identification of emergent wetland vegetation and alga respectively.

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CHAPTER

1

INTRODUCTION

1.1 WETLANDS ON THE SWAN COASTAL PLAIN

At the time of European settlement the area covered by the Perth Metropolitan Area contained a profusion of wetlands (Serventy 1948, Bekle 1981, Singleton 1989). An initial survey of the Swan Coastal Plain (Riggert 1966) established that about half of all wetlands had been destroyed. Twenty five years later Godfrey (1989) estimated that 80% of wetlands existing at the time of European settlement had been lost forever. Compared to other Australian cities, Perth is uniquely blessed with an abundance of wetlands, yet for over a century the response to this asset was to devalue it (Halse 1989). Many small, and some larger wetlands close to the Perth Central Business District (CBD) were drained or filled, initially for agricultural development and later for housing or parks. Using wetlands for rubbish disposal was a widespread and convenient intermediate step in this progression. Singleton (1989) notes that the prevailing philosophy was dominated by European perceptions of water bodies (deep, clear, seasonally permanent water, firm sandy bottoms and well defined shorelines). Instead the initial European inhabitants found very shallow lakes with ill defined swampy littoral zones and bottoms of odorous mud or peat. These wetlands were viewed mostly in terms of economics and public health. Few were considered worthy of preservation. Those which survived have frequently been 'beautified' by removing natural fringing and emergent vegetation and reforming banks to remove the littoral zone. Water levels in many of the wetlands which remain have undergone marked changes (Froend *et al* 1993). In particular urban clearing and introduction of storm water has raised some wetland levels while others have suffered declines due to groundwater extraction. Rainfall however remains the principal determinant of groundwater and ultimately wetland water levels (McFarlane 1984, Davidson 1995). A persistent decline in rainfall throughout all of south west Western Australia (Bates 1999) has resulted in water levels in many wetlands falling to their lowest levels since European settlement. In Perth, climate coupled with increasing groundwater extraction is creating new challenges for wetland managers and posing serious threats to the viability of many wetland systems. We cannot manage what we fail to understand. This thesis represents another small step in understanding wetlands and our influence, intentional and otherwise, upon them. It also poses questions and problems which future researchers and managers will need to resolve if the conservation and social values of Perth's urban wetlands are to be preserved.

1.2 BACKGROUND

Recently there has been increased public resistance to wetland destruction and a growing public interest in wetland conservation (Environmental Protection Authority 1989, McComb & Lake 1988 & 1990). In Perth, the turning point may have been a period of severe drought in the 1970's which saw groundwater levels decline and many wetlands dry up. This coincided with the initiation of a number of public water supply schemes to draw water from the extensive unconfined aquifer. Private domestic abstraction also increased dramatically in response to water restrictions, a development encouraged by the then Metropolitan Water Board in its efforts to reduce the demand for reticulated water (Cargeeg *et al* 1987). There was however a growing awareness that public and private extraction of groundwater could have a permanent impact on wetlands. There was also an increased public perception and appreciation of lakes and wetlands as having environmental and aesthetic values worth preserving (Wetlands Advisory Committee 1977). The Perth Urban Water Balance Study (Cargeeg *et al* 1987) commenced in 1982 with a view to developing management strategies for the unconfined aquifer. The study was unique in that it took a holistic approach to urban hydrology. It included two studies completed by the Environmental Protection Authority (EPA) of Swan Coastal Plain wetlands and led directly to a formalisation of strategies for wetland management (EPA Bulletins 227, 374 & 686) and wetland protection (EPA Bulletin 685). A formal policy *Environmental Protection (Swan Coastal Plain Lakes) Policy* was gazetted in 1992. Under the auspices of the Environmental Protection Authority, the Water Authority and the Land and Water Resources Research and Development Corporation (LWRRDC) five major wetland research projects were initiated in 1988 (EPA Bulletin 685, Balla 1994). The result was the seven volume series *Wetlands of the Swan Coastal Plain.* Volume 3 (Townley *et al* 1993b) deals specifically with the special role of lakes in a regional aquifer system. It utilised and expanded upon earlier theoretical work (Oo 1985, Townley & Davidson 1988, Nield *et al* 1994) and field studies (Allen 1979, Hall 1985, Davidson 1983, McFarlane 1984, Townley & Turner 1990 & 1992). This study presented both a theoretical framework and preliminary field validation of the way in which lakes interact with a shallow unconfined aquifer based on water balances. It included a specific recommendation for further research including ...'an intense investigation of a single lake, aiming to determine its water balance, but using solute, isotope and thermal balances as well' (Townley *et al* 1993b p108).

During the drought of the late 1970's a number of wetlands within Metropolitan Perth dried up for the first time in recent memory. At Perry Lakes, experiments with artificial summer level maintenance (Carbon *et al* 1988) suggested that locally derived groundwater from the unconfined aquifer could be used to maintain some water in the lakes over dry years. Over the next twenty years this became the accepted management strategy for the wetland managers, initially the City of Perth and their successors the Town of Cambridge. In 1992 CSIRO were approached to assess the effects of local irrigation bores on Perry Lakes. A pilot study commenced in early 1993. A preliminary assessment of the monitoring work was presented to the Town of Cambridge in August 1995 (Townley *et al* 1995). It too provided detailed recommendations for further research, including:

- a detailed water balance at Perry Lakes with a view to expanding our knowledge of the seasonal interaction between the lakes and the superficial aquifer including the effects of storm water input in winter and lake maintenance in summer
- addressing specific issues of wetland management, in particular the effects of pumping near lakes and groundwater extraction within surrounding residential areas

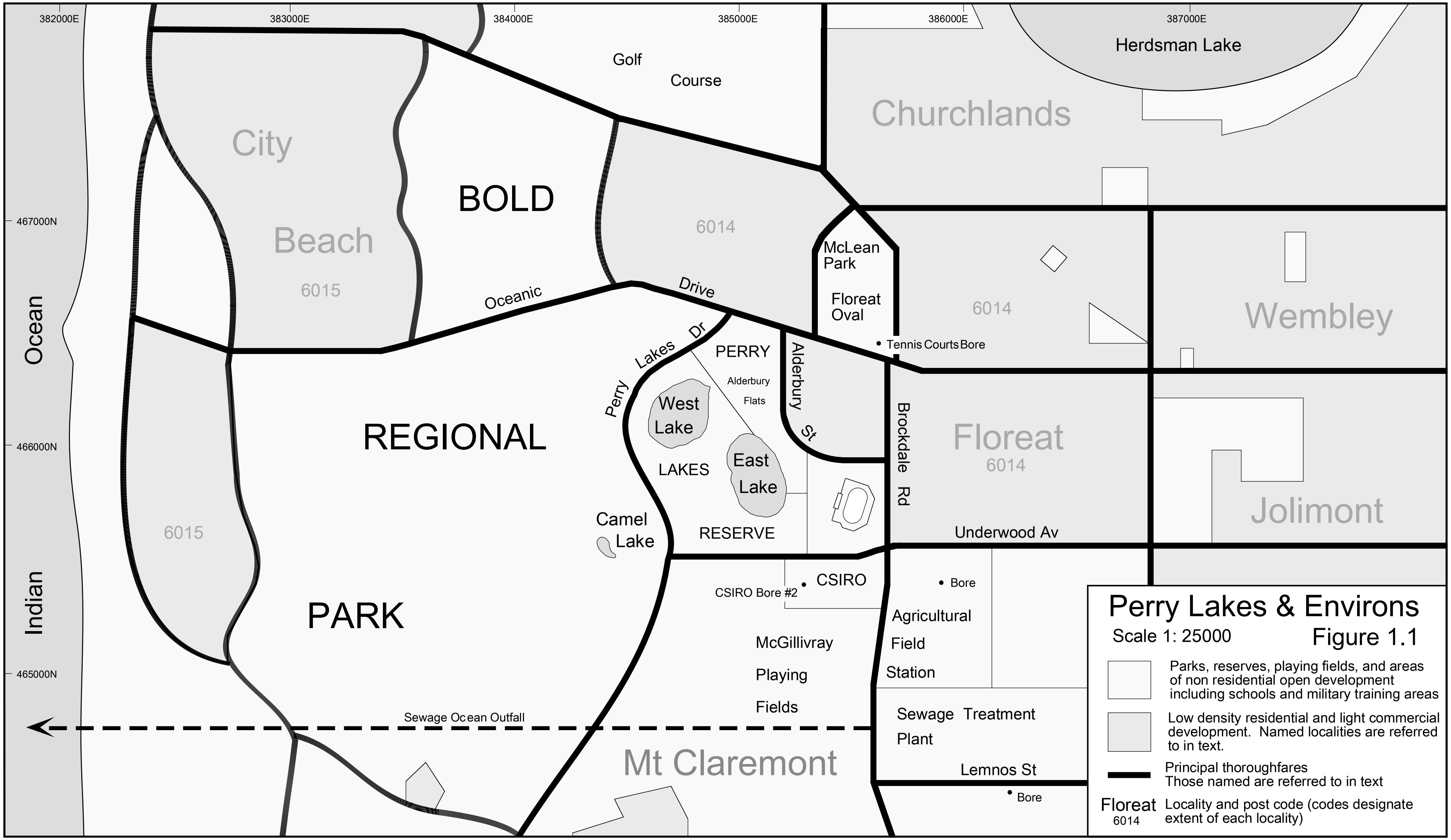
These recommendations form the basis of this thesis.

Perry Lakes represented a practical opportunity to undertake the intense investigation of a single lake (or set of lakes) as envisaged by Townley *et al* (1993b) and address management issues pertinent to many wetlands on the Swan Coastal Plain as recommended in Townley *et al* (1995).

1.3 INTRODUCTION TO PERRY LAKES

1.3.1 Physical Setting

Perry Lakes, comprising West Lake (ca 5.2ha) and East Lake (ca 6.9ha) are two small semi-permanent freshwater wetlands located within the western suburbs of Metropolitan Perth, Western Australia. They are situated 3km east of the Indian Ocean and 8km west of the Perth CBD (Figures 1.1 & 1.2). Perth has a Mediterranean climate, characterised by long hot dry summers and cool wet winters. The lakes are located within Perry Lakes Reserve, a 60ha park comprising both grassed playing fields (Alderbury Flats) and open, largely native bush with rough cut lawn which is partially maintained by irrigation over summer. Immediately adjacent is the Perry Lakes stadium complex built for the 1962 Commonwealth Games, CSIRO Floreat Laboratories and the University of Western Australia (UWA) Agricultural Field Station. Immediately to the west is Bold Regional Park, a 465ha bush reserve now managed by the Kings Park and Botanic Garden. Bold Park includes Camel Lake, a small wetland adjacent to Perry Lakes Reserve which for the purposes of this thesis is broadly included within the umbrella term 'Perry Lakes'. Water levels in Perry Lakes have declined markedly over the past twenty years. East Lake is now maintained over summer by adding groundwater derived from irrigation bores within Perry Lakes Reserve. West Lake has been dry over summer since 1995. Camel Lake has been dry since the 1980's.



Perry Lakes & Environs

Scale 1: 25000

Figure 1.1

Perry Lakes form part of the S2 consanguineous wetlands suite of Semeniuk (1988). Consanguineous wetlands are those which are related through similarity of physical characteristics or origin (Semeniuk 1988 & 1989). The S2 suite includes Herdsman Lake and Lake Claremont (Figure 1.2). Semeniuk (1987) proposed a geomorphic classification for individual wetlands based on their degree of 'wetness' and 'landform'. This classification has become the accepted framework for wetland classification on the Swan Coastal Plain (see also Hill *et al* 1996). Under this classification, the Perry Lakes area contains three wetland types (Table 1.1):

Table 1.1 Semeniuk wetland classification

Wetland	Designation	Description (Semeniuk 1987 & 1989)
Perry Lake East	lake	a permanently inundated basin
Perry Lake West	sumpland	a seasonally inundated basin
Camel Lake	dampland	a seasonally waterlogged basin

It is important to note that East Lake is now 'permanent' only in the sense that it is artificially maintained over summer.

1.3.2 Conservation Value

It is only in recent times that wetlands have come to be appreciated as more than impediments to development or as convenient depositories for storm water. Cargeeg *et al* (1987) noted that wetlands are important features of the urban environment and their maintenance should comprise an important component of any groundwater management strategy. EPA Bulletin 686 (and its predecessors Bulletins 227 & 374) outline broad management objectives for wetlands within the Perth Metropolitan Area and provide a system of wetland evaluation. This is based on recognition of wetlands as valuable assets which fulfil a number of 'functions' embracing ecology, hydrology, education and recreation. Using this evaluation, wetland value is measured on a five point scale ranging from 'high conservation value' (wetlands with a high degree of naturalness) to 'multiple use' (representing degraded wetlands with few remaining natural attributes). The EPA in Bulletins 227 & 374 classified Perry Lakes in the median category of 'Conservation and Recreation', representing wetlands which have been modified to some extent but are still considered to retain many natural attributes and have important social, recreational and educational functions. A more comprehensive classification by Hill *et al* (1996) assigned an H* management category, defined as representing a wetland of high conservation value. During the period 1995-2003 as field work and data analysis for this study were completed, Perry Lakes experienced significant environmental degradation, principally invasion by exotic weeds in response to declining water levels.

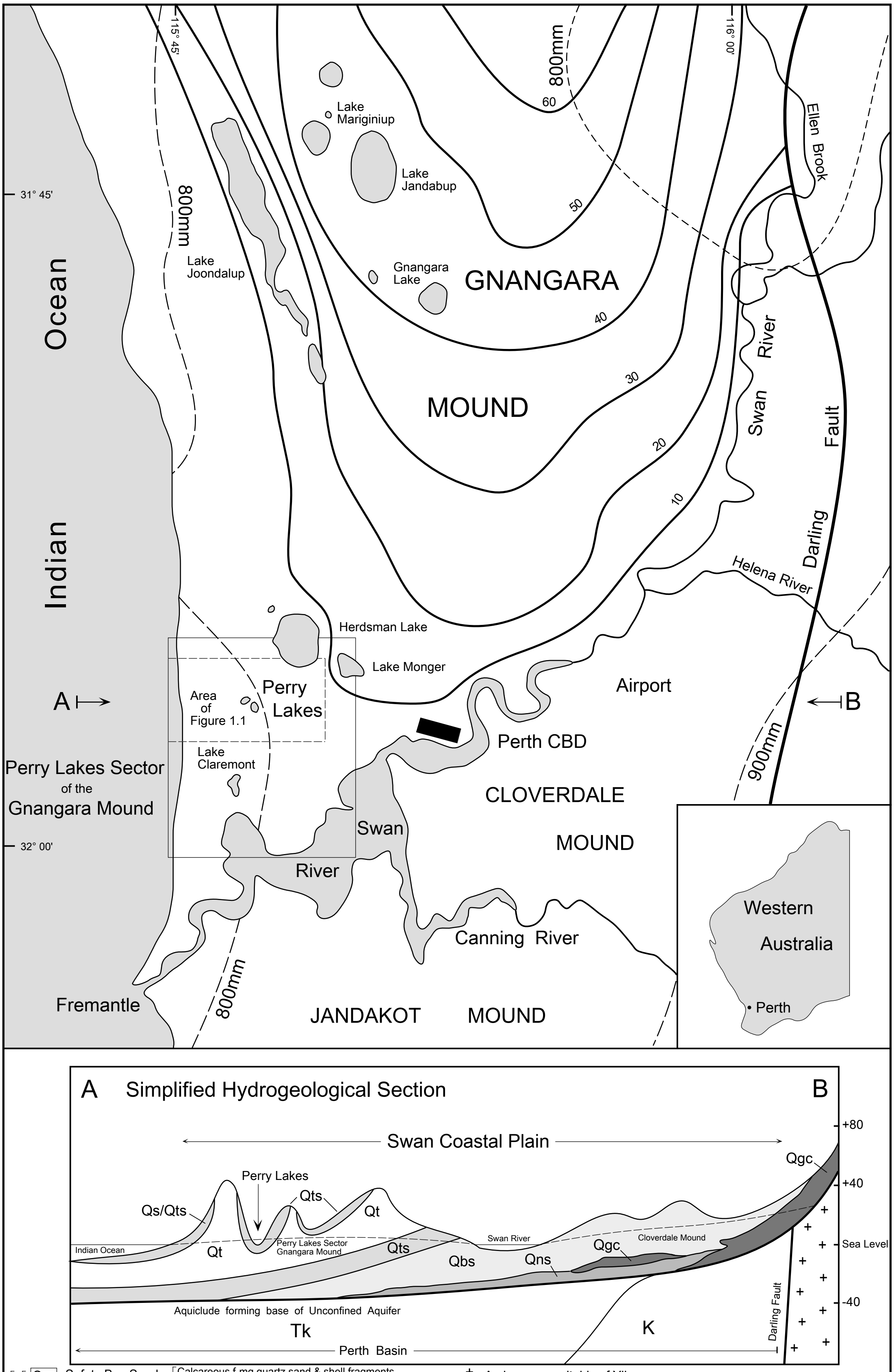
1.4 SWAN COASTAL PLAIN HYDROLOGY

The Perth Metropolitan Area is cut obliquely by the Swan River. This river is estuarine for 60km up stream to Ellen Brook (Collins, 1987, Hodgkin 1987). In combination therefore, the Indian Ocean, Swan River and tributaries comprise extensive constant head boundaries to a number of discrete groundwater systems or 'mounds' within a regional unconfined or 'superficial' aquifer (Figure 1.2). Perry Lakes and the surrounding portion of the unconfined aquifer, is designated for the purpose of this thesis as the 'Perry Lakes Sector of the Gnangara Mound' (Figure 1.2). The Perry Lakes Sector is triangular in shape, bounded by the Indian Ocean and lower reaches of the Swan River. This unique hydrological setting has significant implications in terms of wetland hydrology and management which will be explored within this thesis.

Shallow lakes on the Swan Coastal Plain (Figure 1.2) occur where the regional unconfined aquifer intersects the undulating land surface. This aquifer has as its upper surface a 'water table' representing the top of the saturated zone. The elevation of the water table to some extent follows surface landforms. The difference in surface elevation plus the combined effects of elevation and pressure, (a quantity known as piezometric or hydraulic head) provides the driving force for groundwater flow. In the case of Perry Lakes, flow originates 30-40km to the north east on the Gnangara Mound (Figure 1.2). Over this distance the elevation of the water table drops by only about 60m so that for practical purposes the water table and groundwater flow gradient may be thought of as being essentially horizontal.

The Swan Coastal Plain comprises predominantly marine and aeolian sediments of Quaternary age. It is bounded to the east by the Darling Plateau, formed over granitoids of the Archaean Yilgarn Craton. The Darling Fault and associated Darling Scarp mark the boundary between these two physiographic units. Marine sediments on the Swan Coastal Plain were deposited under fluctuating sea level conditions associated with Pleistocene glacial events (Playford *et al* 1976). Aeolian sediments represent a reworking of these marine deposits (McArthur & Bettenay 1960) along with terrestrial material derived from the continental interior (Glassford & Killigrew 1976, Glassford & Semeniuk 1990). These unconsolidated to weakly consolidated Tertiary units host the unconfined aquifer shown and described in Figure 1.2.

Within the Perry Lakes Sector the unconfined aquifer is 35-40m thick. Older Tertiary and Mesozoic sediments (principally shales and sandstones) of the Perth Basin form the base of the unconfined aquifer. In most areas this boundary is an aquiclude although some communication between the unconfined aquifer and deeper artesian aquifers does occur (Allen 1981, Davidson 1995).



Quaternary	Qs	Safety Bay Sand	Calcareous f-mg quartz sand & shell fragments Forms Quindalup Dune System
	U/c		
Quaternary	Qt Qts	Tamala Limestone & Sand	Calcareous weakly cemented eolianite comprising f-mg quartz sand & shell fragments, sands commonly limonitic. Limestone includes karst structures
	U/c		
Quaternary	Qbs	Bassendean Sand	Marine quartz sand, f-cg, abundant heavy minerals Reworked surface forms Bassendean Dune System
Quaternary	Qns	Gnangara Sand	Feldspathic quartz sand, f-vcg, fluvial-estuarine origin
Quaternary	Qgc	Guildford Clay	Silty clay, with lenses of sand and conglomerate
	U/c		
Tertiary	Tk	Kings Park Fm	Shale, calcareous & glauconitic with incised sandstone Perry Lakes Sector partially underlain by Mullalo Sandstone
	U/c		
Cret	K	Osborne Fm	Shale & sandstone of Cretaceous age

\+ + + Archaean granitoids of Yilgarn Craton east of Darling Fault

20 Water table contour (m)

800mm Rainfall Isohyet (increases towards figures)

Note: Contours drawn for Gnangara Mound ONLY

U/c Unconformity

Geology adapted from Davidson (1995)

Locality Map

Figure 1.2

1 2 3 4 5 kilometres

Scale : 1: 250 000

1.5 INTRODUCTION TO WETLAND-AQUIFER INTERACTION

Where lakes intersect the unconfined aquifer, there is effectively no horizontal gradient. This occurs because the lake surface is horizontal and the piezometric head at the lake bed is everywhere equal to the elevation of the water surface. As a result, groundwater flow beneath the lake tends to stagnate while at the same time groundwater flowing towards the lake on the up gradient side tends to rise, generally discharging from the aquifer through the lake bed, close to the up gradient shore (Congdon 1985, Townley *et al* 1993 a&b). In many Swan Coastal Plain lakes, springs are frequently reported on the up gradient shore (Allen 1979, Hall 1985). Similarly on the down gradient side of the lake, water is recharged to the aquifer through the lake bed, again close to the down gradient shore. Such water descends into the aquifer, eventually resuming its original flow gradient. These are termed 'flow-through' lakes (Townley *et al* 1993b, Nield *et al* 1994) and represent the most common form of water table lakes on the Swan Coastal Plain. They interrupt the normal horizontal groundwater flow, and induce significant zones of upward and downward flow, diverting large quantities of groundwater through the lake bodies themselves. Such lakes effectively represent a short circuit in the lake-aquifer system and as such are important components of the regional hydrology.

Water table lakes include two special cases. 'Discharge' lakes receive groundwater over the whole of their bottom surface while 'recharge' lakes release water to the aquifer over the whole of their bottom surface. Such lakes represent the end members of a large continuum of flow-through lakes defined by differing physical properties and ratios of aquifer discharge and recharge (Nield *et al* 1994). Many lakes have been studied on the Swan Coastal Plain (Allen 1979, Megirian 1982, Davidson 1983, McFarlane 1984, Congdon 1985, Hall 1985, Townley *et al* 1993 a&b, Sim 1995) and so far all appear to function as flow-through lakes. Transition to a recharge or discharge state may occur for short periods either in response to seasonal variation or anthropogenic intervention such as artificial lake level maintenance or use of wetlands as stormwater compensating basins.

1.6 THESIS OUTLINE & OBJECTIVES

This thesis examines wetlands and their underlying hydrology at two scales:

- at the individual wetland level (Perry Lakes)
- at a regional level (the Perry Lakes Sector of the Gnangara Mound)

Research is often initiated to provide insights into an unanswered question or test a new hypothesis. As the work proceeds initially unrecognised layers of complexity are revealed. One problem becomes many and the investigator must focus on a particular aspect of the original. This project is no exception. Its genesis was based on the theoretical research into lake-aquifer interaction undertaken by Dr Lloyd Townley and Simon Nield (Nield *et al* 1994). They were able to demonstrate theoretically that lakes within unconfined aquifers are not simply passive windows to the water table. Rather, they induce complex families of lake-aquifer interactions or 'flow regimes'. Using dimensionless ratios of simple physical characteristics such as lake and aquifer dimensions and hydrologic parameters such as recharge and evaporation they were able to model these in plan and 2D vertical section (Chapter 7). Regional field work on the Swan Coastal Plain (Townley *et al* 1993 a&b) using mass, solute and isotopic methods provided an initial field validation of the theoretical concepts. The underlying foundation for such modelling is knowledge of the lake water balance. The concept of a water balance (Chapter 4) is deceptively simple. In practice however it presents exceedingly difficult field problems (Winter 1981).

This study was initially intended to be a detailed field validation of the theoretical modelling of lake-aquifer interaction. After determining the seasonal changes in water balance components (using detailed 12 day balance periods), computer modelling would compare reality with theory. Perry Lakes were chosen because they represented an extremely dynamic system, forced artificially by storm water inputs and summer lake level maintenance 'top up'. The lakes (and the surrounding regional groundwater system) had suffered from declining water levels for several decades (Chapter 2), and the Town of Cambridge as wetland managers were supportive of any research into the lakes which might provide an understanding of the water level problem and provide long term management solutions to it.

It was understood that the groundwater fluxes into and out of the lakes would be particularly difficult to measure. The proposed solution was to use integrated mass, solute and isotopic balances as suggested by Townley *et al* (1993b) which in combination would allow the elusive groundwater flux components to be teased out. A theoretical framework for this had been established (Townley *et al* 1993a) but again a practical field validation had not been demonstrated. The pilot study at Perry Lakes (Townley *et al* 1995) specifically proposed this approach. These balances and the resulting rigorous measurement of their groundwater components (Chapter 6) represents the single most important achievement of the project.

An added complexity of the isotopic balance was the requirement to quantify isotopic exchange parameters relating to evaporation and atmospheric vapour. While these could be estimated using empirically derived general equations, a more rigorous approach was proposed in which they would be experimentally determined specifically for Perry Lakes

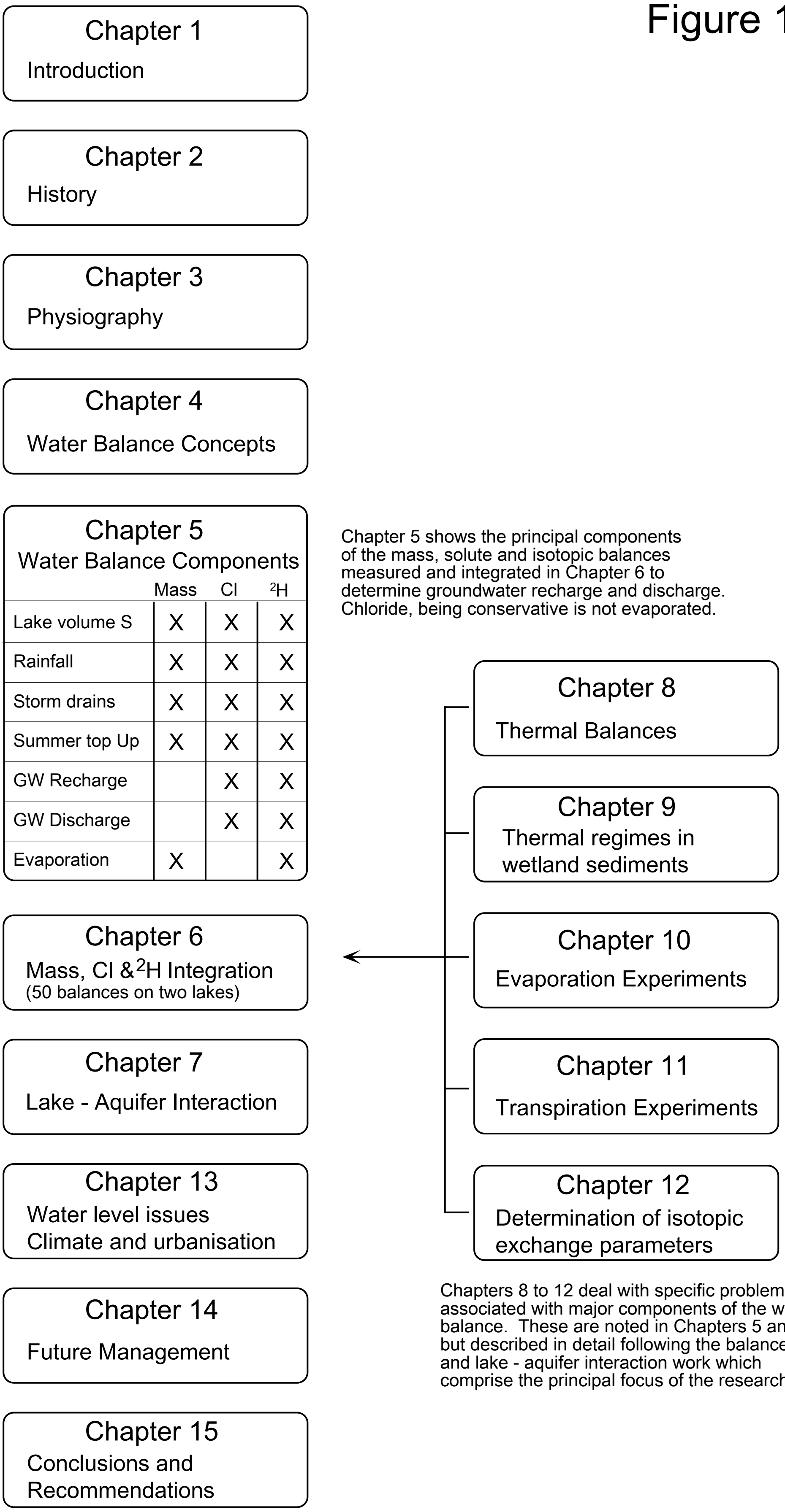
(Chapter 12). Evaporation was also flagged as a water balance component which would be extremely difficult to measure accurately. The proposed solution was to perform a thermal balance (Chapter 8) in which all the thermal components would be measured with the difference being the heat used to evaporate water from the lake surface. Early field data however suggested that in extremely shallow lakes sediment heat flux (a component usually ignored) was potentially of equal importance. Faced with two unknowns in the thermal balance a direct measurement solution in the form of a floating evaporation pan was devised to measure evaporation independently (Chapter 5). Sediment heat flux and the influence of flow regimes on wetland thermal patterns became the subject of a separate study (Chapter 9).

Determining evaporation independently then permitted a number of empirical evaporative techniques to be tested and calibrated specifically for Swan Coastal Plain conditions along with realistic monthly pan:lake coefficients for the Bureau of Meteorology (BoM) pan at Perth Airport (Chapter 10). The importance of transpiration from emergent wetland vegetation was also unknown. Again separate field experiments (Chapter 11) were devised to quantify its contribution to the water balance.

The practical problem of declining water levels in Perry Lakes required regional hydrologic data far more detailed than that available from government sources. Comprehensive regional water table monitoring and domestic bore mapping programs (Chapter 13) were undertaken in tandem with the detailed balance work at Perry Lakes. It was also necessary to determine local aquifer characteristics through pump and other tests (Chapter 3). The result was a comprehensive seasonal picture of the complex lake-aquifer flow regimes induced around and between the two lakes as a result of seasonal forcing from storm water, top up and depression of the water table from bore extraction (Chapter 7). The regional work allowed estimates of the regional water balance to be computed. These strongly suggested that bore extraction and climate change were both significant factors in the declining levels at Perry Lakes (Chapter 13). The study concludes with possible management options (Chapter 14) and conclusions and recommendations (Chapter 15).

Ultimately the three detailed balances (mass, solute and isotope) became the focal points of the study (and hence the basis of the thesis title). The originally proposed computer modelling was simply not possible. The results and data presented in this study however provide a sound basis for its ultimate completion by future workers. The thermal, evaporation, transpiration and isotopic exchange parameter studies (Chapters 8-12) provide data required for the integrated balances but also represent significant and original research in their own right. Figure 1.3 is a graphical representation of the thesis format.

Thesis Outline
Figure 1.3



	Mass	Cl	^{2}H
Lake volume S	X	X	X
Rainfall	X	X	X
Storm drains	X	X	X
Summer top Up	X	X	X
GW Recharge		X	X
GW Discharge		X	X
Evaporation	X		X

Chapter 5 shows the principal components of the mass, solute and isotopic balances measured and integrated in Chapter 6 to determine groundwater recharge and discharge. Chloride, being conservative is not evaporated.

Chapters 8 to 12 deal with specific problems associated with major components of the water balance. These are noted in Chapters 5 and 6 but described in detail following the balance and lake - aquifer interaction work which comprise the principal focus of the research.

CHAPTER
2
HISTORY

2.0 INTRODUCTION

This chapter reviews the history of Perry Lakes since European settlement. Vegetation and water level regimes within Perry Lakes over the past century are reconstructed from botanical, air photograph, water level and flood remediation time series and anecdotal records. Historic records of climatic and groundwater changes in Floreat-Wembley area are reviewed.

2.1 HISTORICAL SKETCH OF PERRY LAKES

2.1.1 Historical Sketch

Very little has been published on the early history of Perry Lakes. The following brief history is based largely on personal interviews and correspondence with people associated with the area[1]. Until its purchase by the City of Perth in 1917, the area appears to have attracted very little interest. Certainly the wetlands were known to and used by aboriginal people who considered them to be a valuable source of turtle meat (O'Connor *et al* 1989). The following details of the area's early history has been summarised from de Burgh (1986).

Lands including Perry Lakes were part of an original land grant designated 'A.k.' covering 308 acres granted to Surveyor General J. S. Roe in 1834 (Figure 2.1). Adjacent location 'A.l.' was taken up by master builder Henry Trigg who established a quarrying and lime burning works and in 1839 purchased location 'A.k.' from Roe. Location 'A.m.' was bought in 1844 by Walter Padbury who three years later also purchased 'A.k.' and 'A.l.' from Trigg. This combined holding of 1234 acres including what we now know as Perry Lakes in its southwest corner and fronting Herdsman Lake in the

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[1] People who kindly provided information of the Perry lakes area:

Greg Bartle, Technical Officer CSIRO
Joy Black, local resident and historian
Gordon Laffer, Licensed Surveyor and local resident, surveyed the lakes and drains for PCC
Nancy Phillious, daughter of George Patchett, 'Caretaker of Endowment Lands' 1947-67.
(Nancy grew up at Perry Lakes, living in the caretakers house now 'Perry House')
John O'Sullivan, early resident of Salvado Road, Floreat
Pennent 'Penn' Smith, former drainage engineer, City of Perth
Warren Somerford, former manager Parks and Gardens, PCC, familiar with the lakes since the 1930's

northeast, became known as the Limekilns Estate. It was sold to Henry and Somers Birch in 1869 and included a slaughter house, boiling down works and a tannery. When later sold to Joseph Perry in 1880, improvements included a substantial three-rail mahogany (jarrah?) perimeter fence. Remains of similar fences within the lakes (Section 2.4) may predate Perry's purchase of the property. Perry (who owned the Perth Horse Bazaar in what is now Forest Place) used the property for general livestock dealing enterprises.

Land to the west of the Limekilns Estate was an area of commonage vested in the Perth City Council (PCC) in 1883. The estate effectively separated the City from the commonage lands. The City bought the Limekilns Estate in 1917, including it and the former commonage or 'Endowment' lands within the City in 1920 (Mitchell McCotter & Ecoscape 1993).

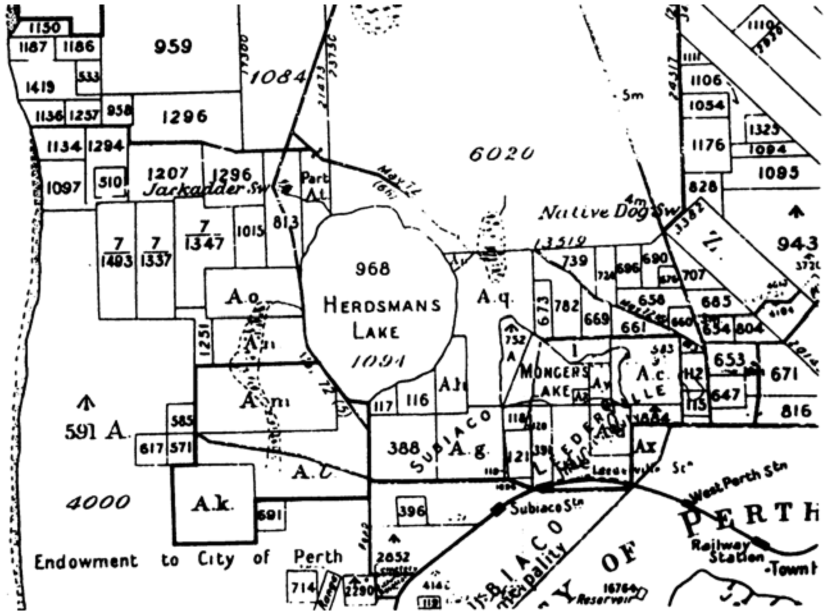


Figure 2.1 Limekilns Estate as it appeared on a 1898 Lands and Surveys map (adapted from de Burgh 1986). Perry Lakes, situated within Location A.k. were sufficiently insignificant to be ignored. Low country to the northeast within Locations A.l. and A.m. (present day Floreat Oval and McLean Park) are described on turn of the century topographic maps as 'White Gum, Banksia & dense scrub (under water in winter)'. The track traversing Location A.l. is present day Cambridge Street and Oceanic Drive.

The lakes appear to have been nameless until Joseph Perry's tenure when they were commonly referred to as Perry's Swamps. Camel Lake was originally known as 'Hidden Perry' (Mitchell McCotter & Ecoscape 1993). The name does not appear to have come into common usage until the 1950's when it was formally proposed by PCC surveyor G. Laffer (Laffer pers com). Perry Lakes have a long association with the use of camels in Western Australia. Camels used by Ernest Giles in his first overland expedition from South Australia were agisted at Perry Lakes in 1875 (de Burgh 1986). Later during the 1890's camels imported through Fremantle for use in the goldfields were quarantined at

Camel Lake (Laffer pers com, Smith pers com), although this practice appears to have ceased in 1896 when a large area at Star Swamp was set aside as a quarantine station (de Burgh 1986).

Livestock appear to have been grazed around the lakes from at least Perry's time. The lakes lay close to the original stock route from Geraldton. As late as the 1930's drovers moving mobs down from Geraldton would hold cattle at Perry Lakes (the final watering point before Rob's Jetty), so they could be driven across the Fremantle traffic bridge in the evening. There were extensive cow bog holes around the lakes (Somerford pers com). As late as the 1950's the PCC were still leasing sections of endowment land for livestock. Laffer (pers com) and Somerford (pers com) report both sheep and cattle using the area. South Lake (Figure 2.2) appears to have been an informal name, first appearing on various engineering site plans for the 1962 Commonwealth Games Stadium.

Between 1917 and 1960 the lakes were simply part of the Endowment Lands. Native peppermints, pines and figs were planted around the northern perimeter of West Lake in 1928 to mark the 150th anniversary of the arrival of the First Fleet (Plate 2.1). Perry appears to have cleared some portions of the Alderbury Flats. A photograph taken from the top of One-tree Hill (Reabold Hill) *circa* 1921 shows what appears to be a cultivated paddock (Plate 2.2 & Figure 2.2). Somerford (pers com) described the flats in the 1950's as clayey and open with scattered *Acacia longifolia* (Plates 2.4 a&b). The northeast section (between present day Alderbury Street and Oceanic Drive) was swampy and during the 1950's contained pools of permanent water (Watson 1958). Alexander (1919) notes the presence of a camping ground near the old Perry homestead which stood on the west side of West Lake several hundred metres south of the present site of Perry House. The lakes were adjacent to the Plank Road (now Oceanic Drive) which allowed vehicle traffic from Perth to City Beach and were popular with campers and picnickers. It was common in the 1920's, 1930's and 1940's for Nyungar people to camp in the open scrub surrounding the lakes and live off the natural food available there (O'Connor *et al* 1989).

Clearing for residential housing in Floreat commenced in the 1920's and continued into the 1950's. The original residential roads were of 15 foot width off shot construction (storm water drained into the sand adjacent to the road). These were later replaced by curbing and storm drains into both West and East Lakes (Smith pers com). Open channel drains were constructed from Oceanic Drive into West Lake and from Alderbury Street into East Lake in 1954 (Plates 2.4 a&b and Figure 2.2). These were replaced by concrete storm sewers about 1960 (Smith, pers com).

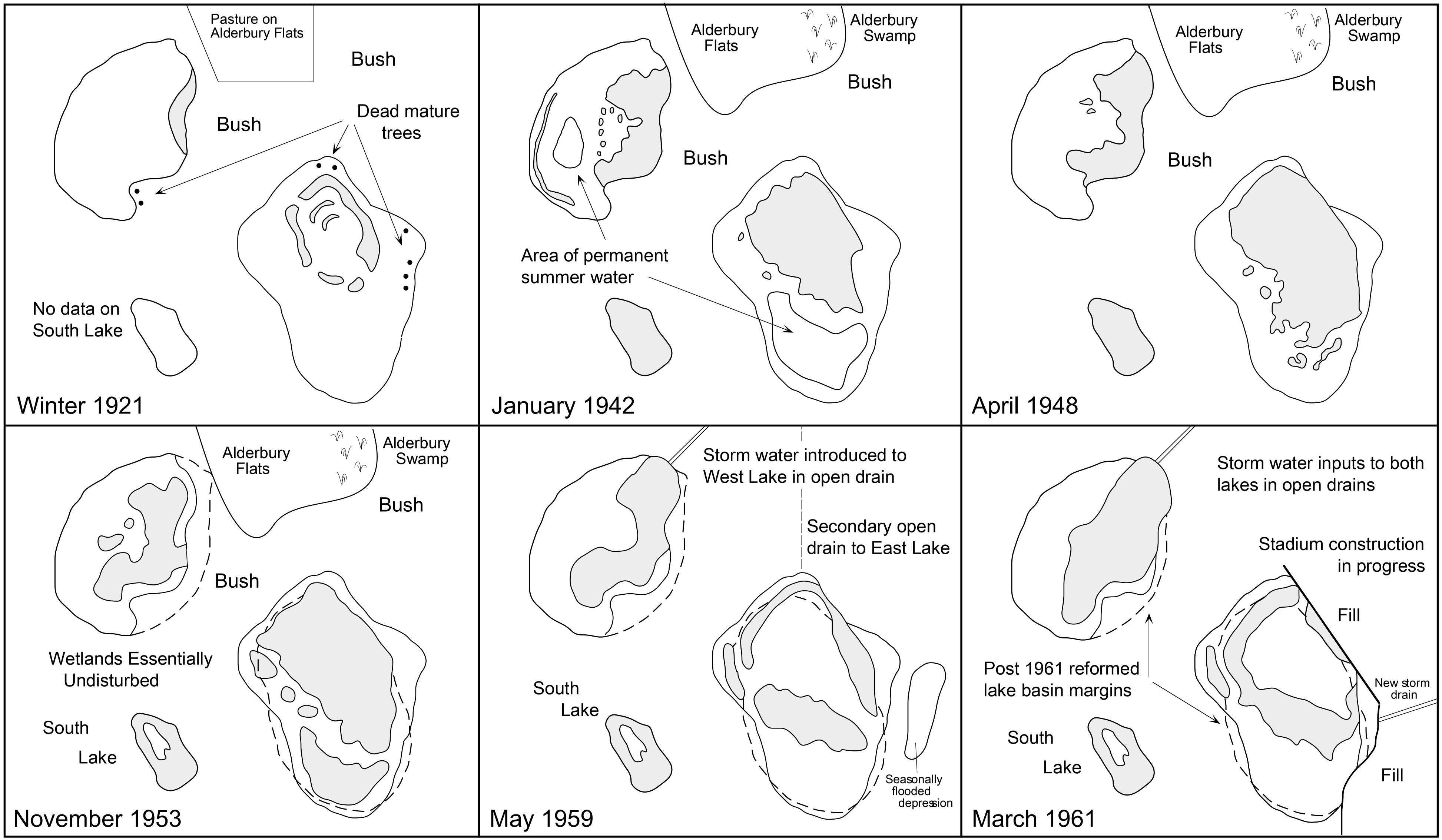

Pasture on Alderbury Flats
Bush
Bush
Dead mature trees
No data on South Lake
Winter 1921
Alderbury Flats
Alderbury Swamp
Bush
Bush
Area of permanent summer water
January 1942
Alderbury Flats
Alderbury Swamp
Bush
Bush
April 1948
Alderbury Flats
Alderbury Swamp
Bush
Bush
Wetlands Essentially Undisturbed
South Lake
November 1953
Storm water introduced to West Lake in open drain
Secondary open drain to East Lake
South Lake
Seasonally flooded depression
May 1959
Storm water inputs to both lakes in open drains
Stadium construction in progress
Fill
Post 1961 reformed lake basin margins
New storm drain
South Lake
Fill
March 1961

Figure 2.2a

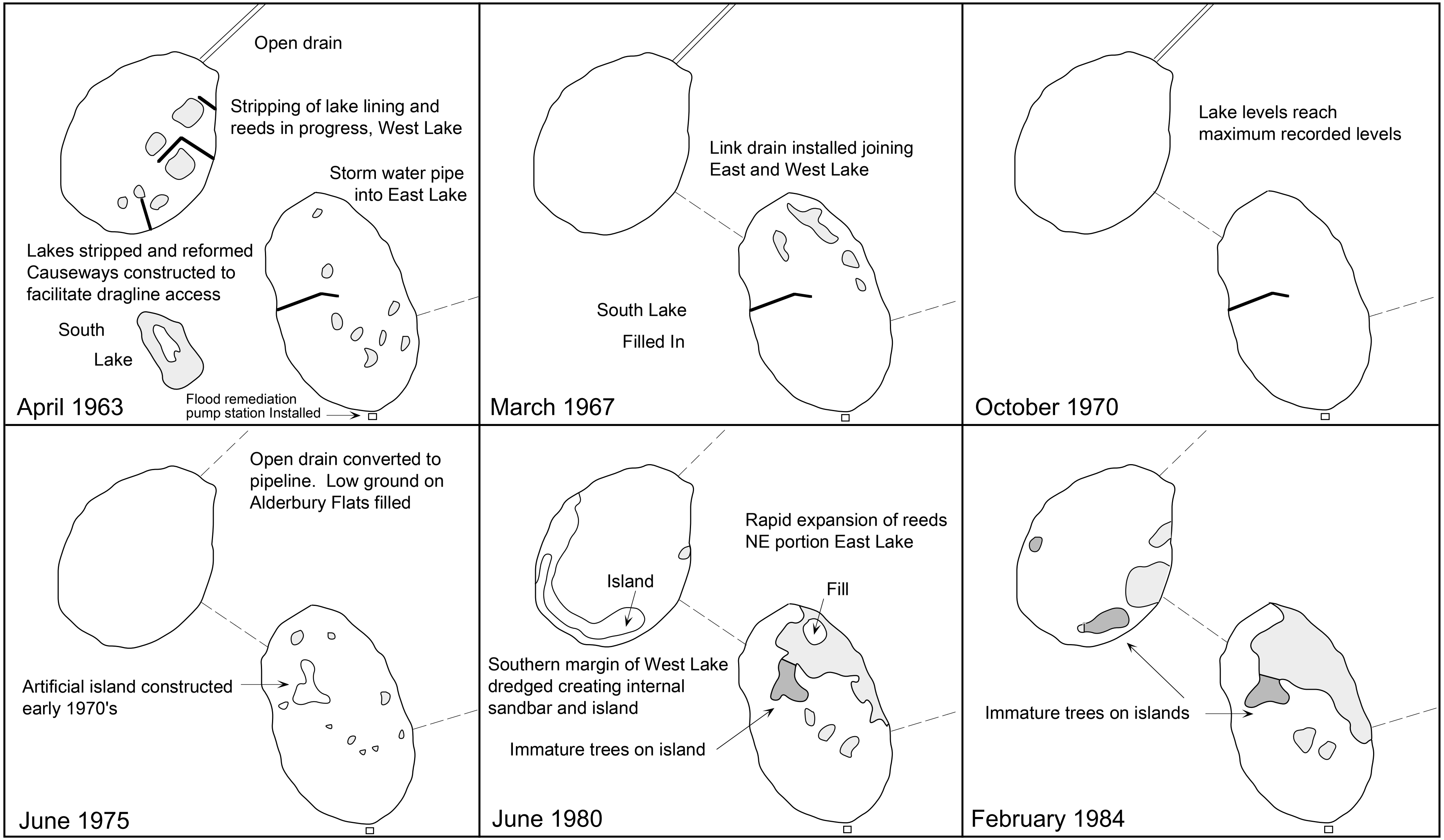
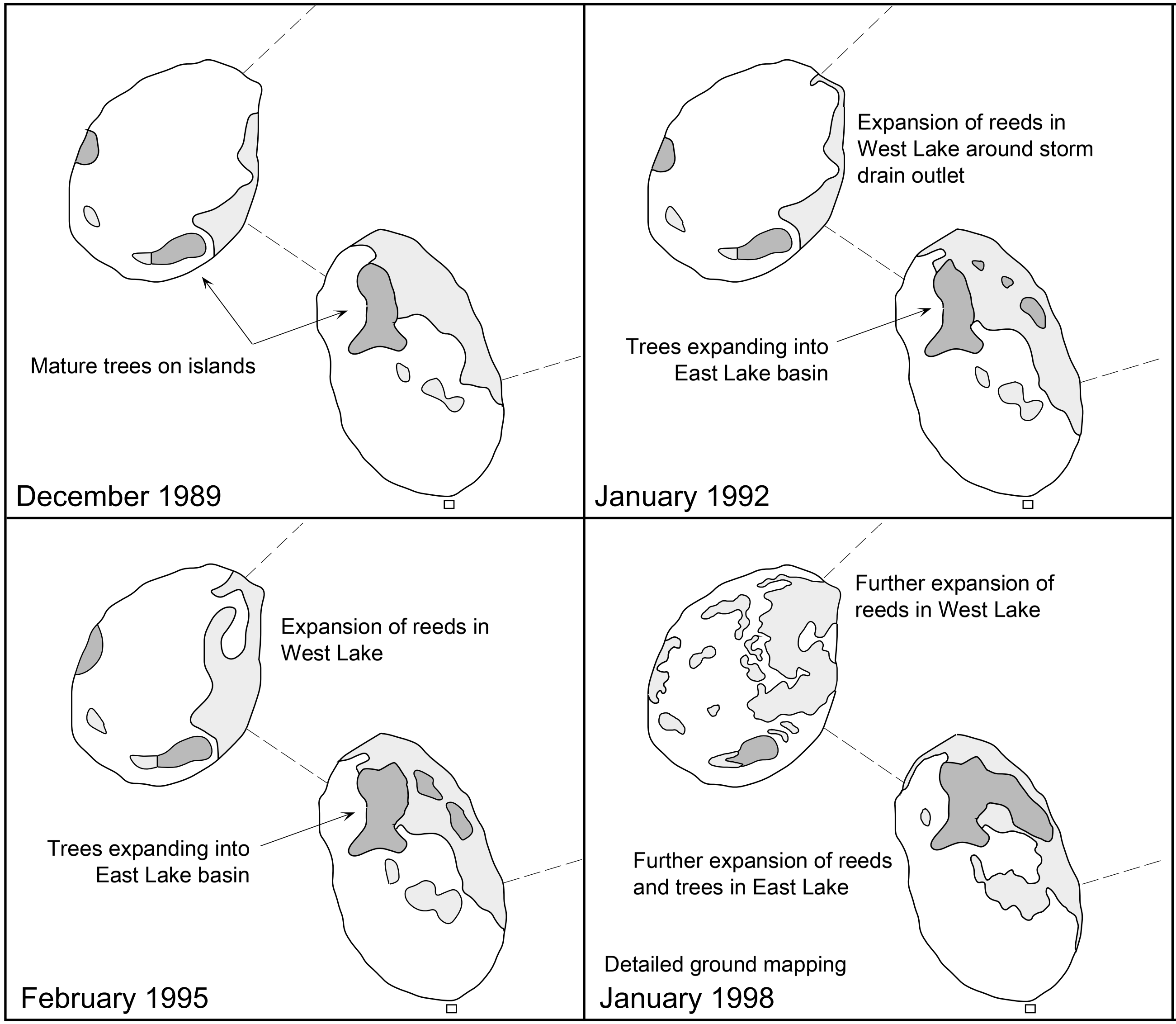

Open drain
Stripping of lake lining and reeds in progress, West Lake
Storm water pipe into East Lake
Lakes stripped and reformed Causeways constructed to facilitate dragline access
South
Lake
April 1963
Flood remediation pump station Installed
Link drain installed joining East and West Lake
South Lake
Filled In
March 1967
Lake levels reach maximum recorded levels
October 1970
Open drain converted to pipeline. Low ground on Alderbury Flats filled
Artificial island constructed early 1970's
June 1975
Island
Rapid expansion of reeds NE portion East Lake
Fill
Southern margin of West Lake dredged creating internal sandbar and island
Immature trees on island
June 1980
Immature trees on islands
February 1984

Figure 2.2b



Vegetation and Drainage History

Interpreted from Aerial Photos

▨	Emergent wetland vegetation, predominantly Baumea articulata ,Typha orientalis Juncus sp & Cyperus sp
■	Trees, predominantly Eucalyptus rudis
☐	Lake basin flooded for sufficient duration and depth to preclude emergent wetland vegetation

Airphoto Details

Year	Date	Run	Frames	Scale
1921	Oblique panorama taken from Reabold Hill			
1942	January	12	13894 & 95	4000
1948	April 11	19	5205 & 06	2500
1953	October 30	08	163 & 164	15840
1953	November 27	08	164-165	15840
1959	May 14	19	19/26 & 27	7500
1961	March 13	03	0035 & 36	15840
1963	April 04	17	5696	40000
1963	October 13	17	5096 & 97	12000
1967	March 13	08	5088 & 89	15840
1970	October 19	14	5124	12000
1975	June 11	06	5077 & 78	25000
1980	June 07	06	5071 & 72	25000
1984	February 02	07	5233 & 34	20000
1989	December 20	07	5044 & 45	20000
1992	January 25	single frame 5005		7000
1994	January 04	07	5163 & 64	20000
1995	January 06	08	5359 & 60	20000

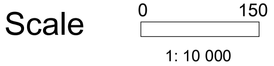


Figure 2.2c

In the late 1950's the decision was made to build a sports complex at Perry Lakes to host the 1962 Commonwealth Games. As part of this development Perry Lakes were extensively modified. The original plans called for extensive dredging to deepen and reclaim the shorelines to 4 feet (1.22m) depth and join the two lakes, leaving a central island accessible by foot bridges (*The West Australian* January 3, 1962). Financial restraints eventually limited these modifications to dredging and bank reclamation. Rubber tyred scrapers were used to deepen and form the lake perimeters and fill the Alderbury Street swamps (now Alderbury Reserve) which were finished to 20 feet above Low Water Mark Fremantle (5.34m AHD). Limestone causeways were built into both lakes to facilitate dragline access (Figure 2.2 and Plate 2.8). Mud and emergent wetland vegetation was scraped out, much ending up as fill in the swamps between West Lake and Alderbury Street (Alderbury Reserve). Extensive grassed areas were established around both lakes, and the first bores established in 1962 for lawn irrigation (Somerford pers com). South Lake (Figure 2.2 and Plates 2.1 & 2.4a) was considered to be a mosquito breeding hazard and was filled in the late 1960's and later capped with beach sand (Smith pers com).

These modifications were carried out at a time of very high groundwater levels. Aerial and press photographs taken at the opening of the Commonwealth Games in November 1962 show two oval sheets of water with distinct banks and little emergent wetland vegetation (Figure 2.2 and Plate 2.8). The lack of safe nesting areas for water birds prompted further modifications which included construction of an island in East Lake about 1974 and deepening and construction of an island in West Lake in the early 1980's.

2.1 2 A History of the 'Problem' of Declining Water Levels in Perry Lakes

Drought during the late 1970's contributed to a widespread decrease in groundwater levels throughout Perth (Townley *et al* 1993b). For the first time since Perry Lakes had been dredged and reformed, portions of the lake bottoms became exposed over summer (Figures 2.10 & 2.11). The PCC experimented with artificial lake level maintenance during the summer of 1977-78 by pumping groundwater into both lakes. Between February and May 1978 levels in East Lake dropped to below 3.1m AHD (Figure 2.11). At this stand, over half of the lake basin would have been exposed. Carbon *et al* (1988) recognised that the lakes are physically part of the surrounding water table, and that overall, lake levels directly reflect the surrounding groundwater levels. They also concluded that lakes with a well developed clay bed could be maintained during periods of low summer groundwater levels by pumping from a remote source. They added the further caveat however that where dredging had destroyed the natural integrity of the lake beds, such artificial maintenance would be more difficult.

The PCC clearly recognised that pumping locally derived groundwater into Perry Lakes was untenable in the longer term. In 1984 serious consideration was given to diverting water from Herdsman Lake via gravity drainage into Perry Lakes. It was clear however that this approach would be problematic due to then unacceptable heavy metal and nutrient levels (Environmental Systems Research Institute 1984, Churchward 1984 unpublished). In 1985 Barry Carbon, then Chairman of the (W.A.) Environmental Protection Authority, but acting in the capacity of local resident and former researcher at Perry Lakes, proposed to the PCC that a public seminar and workshop be held to review options and provide some direction for dealing with both the problem of declining water levels and the associated ecological problems (PCC 1985 unpublished). Minutes of this meeting (attended by approximately 100 local residents) held in January 1986 (PCC 1986a unpublished) clearly suggest a consensus that the lakes constituted a valuable wildlife habitat. There was general support for allowing some increase in the amount of natural vegetation around the lakes and protecting it from invasion by exotic species. The crucial question of how to maintain summer water levels remained unresolved. Engineered solutions including diversion of water from Herdsman Lake and/or dredging were presented and discussed along with their environmental implications. While not stated explicitly, this meeting appears to represent the initial public recognition that wetland hydrology is intimately associated with the regional groundwater system. The dilemma facing the PCC was how to protect and if possible increase the natural integrity of the wetlands on the one hand while at the same time addressing the question of declining water levels, a problem which could be only adequately addressed through environmentally unacceptable engineered solutions. There was a persistent theme however that indiscriminate use of groundwater both privately and publicly was probably contributing to the problem and a recognition of the underlying role played by climatic change. Subsequent recommendations to Council (PCC 1986b unpublished) clearly note that

> 'pumping from adjacent bore water supplies is not an option as this simply recycles the water in the aquifer...'

Despite this, it was recommended however that the use of groundwater to maintain summer lake levels be adopted along with limited deepening and further studies.

Publication of the Perth Urban Water Balance Study (Cargeeg *et al* 1987) and earlier direct correspondence between the Water Authority and the PCC (Cargeeg 1986 unpublished) emphasised the links between long term climatic trends and groundwater levels. It was concluded that the problem at Perry Lakes might become critical only during exceedingly dry years when some reduction in groundwater use might be sufficient to maintain some water in the lakes over summer. A year later, in response to increasing public concern the PCC again sought assistance from CSIRO, CALM and other institutions to determine directions for a formal Plan of Management (PCC 1988 unpublished). A study completed in 1992 (Dames & Moore 1992) outlined the present and historical water regime within the lakes and re-examined and costed previous options for maintaining permanent summer water along with possible use of treated sewage effluent. This report recommended (on the basis of cost and questionable environmental and public health implications associated with engineered solutions) maintaining East Lake through pumping from irrigation bores and allowing West Lake to dry out seasonally. This has been the management strategy employed since then and throughout the period of this study.

CSIRO were approached later in 1992 to assess the effects of irrigation bores on lake levels within Perry Lakes Reserve and provide recommendations for the possible placement of a dedicated bore for lake maintenance, located to provide minimal effect on lake levels. Four observation wells (PL 1-4) were drilled and equipped with data loggers along with two data loggers (PL 5 & 6) to monitor lake levels (Figures 3.3 and 5.1 a&b). Records from these commenced in March 1993 and are on-going, maintained by CSIRO. A preliminary assessment of the monitoring work (Townley *et al* 1995) was unable to conclude precisely how pumping was affecting lake levels. In addition to the seasonal decline (which occurs throughout the metropolitan region in response to evapotranspiration and extraction) the data suggested that on a daily basis pumping close to Perry Lakes probably predominates over evapotranspiration at certain times of the year.

The Court Liberal government was elected in February 1993 and announced shortly after plans to divide the City of Perth into a number of smaller municipalities. The new Town of Cambridge administered by a Board of Commissioners became the new managers of Perry Lakes in July 1994 with the first council elected in May 1995. Subsequent fiscal restrictions precluded funding for further research (including this study). No dedicated lake maintenance bore has been drilled.

2.2 RAINFALL

Wetlands which are windows on the water table, ultimately reflect net rainfall and recharge rates to the superficial aquifer (Sharma *et al* 1991, Davidson 1995). Numerous other factors influence the amount of rainfall which ultimately becomes recharge. These include soils and geology of the vadose zone (Davidson 1995), vegetation (Carbon & Galbraith 1975, Butcher 1979, Greenwood 1979, Carbon *et al* 1982, Sharma *et al* 1983, Stoneman 1986), seasonal timing of rainfall (Pollett 1981) and depth to the water table (Allen 1981, Burton 1976, Pollett 1981). Urbanisation further complicates the picture by promoting increased recharge on the one hand and increased groundwater usage on the other. It may also have a direct affect on rainfall distribution (McFarlane 1984). The net effect of urbanisation is therefore frequently difficult to measure since it is superimposed on climatic events of varying frequency and may take time to stabilise (McFarlane 1981).

Rainfall at the local scale varies within the Perth Metropolitan area depending on orographic and maritime effects from less than 800mm at Fremantle to over 900mm on the Darling Scarp. Isohyets are included in Figure 1.2. This spatial variability probably affects local groundwater levels (Whincup & O'Driscoll 1979 cited McFarlane 1984). The longest complete records come from Perth City. Less complete data sets are available for Fremantle, UWA Floreat Research Station (adjacent to Perry Lakes, Figure 1.1) and Guildford (Perth Airport, Figure 1.2). Table 2.1 shows comparative annual rainfall averages for these stations.

The Perth records are frequently cited when discussing wetlands on the Swan Coastal Plain generally, however it is important to remember that stations close to the coast frequently receive less rainfall than Perth. These data suggest Perry Lakes rainfall is about 94% of that reported from Perth. Floreat data is available only from 1963. If we take Fremantle to be typical of Floreat and compare the available data 1876-1988 (last complete year for Fremantle), this ratio drops to about 89%.

Table 2.1 Comparative Rainfall, Perth Metropolitan Area

Station	Fremantle	Floreat	Perth City	Guildford
Rain 1963-1988 (mm)	788.0	781.1	827.6	786.6
Distance from ocean (km)	0.5	3.8	10.0	20.0

Note: Excludes data for 1982

Raw monthly rainfall data for Perth are plotted in Figure 2.3. Moving 9 point averages were applied to annual and winter rain (comprising June-July-August totals). Winter rain is the most important in terms of recharging the aquifer. The data clearly show that since the 1970's Perth has experienced the driest period on record. Data to the end of 1998 suggests a gradual upward trend but with annual totals still below the long term average. The averaged rainfall also displays an obvious cyclicity. McFarlane (1984) noted an 11 year (sunspot) cycle using auto correlation techniques. Allison & Davis (1993) found a 22 year 'double solar' signal applying geostatistical techniques to a 100 year data set. Examination of the power spectrum using Fourier analysis (Pittock & Lean cited Allison & Davis 1993) suggested only an 11.2 year signal while similar analysis (this study Chapter 13) suggests a 10.3 year signal. The presence of such solar related cycles corresponding to sunspot, solar irradiance and the solar magnetic cycles (Lean 1991, Webb *et al* 1984) is common in meteorological time series (Burroughs 1992). The data suggest that the next rainfall peak may occur about 2013. Early records of the Swan

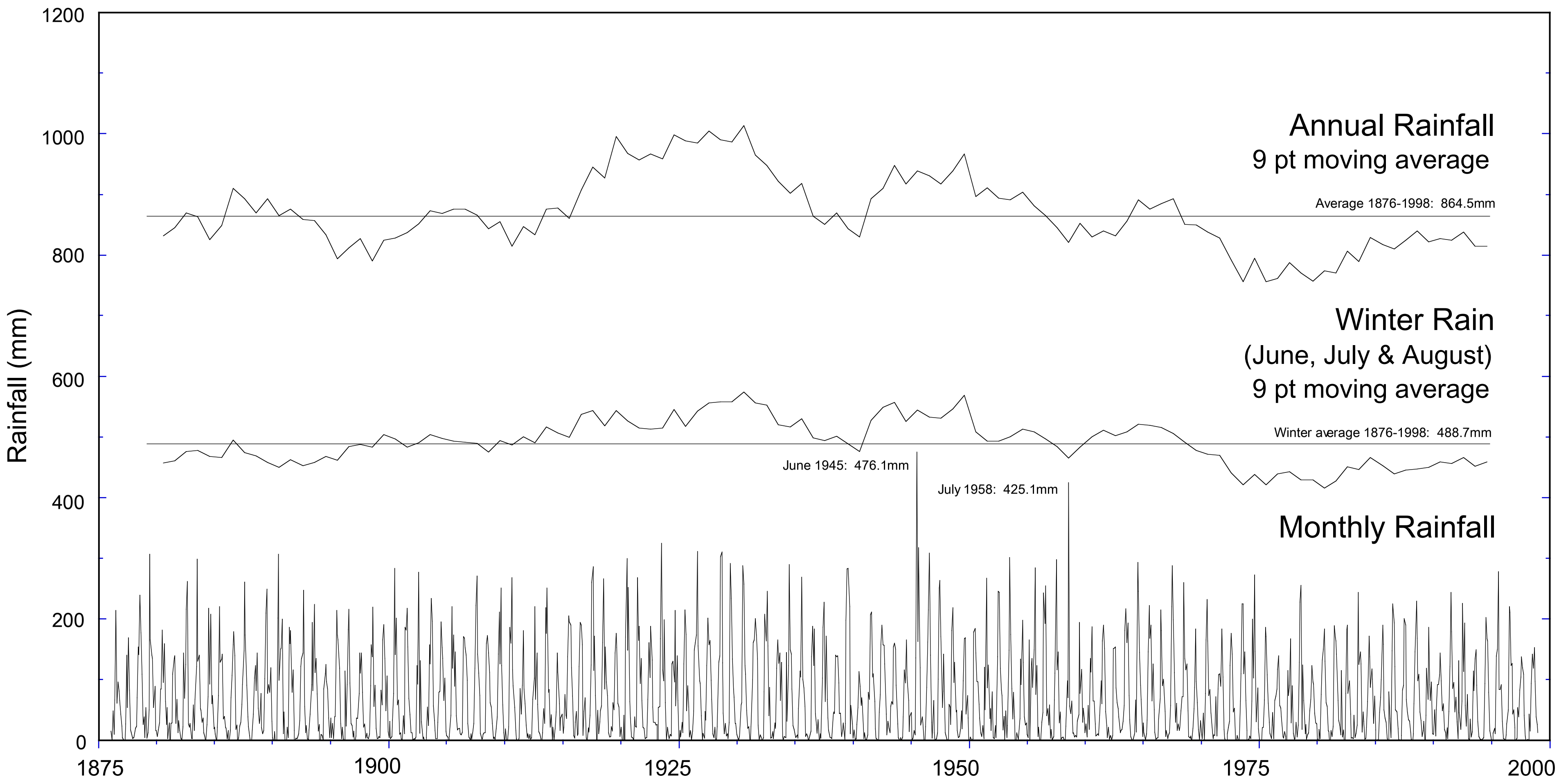


Figure 2.3

Perth Historic Rainfall 1876-1998

River Colony however lend only meagre support to extrapolated climatic trends. Increased rainfall years might be expected to centre around 1859 and 1837, however contemporary accounts suggest that the period 1831-1841 and 1848-1854 were relatively dry (Le Page 1986) although a 3 year rainfall data set from Fremantle 1853-1855 indicates rainfall was 2.8% above average. Perth recorded flooding in the winters of 1842, 1845 and 1847 (Le Page 1986) and 1857, 1858 and 1871 (Serventy 1948, Bekle 1981).

The present decrease in Perth rainfall is part of a regional phenomenon. Since the 1950's there has been a major reduction in rainfall throughout the south west of Western Australia (Wright 1992). Research in progress (Nicholls 1998) suggests that neither ENSO[2] events nor variations in Indian and Southern Ocean sea surface temperatures display a strong correlation with this change. Allan & Haylock cited Wright (1992), note that long term rainfall variation may have multiple causes including natural long term variations, random fluctuations in rainfall pattern and natural or anthropologically induced climate change, acting alone or in combination. The possible implications of low frequency rainfall periodicity is further developed in Chapter 13.

2.3 GROUNDWATER

2.3.1 Regional Groundwater Levels

Systematic monitoring of groundwater levels in the Perth metropolitan area did not commence until the 1950's. Systematic exploratory drilling to assess groundwater resources commenced in 1962 (Allen 1975, Davidson 1995) when a broad network of water table monitoring wells was established. In the Perry Lakes area 5 such wells occur within a 5km radius of the lakes with continuous monthly data since 1978. However discontinuous lake level records cover much longer time periods.

Water table or 'flow through' lakes reflect the seasonal variations of the surrounding water table and the balance between precipitation and evapotranspiration. Within urban areas however, such wetlands are also prone to extreme seasonal stage changes from winter storm water inputs. While lake level records frequently span longer time frames, accurate appraisal of water table trends is best provided by monitoring wells augmented with surface water records.

Historical levels (Figure 2.4) are the approximate water table winter maximum for the period 1958-1966 compiled from planar records now held by Water and Rivers Commission. These reflect the water table as it was about 1960 when sufficient regional data first became available and provide a reference to which current levels can be compared.

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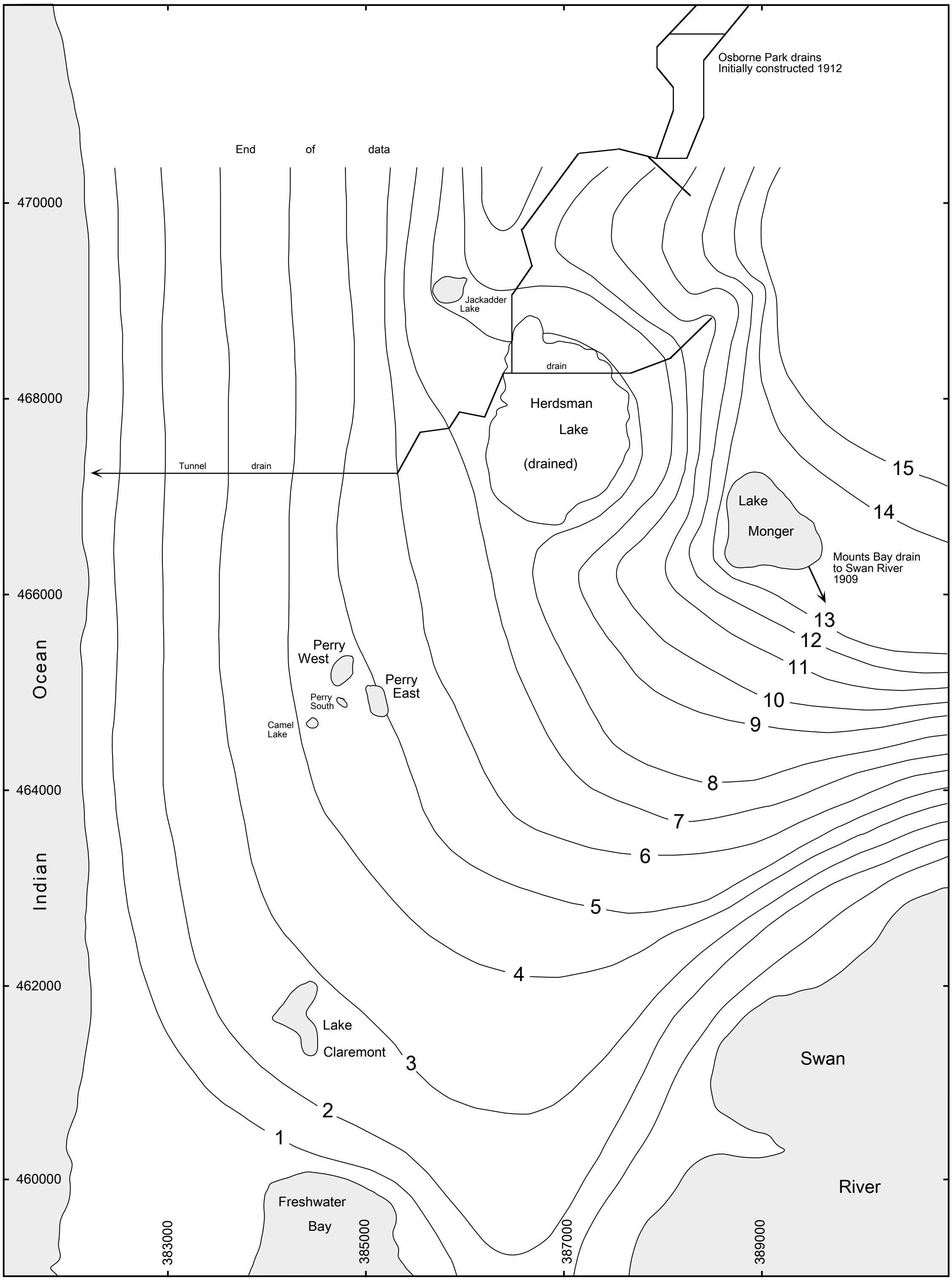
[2] El Niño-Southern Oscillation



Scale: 1: 65000

Data compiled from:
Metropolitan Water Supply, Sewerage & Drainage Department Plan 2611
Original data in feet above low water at Fremantle (see note)
Indian Ocean and Swan River set as constant head boundaries at 0.000m
Metric contours developed from original maps, all data in metres AHD

Note:
Conversion from low water Fremantle to Australian Height datum:
[Elevation (ft)-2.48]/3.28 = m AHD

Figure 2.4
Water Table Contours Perry Lakes Sector
Winter Maximum 1958 - 1966

2.3.2 Perry Lakes Study Regional Monitoring Well Network

A network of 87 monitoring wells and 8 surface water bodies within an approximate 5km radius of Perry Lakes was established in 1997. This utilised Water and Rivers Commission monitoring wells, private and public irrigation bores, miscellaneous research wells drilled by CSIRO and research wells drilled for this study around Perry Lakes (Appendix 2.1).

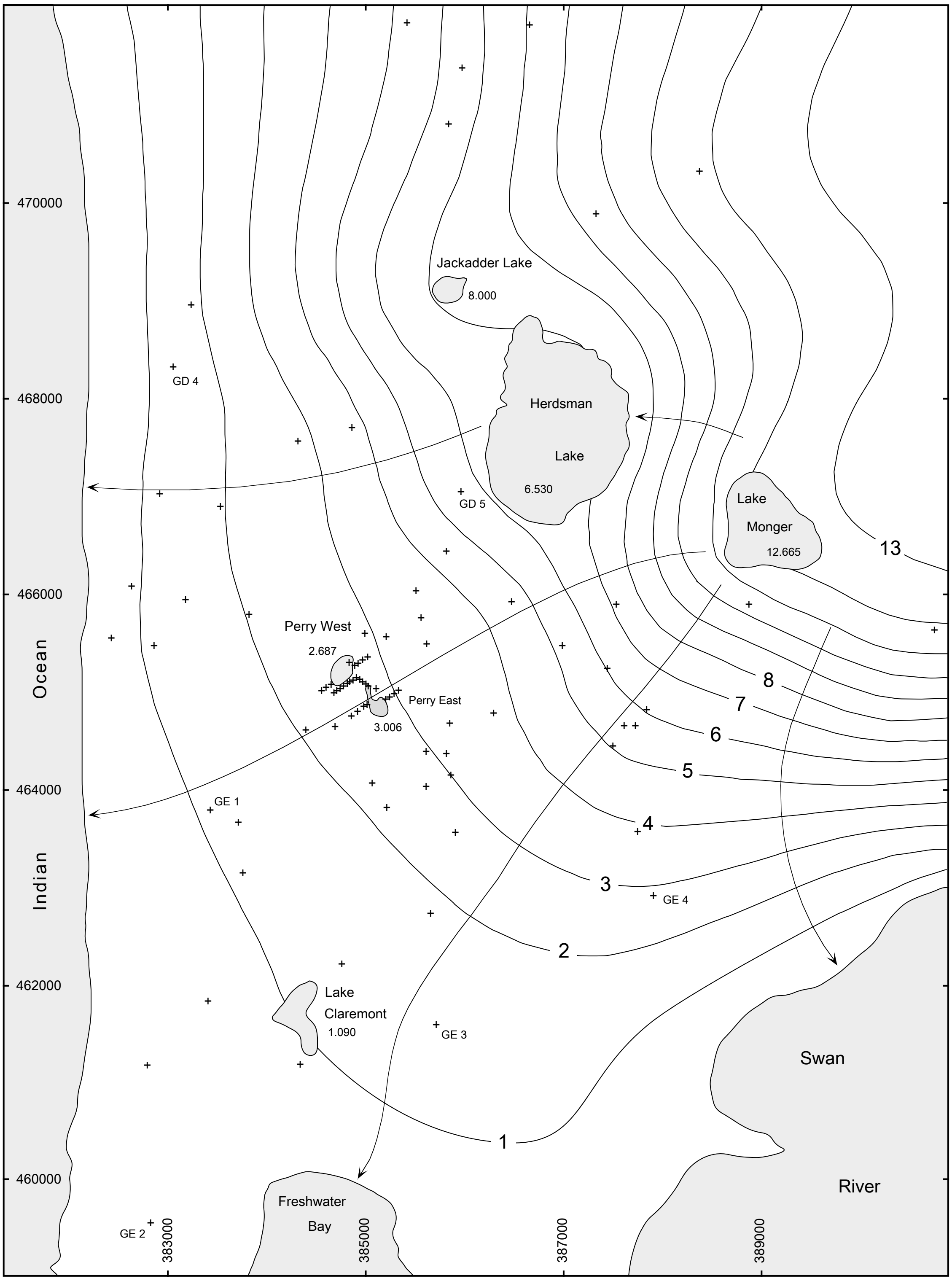
The use of public irrigation bores for groundwater monitoring is problematic. Such bores are screened towards their base and are not therefore fully penetrating and do not necessarily measure the water table. At a regional scale however they may provide a usable estimate. Summer minimum levels (Figure 2.5) typically occur in March or April, however bores could not be measured until early May when all lawn irrigation had ceased. Summer 'minimum' levels are therefore considered conservative. Bores were read at least one week after pumping had ceased for the winter. Similarly winter maximum levels (Figure 2.6) were recorded in mid September before commencement of lawn irrigation but also possibly before the winter peak. These also are therefore considered conservative.

A partial flow net (Figure 2.5) also provides some important clues regarding the general hydrology of the superficial aquifer around Perry Lakes. The Swan River meets the Indian Ocean at an oblique angle (Figure 1.2). Groundwater entering the Perry Lakes sector of the superficial aquifer does so across an extremely small aquifer section between Herdsman Lake and Lake Monger. This water ultimately leaves the aquifer across a very much larger section represented by the constant head boundary comprising the Indian Ocean and the Swan River estuary. The Perry Lakes sector is therefore a zone of decreasing water table gradients. This phenomena is further discussed in Chapter 13.

The maps (Figures 2.4 to 2.6) depict the historical change in regional water table level over approximately 35 years. Points to note include:

- All areas have suffered a decline but the magnitude of this decline has varied within the sector. The relative magnitude of this change is reflected in water table contour spacing.
- The greatest decline has occurred roughly within the triangular area defined by Perry Lakes, Lake Claremont and GE 4 where the winter maximum level has declined about 1.5m. Here contour spacing has increased, indicating a historic decrease in water table gradient.

The water regimes in Lake Monger and Herdsman Lake have also been extensively modified over time. These modifications between 1909 and 1924 (essentially flood control and drainage) must have affected the down gradient regime at Perry Lakes. Lack of any regional water table data within the Perry Lakes sector prior to the 1950's however precludes any detailed analysis of how these drainage schemes may have affected



Data compiled May 4-11, 1997
Lake stands are approximate maxima during survey period, all data metres AHD
Indian Ocean and Swan River set as constant head boundaries at 0.000m
Contours created in SURFER on 100x100m kriged grid

Scale: 1: 65000

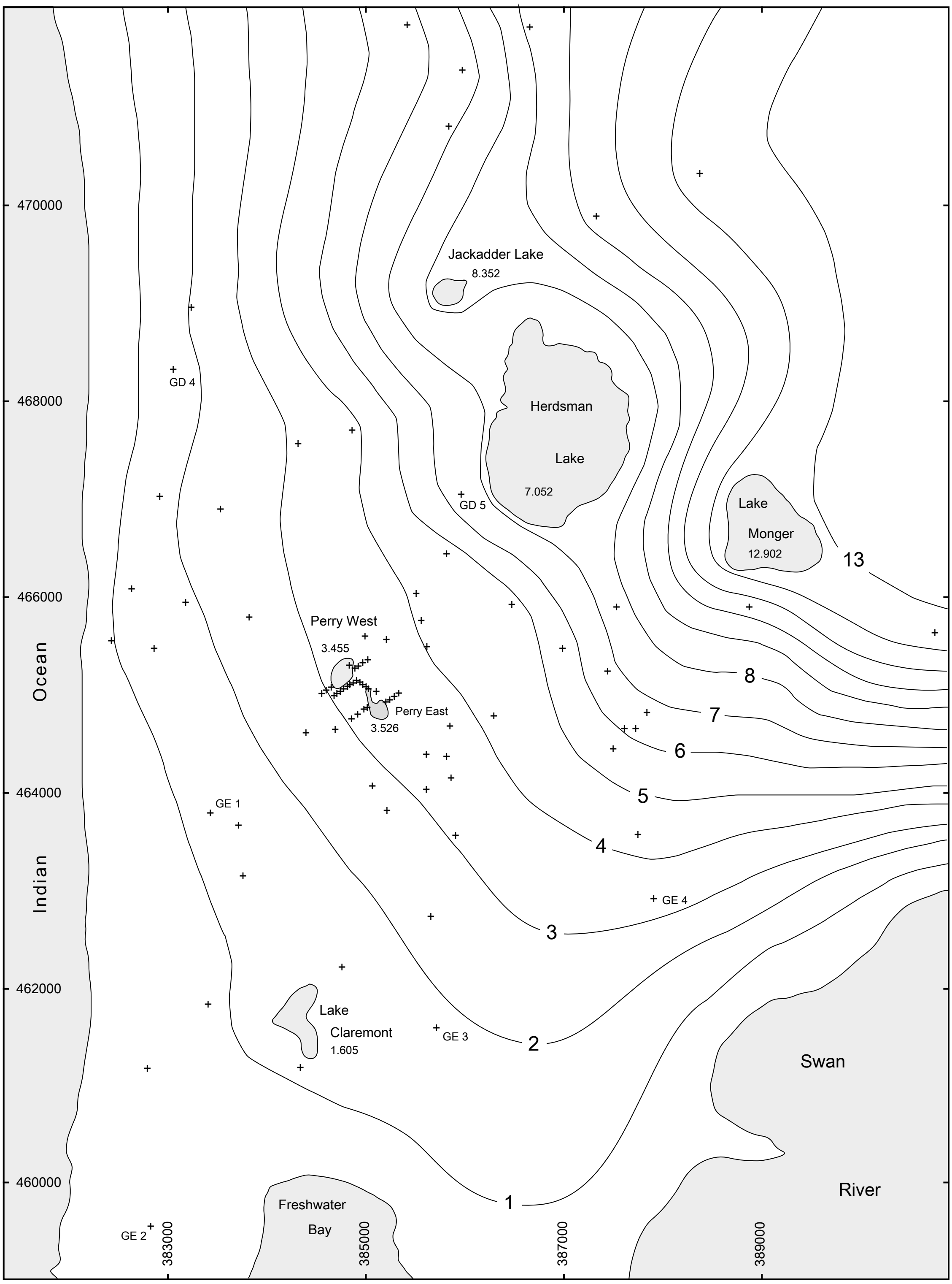
+ Monitoring well or production bore used as data point

+ GE 3 Gnangara Mound monitoring well referred to in text

← Flow line and direction of flow

Figure 2.5

May 1997
Water Table Minimum



Scale: 1: 65000

Data compiled September 10-15, 1997
Lake stands are approximate maxima during survey period, all data metres AHD
Indian Ocean and Swan River set as constant head boundaries at 0.000m
Contours created in SURFER on 100x100m kriged grid

+	Monitoring well or production bore used as data point
+ GE 3	Gnangara Mound monitoring well referred to in text

Figure 2.6

September 1997
Water Table Maximum

Perry Lakes although the overall effect can be predicted. Drainage lowers the water table, decreasing the regional gradient and probably resulted in some reduction in down gradient wetland levels, (all of this superimposed on climatic effects). The important point however, is that over 35 years at Perry Lakes and the surrounding area the water table has declined between 1.5-1.7m. This has significant and obvious implications for wetlands whose maximum water depths are typically less than 2m (Balla 1994).

2.3.3 Recent Monitoring Well Time Series

Regional wells constructed to monitor the superficial aquifer provide 20 years of monthly data. These wells are labelled on Figures 2.5 & 2.6 and Appendix 2.1. They confirm the continued decline in groundwater levels in the Perry Lakes sector of the superficial aquifer (Figure 2.7). The wetland data indicate that the most dramatic decline occurred over the decade 1970-1980. Although incomplete these well records confirm a consistent regional ongoing decline of 0.3-0.4m since 1980. Only GD 5 displays a different pattern, influenced by drainage and level controls on adjacent Herdsman Lake.

2.3.4 Data Series from Wetlands

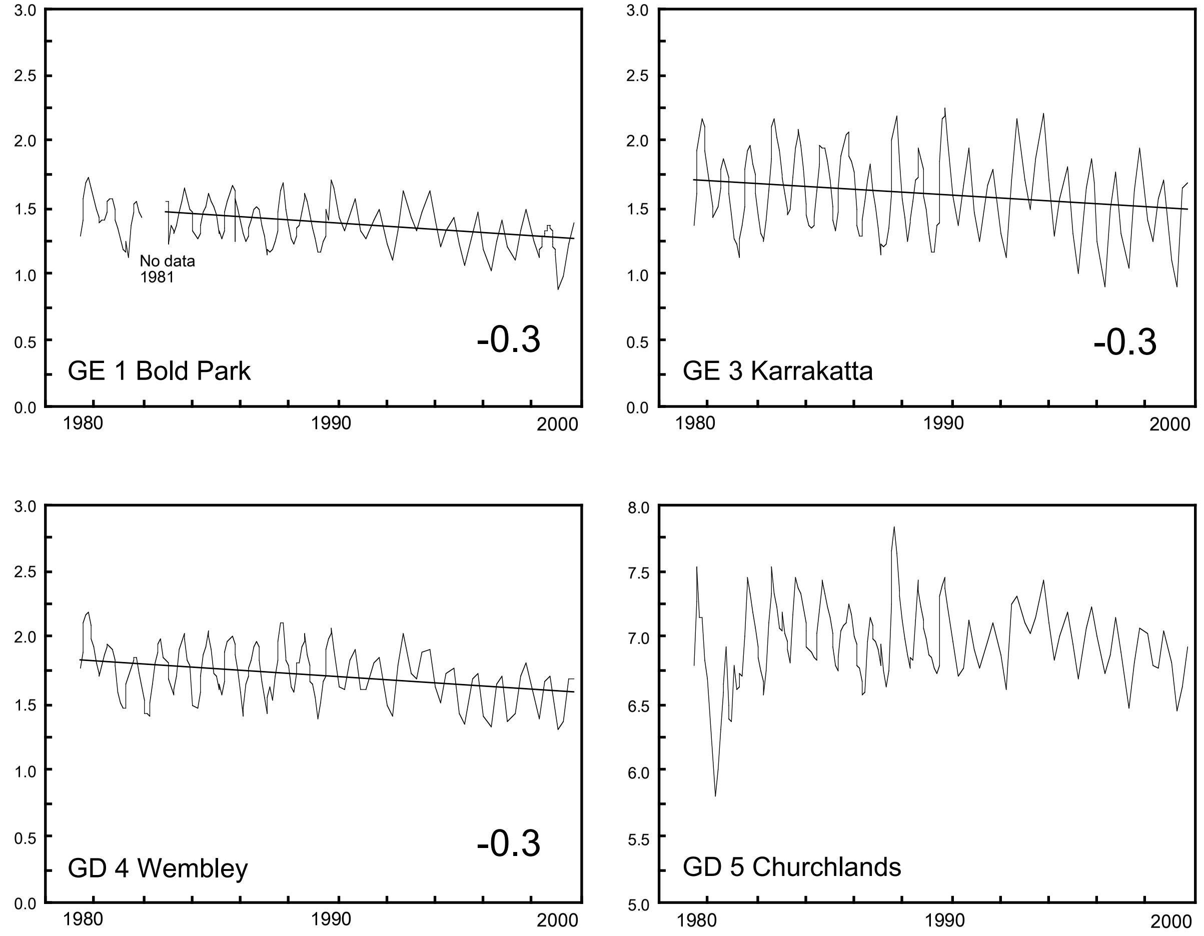
Records of other wetlands in the Perry Lakes sector provide additional longer term water table information.

Lake Monger

The Mounts Bay drain to the Swan River was completed in 1909 (Bekle 1981). The drain controls winter lake levels which are augmented by considerable inputs from storm drains. Between 1895 and 1908, measured lake stage varied from 11.81 to 12.93m AHD (range 1.12m). Lake Monger now has a very limited range (0.24m in 1997), reflecting the effect of the Mounts Bay drain (Figures 2.5 & 2.6).

Herdsman Lake

Proposals to drain Herdsman Lake for agriculture first appeared in 1848 (Bekle 1981). While this did not eventuate for another 76 years, the lake continued to attract attention for its agricultural potential. There are a number of early dated references to water depth. These data provide relative indications of lake stage. Later data providing both depth and stage can be used to construct estimates of lake stage from earlier data. This is only possible because Swan Coastal Plain wetlands tend to be saucer like in form so that the exact location of early depth measurements was not critical. Table 2.2 is a compilation of both depth and stage data. Approximate stage has been estimated for depth only data using the lake bed RL measured prior to drainage works in 1924 (refer notes Table 2.2).



All data sets cover period June 1978-October 1998

Vertical axes are water table elevation m (AHD)

Trends estimated by linear regression

All data Water & Rivers Commission except GE1
which includes weekly data (this study) 1997

Refer to Figures 2.5 & 2.6 for well locations

Figure 2.7

Perry Lakes Area
Regional Water Table
1978-1998

Some of this reworked data has been included in Figure 2.8. Wetlands to the north in Osborne Park were drained into Herdsman Lake in 1912 (Figure 2.4 & 2.8), further contributing to water levels which were already rising in response to increased rainfall.

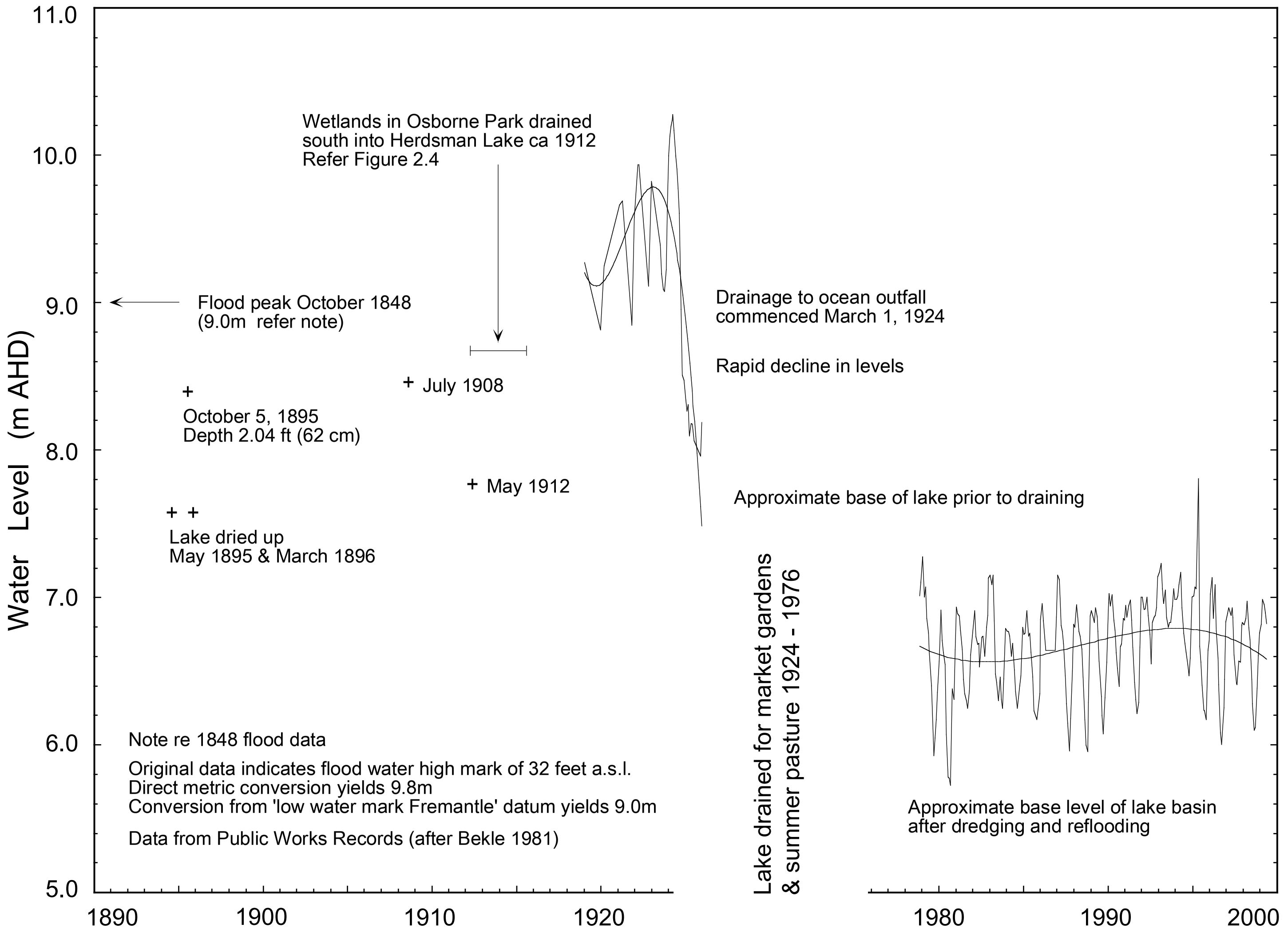
When dry, the water table beneath the lake would be less than lake bed RL, surveyed prior to drainage as 28 feet LWMF (refer notes Table 2.2) or 7.78m AHD. This is at least 1m higher than in May 1997 (Figure 2.5) and indicates that during the dry period in the 1890's the summer water table around Herdsman Lake and Lake Monger (and by inference around Perry Lakes) was much higher than that recorded at end of summer 1997. This provides substantiation for the hypothesis that Perry Lakes contained minimal but permanent summer water during the 1890's.

Table 2.2 Herdsman Lake reconstructed hydrology prior to formal records

Date	Depth (ft & m)	Stage (LWMF)	Stage (m AHD)	Reference	Comments
October 1847	3.0 (0.91)	31.00	8.69	2, 3	Flooding in Perth
October 1848		32.00	9.00	5	Flood peak
May 1895	nil		<7.78	1, 2	Lake dry
October 5 1895	2.04	30.04	8.40	1, 2, 7	
October 23 1895	1.81	29.81	8.33	1, 2	
March 1896	nil		<7.78	1, 2	Lake dry
July 1908		30.30	8.48	7	
May 21 1912		28.05	7.80	7	almost dry
July 29, 1918		32.90	9.272	6, 7	
July 7, 1919		31.40	8.815	6, 7	
September 1919	4.0 (1.22)	32.00	9.00	1, 2	
September 29, 1919			9.248	6	
August 20, 1920			9.659	6	
October 19, 1920			9.693	6	
November 10, 1920	5.99 (1.82)	33.99	9.606	1, 2	

Notes: Where unspecified, datum taken to be LWMF (Low Water Mark Fremantle), converted to metres AHD
Formal records commence May 1921
Lake bed taken as 28 feet above LWMF prior to drainage in 1924 (Public Works Department records) cited Le Page 1986
References: 1: Teakle (1935 cited Bekle 1981), 2: Southern & Teakle (1937), 3: Serventy (1948), 4: Bekle (1981), 5: Le Page (1986), 6: Water and Rivers Commission Records, 7: Metropolitan Water Supply, Sewerage & Drainage Department Plan 2611

In 1923, Herdsman Lake experienced a pronounced rise in level, peaking at 10.278m AHD in October 1923 (equivalent to a water depth of 2.5m). It was completely drained for agricultural purposes in March 1924 via a tunnelled drain to the ocean (Le Page 1986). The former lake basin was partially dredged and allowed to reflood in 1978 (Figure 2.8). The current water level fluctuates between about 5.7 to 7.3m AHD, with surplus water still removed via the original ocean drain. Current lake stage range is well below the original lake bed of approximately 7.78m AHD, and 2-3m less than levels which prevailed around the turn of the century, a result of both dredging and subaerial compaction of the original lake lining. The Herdsman data, limited as it is, does not suggest prolonged extremes of either drying out or flooding during the period 1847-1915. The period of pronounced higher water levels experienced 1920-1960 is therefore unique, at least in the short term.



Notes

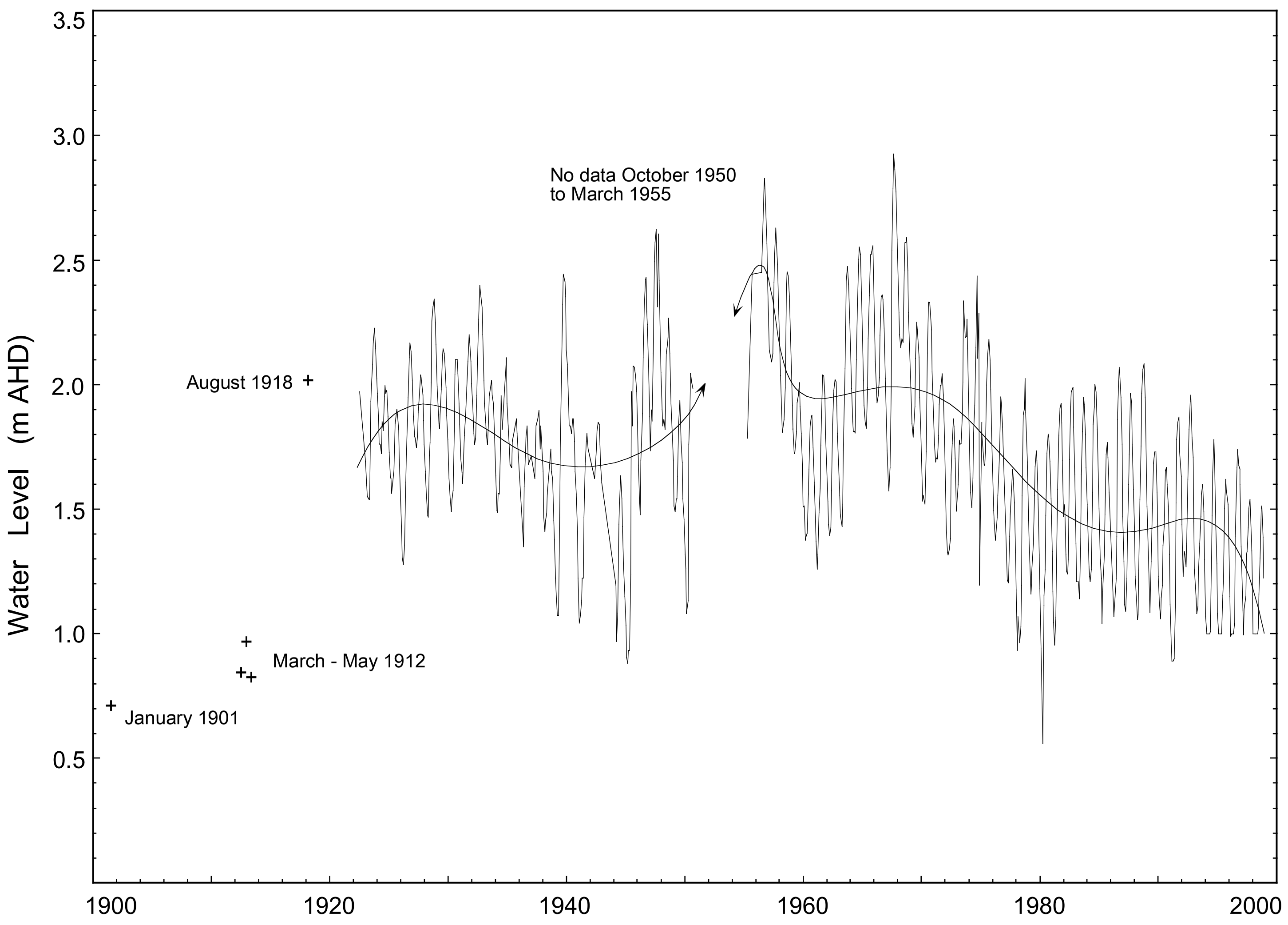
Spot data from:
Serventy (1948)
Bekle (1981)
Le Page (1986)

Lake level trends estimated by fitting 3rd degree polynomials

+ Spot lake stage data

Figure 2.8

Historic Levels
Herdsman Lake



Notes

All data Water & Rivers Commission
except October 1946 - September 1950
which is Evans & Sherlock (1950)

Lake level trends estimated by
fitting 4th & 5th degree polynomials

\+ Spot lake stage data

Figure 2.9
Historic Levels
Lake Claremont

Lake Claremont

Formerly known as Butler's Swamp, much of what is now lake was, until 1920, cultivated with buildings and a roadway (Serventy 1948). Prior to 1918 the swamp held virtually no permanent water, a situation virtually unchanged since 1844 (Evans & Sherlock 1950). Over a century earlier, 5th January 1697 Willem de Vlamingh's party landed (probably at Swanbourne) and walked to an 'inland lake', probably Lake Claremont, which contained significant water (Playford 1998 p35). This was the time of the 'Little Ice Age' in Europe and suggests that on the Swan Coastal Plain it corresponded to a wetter climate than now. Between January 1901 and commencement of systematic records in 1923 (Figure 2.9) the water level rose about 1m, peaking in the 1950's and 1960's. The data represents the most complete record of the wetlands examined and clearly shows peaks around 1925, 1947 and 1969.

2.4 PERRY LAKES WATER LEVELS

2.4.1 Photographic and Anecdotal Records

Formal monitoring of water levels on a systematic basis did not commence at Perry Lakes until 1963. Apart from a few spot measurements (generally collected during flood events in the 1950's), no early hydrologic records exist. George Patchett who was Caretaker of the Endowment Lands and resident at Perry Lakes from 1947 to 1962 apparently recorded lake levels on a regular basis in reports to the City of Perth (Phillious pers com). Attempts to locate these Ranger's Reports were unsuccessful. Aerial photographs exist from 1942, however many are high level and difficult to interpret. Oblique low level aerial photographs taken during preparations for the 1962 Commonwealth Games provide some of the best information on the state of the lakes before and after the dredging and bank reclamation program. Anecdotal evidence from people associated with the lakes is available back to the 1920's. Anecdotal data can be notoriously inaccurate (Loftus & Loftus 1980, Loftus 1982) and probably tends to emphasise extremes such as drought and flood rather than the norm, however from the hydrological point of view this information can be extremely valuable.

Vegetation Distribution on Aerial Photographs

Dated photographs showing the distribution of emergent wetland vegetation can provide clues on the prevailing hydrological regime. Distinctive arcuate patterns on the earliest aerial photographs strongly suggests that *Baumea articulata* was the dominant emergent species. *Baumea* has an optimum water depth of 0.25m, but will tolerate mean annual water depths of +/- 0.4m (Chambers *et al* 1995). Therefore non vegetated areas are

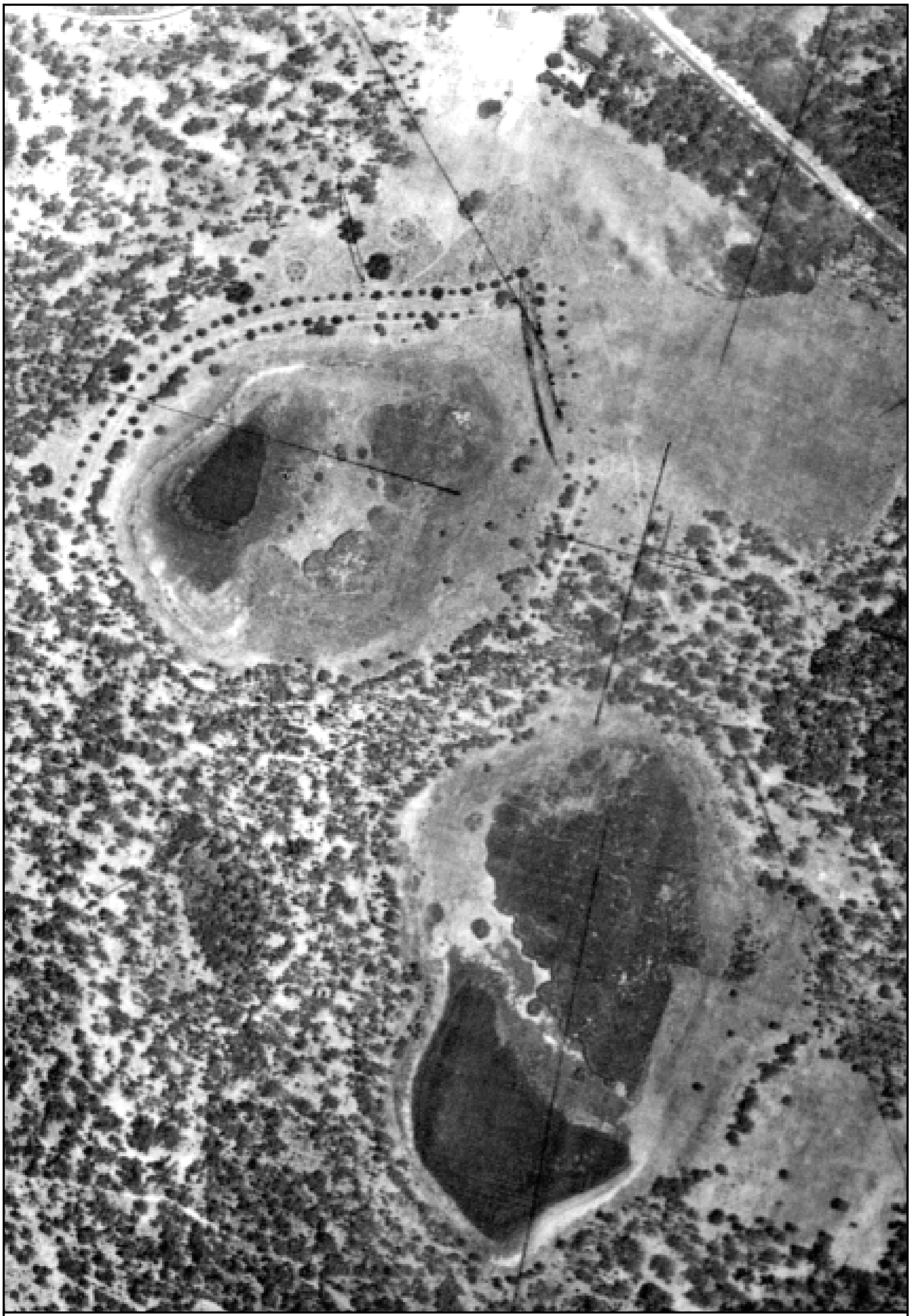


Plate 2.1 Perry Lakes, January 1942

West Lake (top), East Lake (bottom). Note small areas of permanent summer water (black) particularly in West Lake. In East Lake only the South Basin is filled, stage is estimated to be 2.9-3.0m AHD. South Lake (middle left) appears as an oval dark patch and appears to be dry on the original photo with abundant small bushes growing in it.

Arcuate vegetation patterns in East and West Lakes are typical of *Baumea articulata*. Clear area (lower right) appears to have been seasonally flooded. Ornamental trees around West Lake were planted 1928. Heavy lines are marks on original photo.

Plate 2.2 Perry Lakes 1921

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Location Map

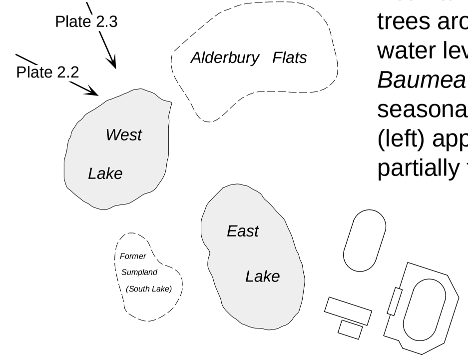

Plate 2.2 appears to have been taken in winter. Both lakes are almost fully flooded. Dead mature trees around both lakes suggest recent rise in water levels. Compared to 1942 (Plate 2.1) *Baumea* is sparcer in both lakes suggesting deep seasonally permanent innundation. Alderbury Flats (left) appear to have been formerly cultivated and are partially flooded. View from One-tree (Reabold) Hill.

Plate 2.3 paddock adjacent to Ranger's residence ('Perry House') overlooking West Lake. Many of the large trees on the far shore are flooded. Rainfall and lake levels peaked about 1930 (Fig 2.3)

Plate 2.3 West Lake 1930

assumed to be flooded in excess of 0.4m for much of the year, while *Baumea* cover suggests shallow seasonal flooding. This is evident over large areas of both East and West Lake in Plate 2.2. Emergent wetland vegetation responds very quickly to changes in wetland hydrology (Froend *et al* 1993). Therefore regardless of what time of year an aerial photograph was taken, the vegetation distribution provides clues to the prevailing hydrology. Vegetation distributions, plotted in Figure 2.2 suggest the following general hydrological trends:

1921: Mean annual level rising severely, reducing emergent vegetation. Presence of numerous dead mature eucalypts close to the margins of both lakes (Plate 2.2) suggests this was preceded by an extended period of lower levels. Historic rainfall peak is centred around 1925 (Figure 2.3).

1921-42: High water levels at least into the early 1930's (Plate 2.3).

1942-53: Distribution of vegetation increasing (Plate 2.1), probably culminating in mid 1950's (dry phase of 1947-1969 cycle).

1959-61: East Lake vegetation wanes as levels increase (peak rainfall occurred 1965-69). An elongate depression to the east of the lake appears to become seasonally flooded.

1962-63: Natural record ends as lakes are dredged and reformed. Formal lake level records commence.

1963-70: Period of persistent high lake levels (Figure 2.10). Remnant patches of vegetation in East Lake in 1967 have disappeared by 1970. The lake basins are covered with water all year. Winter maximum depth in East Lake 2.4m, summer mean depth greater than 0.6m.

1975: Mean annual water levels declining rapidly, *Baumea* re-established in numerous small colonies within East Lake.

1975-80: Dramatic expansion of *Baumea* and *Typha* in East Lake. Portions of lake basin become seasonally exposed. *Baumea* commences re-colonisation of West Lake, followed during the 1980's by *Typha*.

1980-98: Steady expansion of emergent vegetation in both lakes. Trees colonise northeast quadrant of East Lake which reverts to sumpland.

The rapid response of vegetation to recent water level change is examined in Chapter 3.

Graphic, Photographic and Anecdotal Records 1913-1963

The earliest graphic reference known is the 1913 painting by Ramage (frontispiece) showing the northeast end of West Lake. The lake appears as a sheet of water with no emergent vegetation. The season was probably late winter as evidenced by flowering acacias and new leaves (red) on the Tuart tree. The acacias are most likely 'Prickly Moses' (*Acacia pulchella*, flowers July-September) or 'Dune Moses' (*Acacia lasiocarpa*, flowers June-October). Both are common in adjacent Bold Park (B. Knott pers com, Keighery *et al* 1990).

Aboriginal oral history collected by Bodney & O'Connor (1985) cited O'Connor *et al* (1989) relates that swamps surrounding the lakes originally covered a much larger area and were important as a food source because of the prodigious numbers of turtles which lived there. Nyungar women would swim along the reeds carrying a bag into which they put their prey, suggesting water depths of up to 2m or more.

Alexander (1919) describes West Lake in mid August as a 'sheet of water'. The open water clearly visible on the 1921 panorama (Plate 2.2) confirms seasonally high water levels. Lack of emergent vegetation (Figure 2.2) suggests summer water exceeding 0.4m depth. The photo was taken during the wettest period on record (Figure 2.3). Rainfall in the preceding five years exceeded the average by 13% in Perth and 10% in Fremantle (Table 2.3). This rise in the water table occurred throughout the Perth area. Serventy (1948) suggests it commenced about 1918-1920 and continued until at least 1932. West Lake in 1930 (Plate 2.3) was full with waters flooding adjacent mature trees. Southern & Teakle (1937) place the commencement at about 1910. During this period numerous sumplands reverted to permanent wetlands including Native Dog Swamp (now Dog Swamp), Jolimont Lake, Shenton Park Lake and Butler's Swamp (now Lake Claremont).

Table 2.3 Rainfall 1916-1920 (mm)

Year	Fremantle	Perth
1916	744.3	894.3
1917	1036.9	1160.5
1918	883.9	1005.9
1919	754.3	779.7
1920	841.8	1025.9
Average (1916-1920)	852.2	973.3
Historic average	776.8	864.5

Taylor (1986 unpublished) suggested that Perry Lakes appeared to change little between 1935 and 1945. He describes them as marshy swamps, with little open water, and limited access to the waters edge. He describes a distinct post war rise in water level co-incident with clearing and residential development in the suburbs immediately east of the lakes. It is likely that what he observed were the effects of local urban clearing superimposed on the 1947 rainfall cycle peak (Figure 2.3). Plate 2.1 shows Perry Lakes in January 1942.

Table 2.4 Rainfall 1937-1941 (mm)

Year	Fremantle	Perth
1937	748.3	896.8
1938	623.0	753.4
1939	937.5	1161.2
1940	465.3	508.7
1941	745.4	883.1
Average (1937-1941)	703.9	840.6
Historic average	776.8	864.5

The preceding 5 years were only slightly below average (Table 2.4) but followed a sustained period of above average rainfall in the 1920's and 1930's. This photo is unique because it was flown at very low altitude allowing better resolution of vegetation and water level detail. In West Lake it shows an area of possibly permanent water measuring about 20m by 40m surrounded by a barren area comprising about half the lake basin suggesting that the depth of sustained annual flooding here exceeded 0.4m. In East Lake there is a similar pattern, again with about half the wetland vegetated. A decade later during a period of declining rainfall (Figure 2.3) West Lake was dry by 24 February 1953. Gordon Laffer (pers com), referring to his original survey books notes:

> 'I sent my staff man into West Lake to get the water level. He couldn't find any water and thrashed around amongst the reeds till(sic) he found a hole in which there was water below the natural surface.'

Somerford (pers com) believes winter flood waters linked West Lake and Alderbury Swamp (Figure 2.2) possibly 10 times between 1936 and 1957 and that around 1935 the lakes were dry over summer. This corresponds with the rainfall minimum of the 1925-1947 cycle (Figure 2.3). Cows attempting to reach the receding water created large bog holes. Phillious (pers com) confirmed that by the late 1950's the lakes held water summer and winter with winter levels frequently high enough that West Lake, East Lake and Alderbury Flats became one sheet of water.

Watson (1958) provides a detailed scientific description, including ground level photographs of East Lake in 1957. Watson's descriptions in conjunction with low level oblique aerial photographs *circa* 1959 (Plates 2.4 a&b) provide the most complete picture of the lakes described by a scientific researcher, prior to modification. Watson notes (pp 82-83):

> '...the swamp consists of three parts, two distinct deeper lakes and an irregular northern flooded area[3] connected on its western extremity by a drainage channel to the western lake[4]. The two lakes are approximately 10 feet deep in the deepest part, and perhaps 200-300 yards across, while the flooded area is of similar extent but has water of a varying depth to a maximum of approximately 3' 6" in winter and 1'-1' 6" in summer.'

He goes on to note:

> 'As is indicated by dead *Acacia cyanophylla* now standing in the permanent water around the margin of the swamp, the water level has risen in recent times - probably during the rise in water table since 1918-1920...'

Watson includes a ground level photograph taken 18 May 1957 looking south west across East Lake clearly showing standing and fallen dead trees at the (end of summer) water margin (Plate 2.5). *Baumea* and *Typha* are readily identifiable. Standing flooded dead trees are clearly visible in Plate 2.7 taken about 2 years later. In Plates 2.4a, 2.6 & 2.7, East Lake comprises two distinct water surfaces. The southwest portion contains deep

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[3] Alderbury Swamp (Figure 2.2)

[4] This is the open storm drain from Oceanic Drive, visible in Plate 2.4b

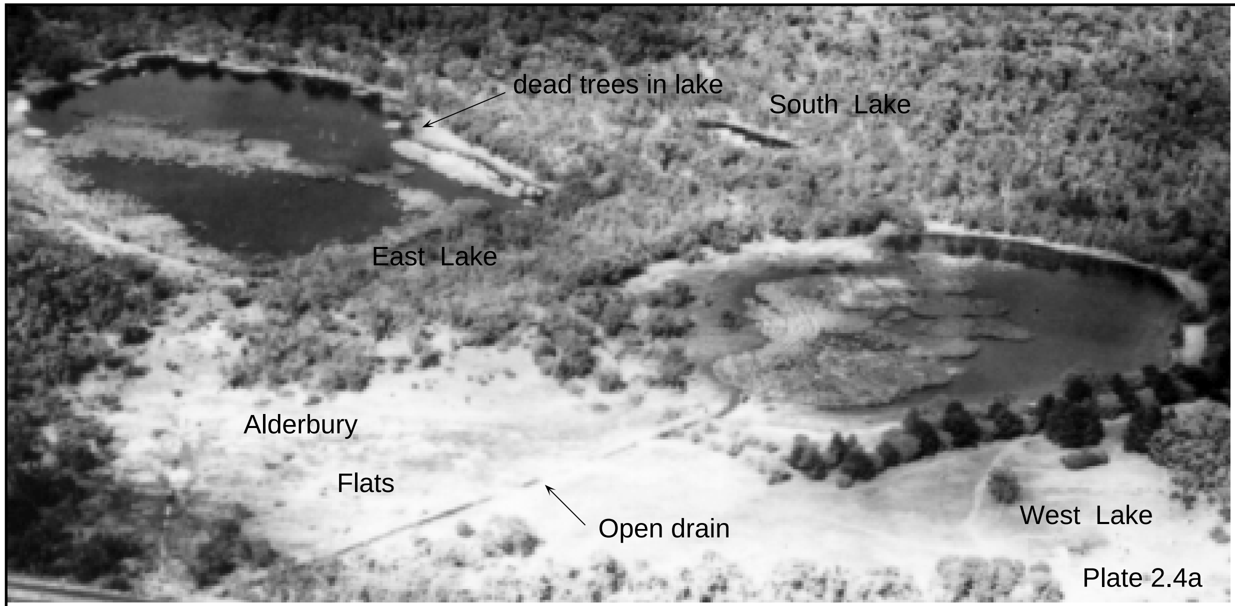

Plate 2.4a

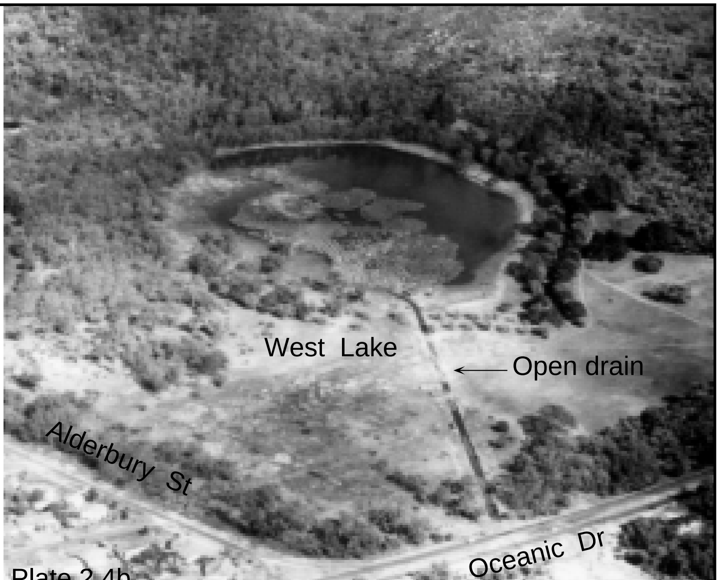

Plate 2.4b

Plate 2.5

Perry Lakes circa 1957 - 1959

Plates 2.4 a&b reproduced by permission Battye Library
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Plate 2.5 © J. A. L. Watson, reproduced by permission

Plates 2.4 a&b are low level aerial shots taken during the initial planning for the stadium complex, probably winter 1959.

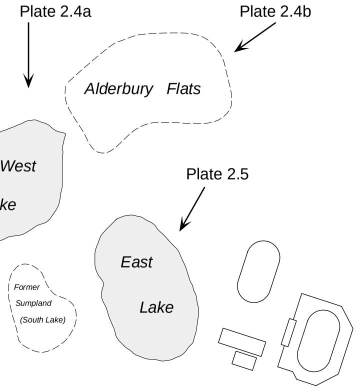

Plate 2.5 taken across East Lake 18 May 1957. Dead trees from 20-30 years of water level rise are clearly evident.

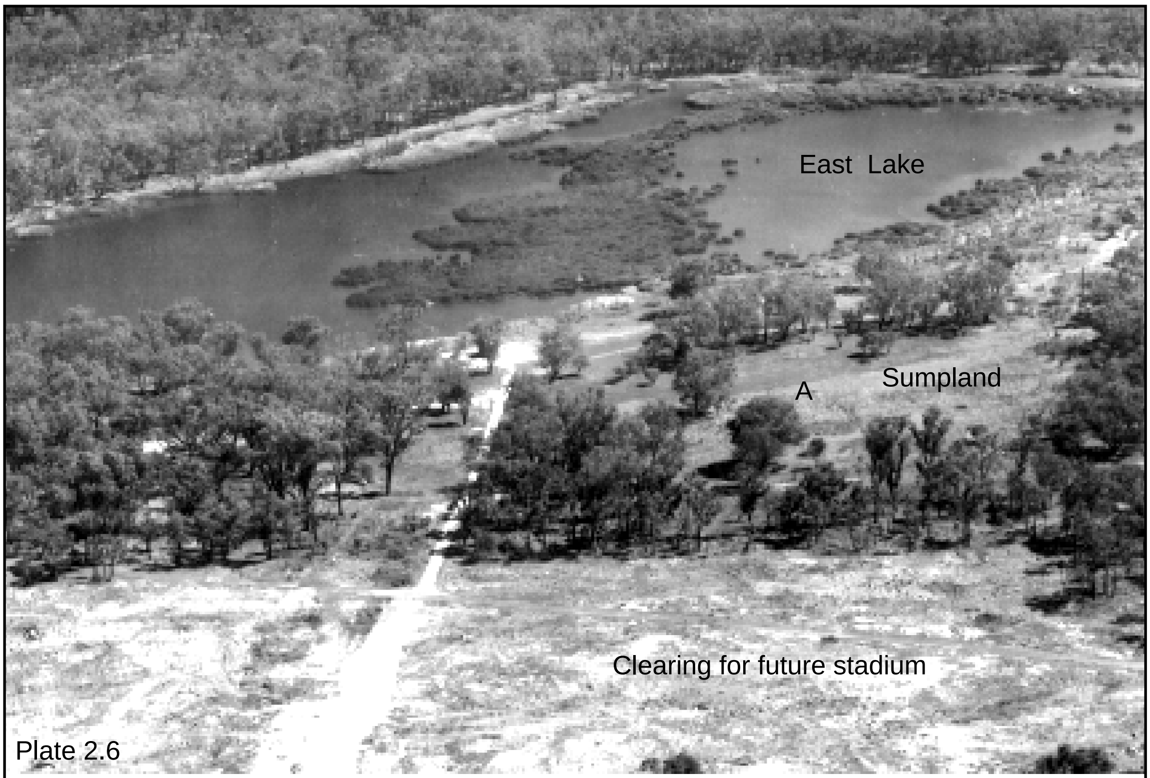

Plate 2.6

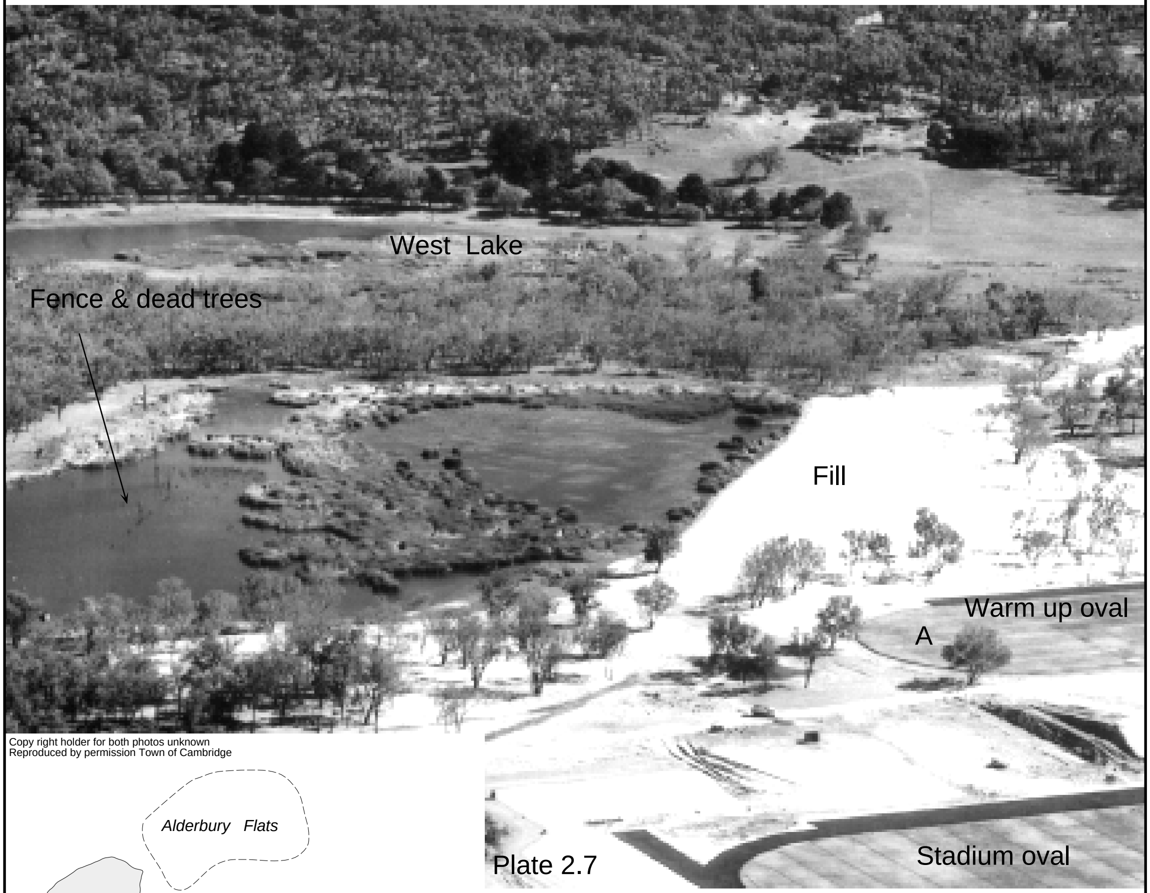

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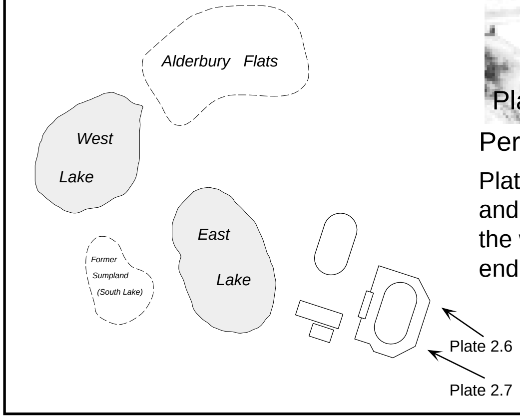
Plate 2.7



Perry Lakes 1961 During Stadium Construction

Plate 2.6 shows the initial site clearing for stadium complex and sumpland adjacent to East Lake filled for construction of the warm up track. Sewage pumping station (Fig 5.1a) is at end of white sand track.

Plate 2.7 shows stadium and warm up tracks in place and fill along East Lake. Dead trees and old fence line (Fig 2.15) clearly visible in East Lake. Tree marked 'A' appears in both photos.

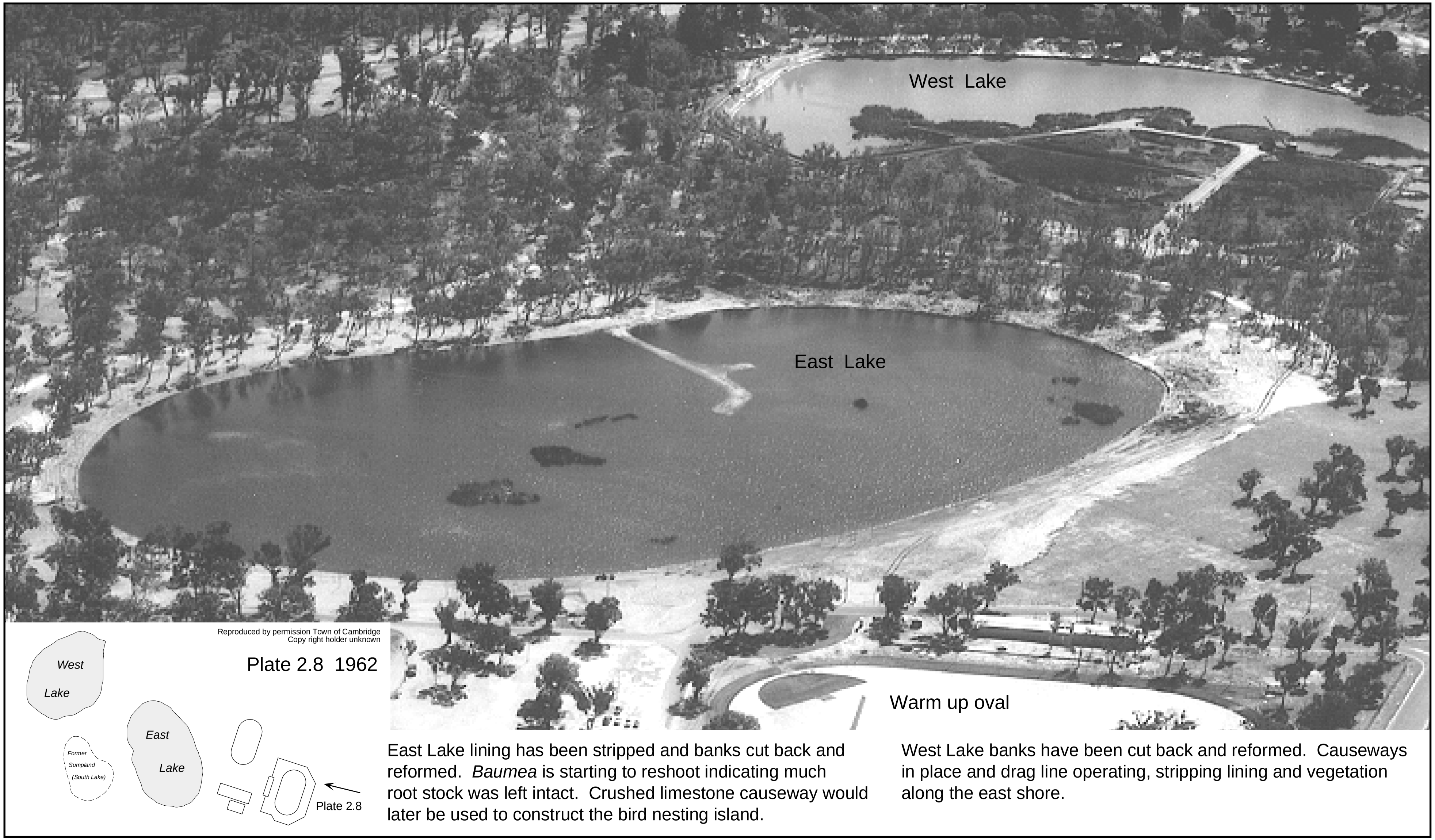


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Plate 2.8 1962

East Lake lining has been stripped and banks cut back and reformed. *Baumea* is starting to reshoot indicating much root stock was left intact. Crushed limestone causeway would later be used to construct the bird nesting island.

West Lake banks have been cut back and reformed. Causeways in place and drag line operating, stripping lining and vegetation along the east shore.

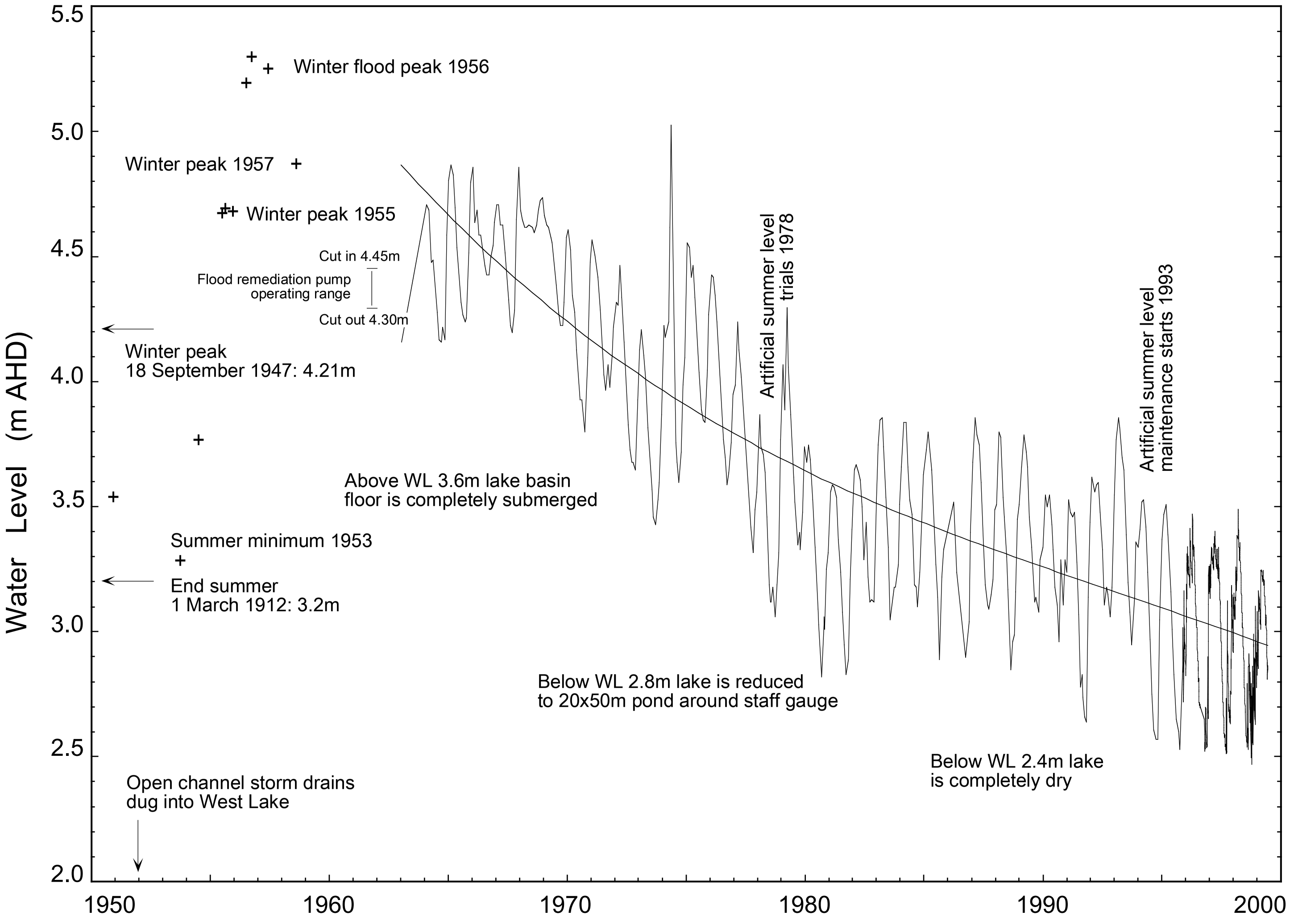
open water while a shallower northeast portion is only rimmed with *Baumea*. The two are separated by a prominent band of tall *Baumea*. Only 17 years earlier in 1942 (Plate 2.1) *Baumea* covered the entire northeast section of the lake. The photos suggest that *Baumea* proliferated in the dry spell around 1940 (Figure 2.3) and then receeded as rainfall and water levels increased from 1942 to about 1952. Water levels in the lakes appear to have remained high in the late 1950's depite a 22 year rainfall cycle low (Figure 2.3). This rise, despite diminished rainfall, may represent the combined effect of urban clearing and introduction of storm water drains. In summary the period from about 1913 to 1963 covers two cycles of extremely high water levels at Perry Lakes. These appear to represent the effects of abnormally high rainfall superimposed on urban clearing and diversion of storm water into the lakes.

2.4.2 Water and Rivers Commission Records and early CSIRO Research

Systematic (generally monthly) WRC levels exist for West Lake from August 1963 (Figure 2.10) and for East Lake from September 1993 (Figure 2.11). Additional published and unpublished East Lake data (Carbon *et al* 1988) has been compiled for the period September 1975-April 1978.

The West Lake data postdates the dredging and deepening (Plate 2.8). Winter flood peaks in 1956 and 1957 correspond to very wet winters but overall occurred during a dry phase of the 22 year rainfall cycle. Levels peaked in the 1969 wet maximum and then declined rapidly (about 1m over the decade 1970-1980, Figure 2.10). Since then, the rate of decline has been less, averaging about 0.4m over the period 1980-1998. This is identical to the rate of regional water table decline noted in monitoring bores over the same period (Figure 2.7).

Systematic records for East Lake commence September 1993. WRC records for monitoring well 1025 located 400m east of East Lake (since destroyed) include sporadic readings back to 1912, and monthly data over the period 1962-1970. Using the current water table gradient as a guide, levels in this well would be expected to be approximately 400mm higher than the lake. The lowest level is 3.25m AHD recorded March 29, 1912 corresponding to the dry period of the 1903-1925 rainfall cycle. A similar surface water level in West Lake of 3.2m was recorded a month earlier (Figure 2.10). These data suggest an annual level range similar to that which prevailed about 1980. No data are available 1912-1947 although the anecdotal data and records from Herdsman Lake and Lake Claremont clearly indicate that levels within Perry Lakes must have been high during this period.



Notes

Data 1912 - 1995 Water & Rivers Commission

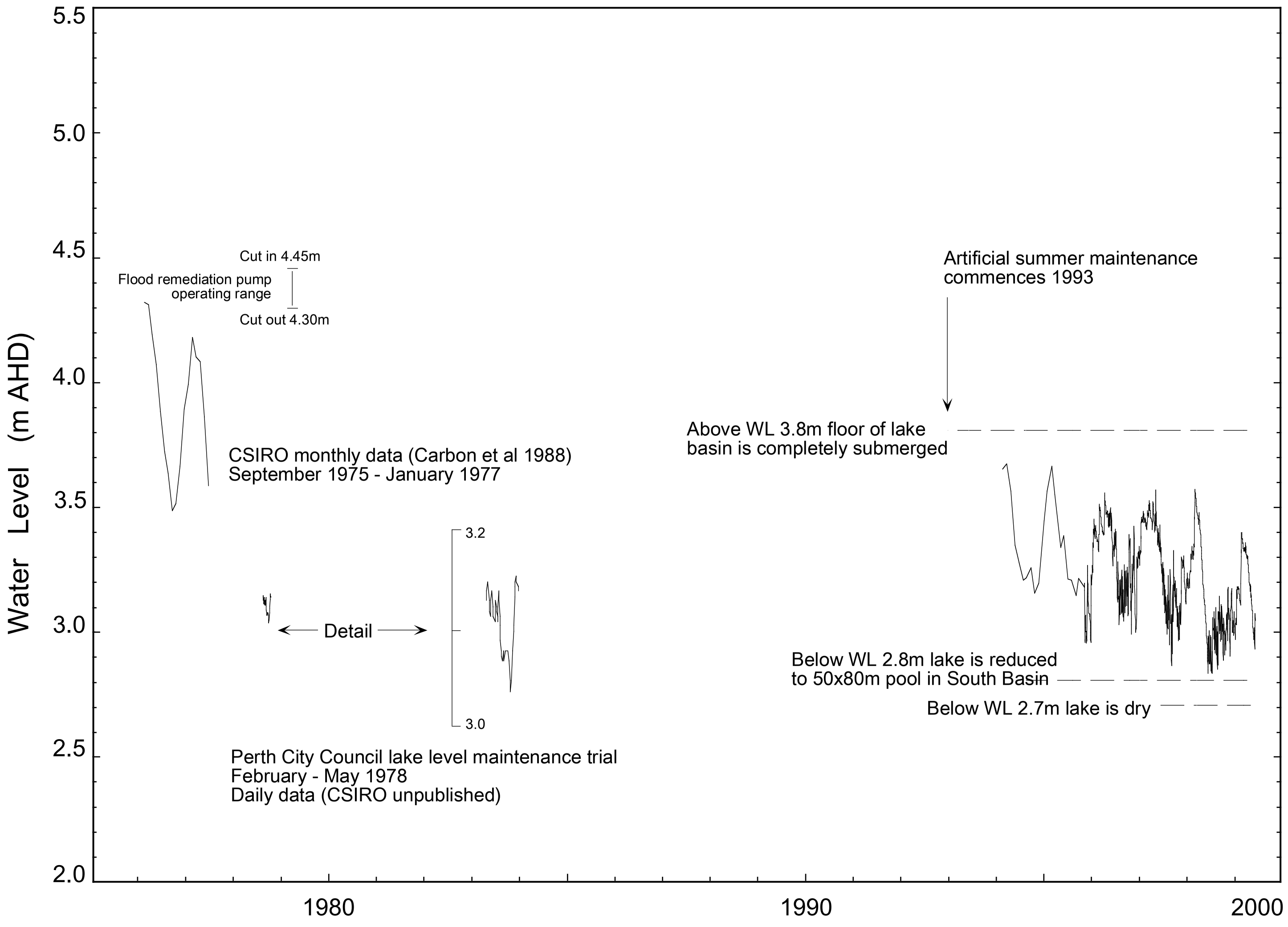
Data 1995 - 1999 data logger (hourly) and manual (daily), this study

Lake level trend estimated by fitting 3rd degree polynomial

\+ Spot lake stage data

Figure 2.10

Historic Levels
West Lake



Notes

Data September 1993 - 1994
Water & Rivers Commission

Data 1994 - 1999 data logger (hourly)
and manual (daily), this study

There is no data for East Lake prior
to September 1975 (CSIRO data)

Figure 2.11

Historic Levels
East Lake

Figures 2.10 and 2.11 indicate levels below which portions of the lake basin floors become exposed. In both lakes this became an annual summer occurrence after 1978. This marks the first trials by PCC at artificial summer level maintenance using locally derived groundwater. CSIRO data (Carbon 1978 unpublished) indicates that PCC pumped into both East and West Lake between February-May 1978. In East Lake levels dropped to 3.04m AHD despite pumping (Figure 2.11). Similar minimum levels were reached again in 1981-82 (based on West Lake data) and have become the norm since 1995. In Figure 2.11, the 'noisy' summer water level data reflect the weekly loss of water via vertical seepage through the lake base, interspersed with weekend top up. Since 1995 the summer water table has been below the base of East Lake *i.e.* less than the 2.7m AHD level shown in Figure 2.11. Under conditions of artificial maintenance, the lake becomes a local groundwater mound. Water introduced artificially drains away quickly. Some is retarded by the remaining clay lining but much of the lining is sand representing the new basin created by dredging the former clay lining and reclaiming the former gentle basin margins. As would be expected the sandy portions of the lake basin are 'leaky'. The further the water table drops below the lake basin, the more difficult it becomes to maintain water levels artificially. Maintenance water quickly drains back to the groundwater system. This is reflected in the mean summer water levels over recent years which, despite artificial maintenance, continue to decline.

In West Lake 1993 was the last year in which winter water completely covered the basin floor. The vegetation data (Figure 2.2) suggests this occurred in East Lake about 1989. This reversion of the lakes to their natural state of seasonal inundation was accompanied by a rapid re-establishment of wetland vegetation. As levels continued to decline this has been replaced by bush indicative of sumpland conditions dominated by flooded gums (*Eucalyptus rudis*). West Lake dried out completely in 1995 and has done so every summer since, accompanied by a rapid expansion and modification of wetland vegetation (Chapter 3). In East Lake, permanent water has become increasingly difficult to maintain as the water table has continued to decline each summer. During summer 1998-99 this artificially inundated area was reduced to a 100m by 100m kidney shaped area known as the South Basin (Figure 2.15).

2.4.3 Perry Lakes Flood Remediation Station Pumping Records

In response to the widespread flooding experienced in 1956 and the generally high winter lake levels, the then Metropolitan Sewage and Drainage Department constructed a flood remediation pumping station at the south end of East Lake (Figures 2.2 & 5.1a). This station was commissioned in July 1964. It comprises two pumps configured as follows:

- design maximum pumping rate is 92 litres/second (331.2m^3/hr), achieved with both pumps running. Normal operation was with one pump active and one stand by

- pumping rate with one pump is approximately 60% of design maximum or 198.7m^3/hr

Originally the station was set up to cut in pump one at level 'A', followed by pump two if the water continued to rise to the 'B' level. These levels were also changed seasonally as follows:

	'A' Cut in	'B' Cut in	Cut out
Summer	4.50m	4.65m	4.35m
Winter	4.30m	4.45m	4.15m

The pumps can drop the lake to 3.30m AHD for maintenance work. Water is ducted via a rising main to the Subiaco waste water ocean outfall. Note that a link pipe (Figure 2.2) connects East and West Lakes at flood stage. This link has a inlet height of 4.45m at the West Lake end, rising to a gully trap of unknown height midway between the lakes. During the initial two years of operation numerous manual measurements were taken of lake stage relative to the pump station floor. The floor was levelled (as part of the lake bathymetry survey, Chapter 3), allowing these measurements to be compiled as lake stage. This data (Figure 2.12) is plotted against corresponding WRC data for West Lake. The data clearly demonstrate the manner in which the pump maintained the East lake levels within the cut in and cut out levels. Under normal circumstances West Lake is typically 100mm lower than East Lake. The data suggest that the link drain was inoperative over this period.

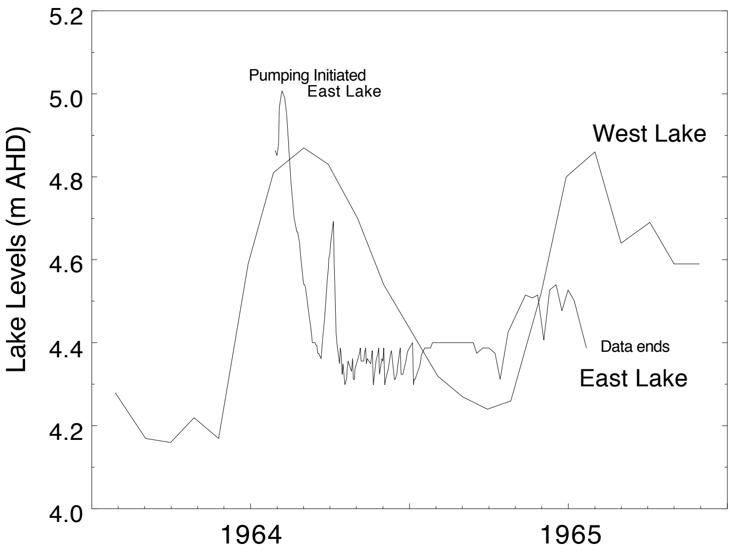


Figure 2.12 Detailed lake stage data following commissioning of flood remediation pumping station. The data suggest that the cut in and cut out levels were raised 100mm between winter 1964 and winter 1965.

Hour meter records for each pump were used to construct annual pumping totals (Figure 2.13). Between 1964-1969 about 2.6 million cubic metres of water were removed, peaking at 0.82 million cubic metres in 1967 alone. At a current winter maximum stage of 3.6m, this represents about 27 present day winter lake volumes.

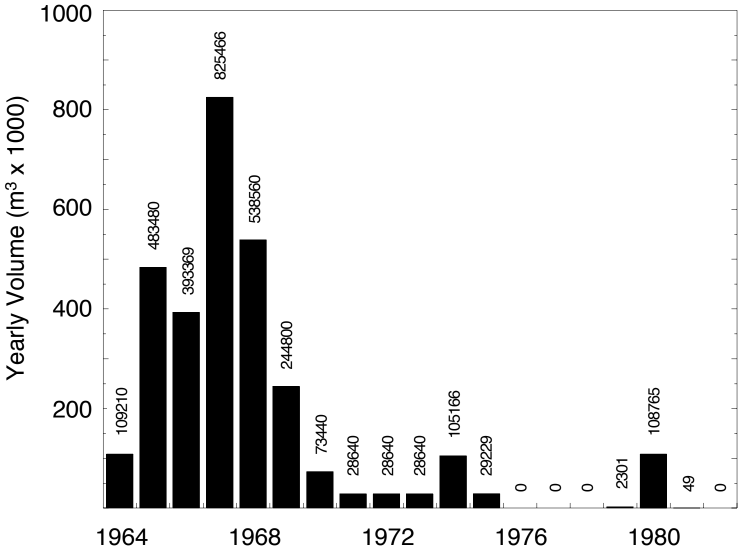


Figure 2.13 Flood remediation station, water volumes pumped 1964-1982

It is likely that the lakes functioned as flow-through lakes for most of the year. Much of the pumping was probably unnecessary, and amounted to extracting groundwater (and artificially creating discharge lakes in the process). The station has not been used since 1980.

2.4.4 Changes in Lake Chemistry

Over the period 1974-1984 Dr. I. Lantzke, then lecturer in Science at the Western Australian College of Advanced Education collected monthly water quality, flora and fauna data from Perry Lakes. The most complete records (Lantzke 1979 & Lantzke 1986) used here are for the period 1974-1976 when data (all of which remains unpublished) was collected monthly. Chloride data (Figure 2.14) demonstrate how lake chemistry has been altered under differing hydrological regimes. During the 1970's lake levels and volumes were high (Table 2.5).

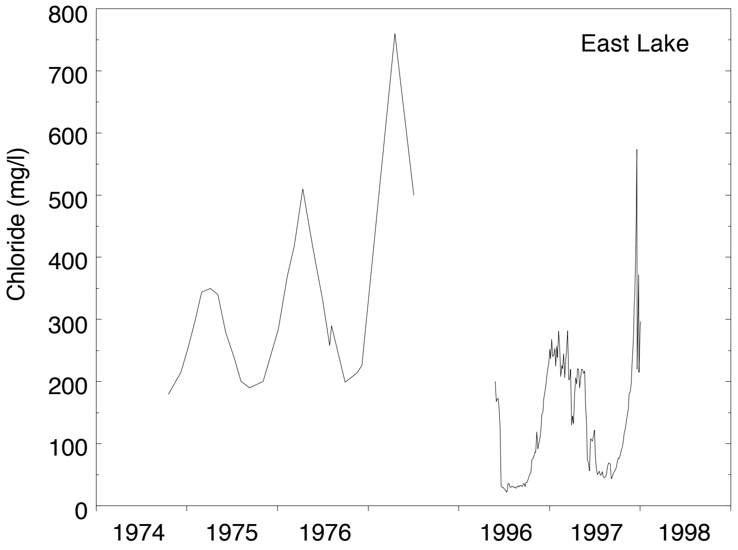


Figure 2.14 Lake chloride chemistry as a function of lake-aquifer interaction and artificial summer maintenance

Table 2.5 Comparative East Lake Hydrology 1974-1997

	1974	1975	1976	1997
Annual rainfall (mm)	938.1	682.1	712.6	651.4
Maximum recorded winter stage (m AHD)	4.560	4.430	4.240	3.575
Corresponding winter lake volume (m^3)	99120	89160	74930	28230
Winter area:volume ratio	0.78	0.85	0.98	2.21
Minimum recorded summer stage (m AHD)	3.600	3.840	3.420	2.887
Corresponding summer volume (m^3)	29820	46210	19220	773
Summer area:volume ratio	2.18	1.51	2.84	13.36
Estimated stormwater input (m^3)				56398
Stormwater as ratio winter lake vol (stage 3.2m)				6.4
Known groundwater input (m^3)				177000

Notes: Rainfall 1974-76 is Perth City, 1997 Perry Lakes
Stormwater flows estimated from 1997 data (refer Chapter 6)
Maximum lake stage 1974-1976 extrapolated from West Lake data
Groundwater input 1997 is pumped lake level maintenance program

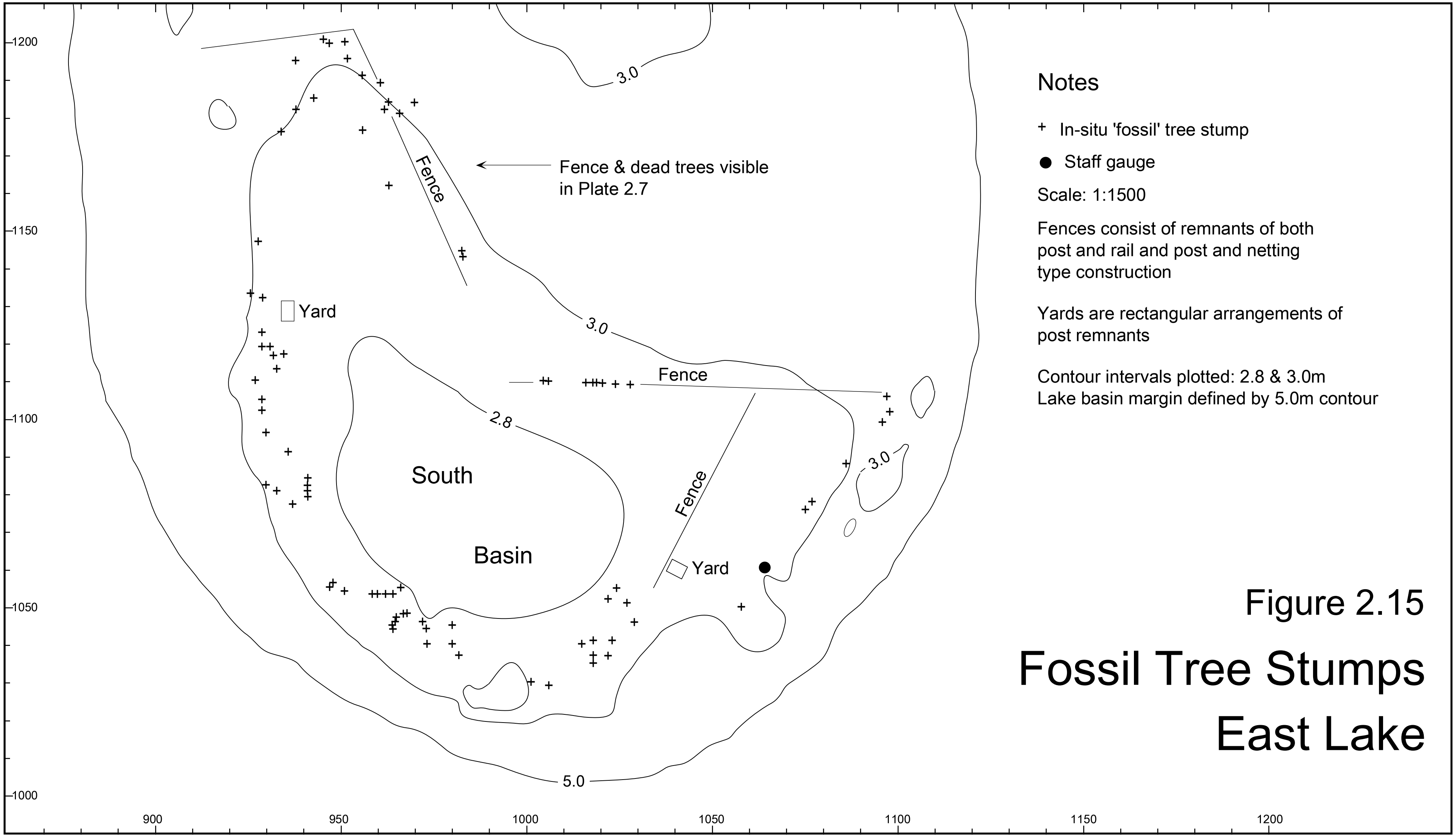
Rainfall in Perth (and by inference stormwater) has a mean chlorinity varying from about 10.7-16.5mg/l Cl (Teakle 1937, Hingston & Gailitis 1976). In winter, stormwater input during the 1970's represented a small proportion of lake volume. The lake probably functioned as a flow-through lake for most of the year. The winter Cl levels of about 200mg/l represent dilution of higher summer chloride concentrations from storm water and groundwater inputs of around 140-200mg/l. The very high summer Cl, up to 760mg/l suggests the lakes may have become discharge lakes or 'evaporative sumps'. Similar spot summer and winter values were obtained by Watson (1958), 31 January 1957 506mg/l and 8 June 1957 410mg/l. In 1997 the early winter lake water was derived solely from rain (either directly or as storm water). As a consequence winter Cl levels are about 30mg/l. The rapid rise in spring Cl levels corresponds to a brief transition to flow-through status, increased evaporation coupled with a high area:volume ratio, and commencement of lake level maintenance with groundwater derived inputs varying from 150-225mg/l. The lake functions as a recharge lake all summer as top up water drains back to the aquifer. Despite the shallow depth (mean depth about 0.3m) and high surface to volume ratio, the mean Cl values of about 200mg/l principally reflect groundwater (maintenance) chemistry. The high recharge flux back to the aquifer precludes significant chloride enrichment from evaporation. In December 1997 (as part of this study) East Lake was allowed to evaporate almost to dryness. Chloride peaked at 574mg/l (stage: 2.836m, volume 357m^3) well below the summer chloride levels obtained in the 1970's despite a much higher area:volume ratio.

The historic data suggests that at higher lake stages elevated winter Cl levels were maintained by flow-through derived groundwater flux and low relative dilution from stormwater. High summer Cl levels resulted from possible discharge flow status and evaporative pumping. Current winter values are solely rainwater derived with very low Cl while current summer Cl values (from bore water) are identical to former winter levels (from groundwater fluxing). In summary, the current lake water is much fresher than it was during the 1970's.

2.4.5 Botanical and Archaeological Research 1998

Remnant *in situ* tree stumps are visible at low water levels around the South Basin in East Lake. These stumps vary in diameter from 10cm to 50cm. Stump locations were mapped on the survey grid and are plotted along with lake basin contours in Figure 2.15.

In trees, spreading roots lie just below the surface and represent the initial roots which developed at germination. These 'surface' roots occur just below the basal flare or root collar and are a distinctive marker of the original surface level at time of germination. The level of these roots relative to the present surface is the principal botanical tool for estimating wetland sedimentation rates (Hupp & Bazemore 1993). In Perry East, surface roots on the larger stumps lie at the present lake bed surface confirming that this surface is essentially unchanged since the trees died. The distribution of the stumps suggests that trees growing on higher ground, closer to the lake basin margins were probably removed during the lake dredging and bank reclamation. The stumps appear to represent both eucalypt and paperbark, probably flooded gum *Eucalyptus rudis* and *Melaleuca rhaphiophylla* or *M. preissiana*. These species presently occur in the northeast portion of the East Lake basin. They are wetland trees well adapted to varying wetland water levels



Notes

- \+ In-situ 'fossil' tree stump
- ● Staff gauge

Scale: 1:1500

Fences consist of remnants of both post and rail and post and netting type construction

Yards are rectangular arrangements of post remnants

Contour intervals plotted: 2.8 & 3.0m
Lake basin margin defined by 5.0m contour

Figure 2.15

Fossil Tree Stumps East Lake

and will tolerate up to several years of continuous inundation before they die (Balla 1994). Co-incident with the stumps are remnants of four mortice and tenon and post and netting fence lines. Two remnant mortice and tenon fence lines are also preserved in West Lake (Figure 5.1b). Along two of the East Lake fence lines preserved stumps are directly on the fence line suggesting they grew while the fences were still serviceable (Plate 2.7). Six large dead tree stumps are visible in low level oblique air photographs *circa* 1959 (Plate 2.4a). These are located close to the northeast fence boundary (approximate local grid 1200N 950E). Watson (1958) specifically notes dead *Acacia* around the lake margin (Plate 2.5) and ascribes their death to a rise in the water table since 1918. This confirms anecdotal evidence from local residents who state that old tree stumps but no fences were visible in the lakes in the early 1950's. What appear to be dead standing mature trees are visible around the east margin of East Lake and the south margin of West Lake in 1921 (Figure 2.2).

The data and photographic evidence suggest that the fences date either from Joseph Perry's ownership (1880-1917) or the Birch brothers (1869-1880) who are known to have constructed extensive rail fencing (de Burgh 1986). The trees most likely represent a period of sustained low summer water levels co-incident with dry conditions from at least 1876 (when records commenced) until about 1916. During this period only the central portion of the Southern Basin below about 2.8m AHD sustained permanent inundation. The fences were most likely constructed to prevent cattle becoming bogged in the mud.

The fence remains also provide some measure of sedimentation rates during historic times. Early Australian mortice and tenon fences were no doubt built to varying specifications. Early guides for settlers (see for example Smith 1992) suggest 10 inches (254mm) clearance between the bottom rail and the ground. Assuming a similar construction style, mortises preserved in upright posts would now provide a ground clearance for the bottom rail of about 100mm, suggesting 150mm sedimentation over 100-150 years or about 1.0-1.5mm per year. This is significantly greater than the mean rate suggested from sediment isopach data (Chapter 3) where 2m to 3m of sediment have accumulated in West and East Lake respectively over about 8000 years suggesting rates of 0.25mm to 0.38mm per year. The apparent recent increase may reflect the introduction of storm drains and the dredging of the basin margins which would have stirred up large amounts of fine sediment.

2.4.6 Argentine Ant Plague, Pesticide Residues and Nutrients

Cores of lacustrine palaeo-sediments (Chapter 3) contain abundant shells from fresh water snails, however the recent sediments from East Lake are devoid of such shells. There is no obvious explanation for this apart from anecdotal evidence (Lantzke pers com, Lantzke

1986 unpublished) that the lakes generally have become devoid of small invertebrates over the past few decades. Possible reasons for this include the extensive spraying around and within both lakes for argentine ants using chlordane and dieldrin during the early 1950's (D. Rimes former WA Government Entomologist, pers com). These were reportedly present in plague proportions to the extent that nesting birds lost all their young to predation by ants. Organochlorine pesticide residues occur in many Swan Coastal Plain wetlands (Davis & Christidis 1997). The introduction of storm water drains at approximately the same time corresponds to this apparent loss of bio-diversity. Ostracods reported in 1957 (Watson 1958) appear to be absent by 1974 (Lantzke 1986).

Lantzke (unpublished) provides orthophosphate (PO_4^{-3}) data for East and West Lake waters from 1974 to 1984. The most complete data is 1976 when both lakes were sampled monthly. The data which range from <0.01mg l^{-1} to 0.28mg l^{-1} display no obvious seasonal trend. Mean (n = 30) for each lake was identical, 0.06mg l^{-1}. The most recent data (for total phosphorous) in August 1991 (Dames & Moore 1992) returned values ranging from 0.01mg l^{-1} to 0.03mg l^{-1}. These data suggest that the lakes at that time were oligotrophic to mesotrophic using the classifications of Wetzel (1975) and OECD (1982). Since these early surveys the lakes have shrunk considerably suggesting that summer nutrient levels are probably significantly higher.

Urbanisation and nutrients carried in storm drains are probably the single greatest contributor to nutrient build up in the lakes. Lantzke (unpublished) measured 0.04mg l^{-1} orthophosphate in West Lake waters but 0.26mg l^{-1} in drain water entering the lake (data for April 1981). Frequent drying out and re-flooding of sediments is known to accelerate the breakdown of nutrients in leaf litter (Ryder & Horwitz 1995) and in particular phosphorous (Qui & McComb 1994) and nitrogen (Qui & McComb 1996). Summer top up of bore water into East Lake also introduces nutrients, particularly phosphorous (Table 2.6)

Table 2.6 Nutrients in irrigation bores

Bore	Total P (mg l^{-1})	Total N (mg l^{-1})
2	0.05	
3	0.05	
4	0.20	
5	0.10	
6	0.05	2.25
7		
8	0.15	3.20

Refer Figure 3.3 for bore locations. Data from Dames & Moore (1992)

2.5 CONCLUSIONS

Records of lake levels provide the best indications of long term water table changes in the Perry Lakes area. These suggest that during the second half of the 19th century levels were relatively unchanged and similar to those now prevailing. Herdsman Lake dried out on several occasions and Lake Claremont was essentially a sumpland with minor seasonal water. At Perry Lakes fence remnants and tree stump patterns suggest minimal summer water. A pronounced increase in levels occurred regionally between 1910-1970. Rainfall peaked around 1925 with lesser peaks centred around 1947 and 1969. These are part of a well documented 22 year cycle, although the 1925 cycle produced the highest sustained period of above average rainfall on record. Water levels in wetlands mimic rainfall but are complicated, particularly in the Perry Lakes and Lake Claremont areas by the superimposed effects of urban clearing and introduction of storm water drains. At Perry Lakes very high levels were formally recorded in the 1950's and 1960's as were similar levels (supported by anecdotal evidence) during the 1930's and 1940's . These levels came to be regarded as the norm when in fact they were clearly abnormal when compared to nearby wetlands with much longer water level records.

In their original state the lakes were shallow depressions within which small seasonal changes in water level resulted in large changes in water surface area. The aerial photographs and anecdotal records clearly suggest that in summer the lakes were reduced either to small pools or dried up completely, then expanded over winter to cover much of the basin. Dredging in the 1960's, but more particularly bank reclamation, served to superimpose the European perception of lake permanence and distinct boundaries between land and water. That this 'Europeanisation' of the lakes coincided with a period of abnormally high water levels merely served to compound the misconception. As levels declined in the 1970's large sections of the lake basins became seasonally exposed. This in fact was what had always occurred when the wetlands were in their natural state. Levels now *are* lower than at any time for which we have records. Rainfall during the 1970's was the lowest on record. Just as the 'problem' of declining lake levels is primarily one of perception, so too are the concepts of 'average' rainfall and 'normal' climatic conditions. Climate is constantly changing and the concept of normal or average rainfall is merely a human construct reflecting the limited time over which formal records have been kept. Where longer formal and proxy records are available such as Europe, China, the Middle East and even North America, significant climate changes have been documented over centuries and millennia (Le Roy Ladurie 1971, Gribben & Lamb 1978, Neumann & Sigrist 1978, Atkinson *et al* 1987, Guiot 1987, Wanner & Siegenthaler 1988, Jacoby & D'Arrido 1989, Mitchell 1990). This theme is further developed in Chapter 13.

CHAPTER 3

PHYSIOGRAPHY

3.0 INTRODUCTION

This chapter is a summary of all the basic physical and biological characteristics of Perry Lakes. The botanical and geological characteristics of the wetlands are reviewed followed by an overview of field experiments completed to measure the basic hydrological parameters of the superficial aquifer and lacustrine sediments. Depth-area-volume relationships are constructed from field surveys.

3.1 VEGETATION

3.1.1 Background

No formal assessment of vegetation has ever been undertaken at Perry Lakes. Passing references include Alexander (1919), Watson (1958), Riggert (1966), Keighery *et al* (1990), Dames & Moore 1992, Mitchell McCotter & Ecoscape (1993). Arnold (1987) includes sketch maps of the distribution of open water and principal vegetation communities within the lake basins *circa* 1986. Surveys undertaken here describe in detail the distribution of vegetation communities and in particular the distribution of the dominant fringing emergent macrophytes *Baumea articulata* (R. Br.) S. T. Blake (Cyperaceae) and *Typha orientalis* C. Presl (Typhaceae), commonly referred to as jointed twig-rush and bulrush (Chambers *et al* 1995). These species dominate the littoral zone at Perry Lakes and are highly responsive to short term changes in water regime (Froend *et al* 1993, Froend & McComb 1994). Mapping also differentiated the distribution of the naturally occurring species *Bolboschoenus caldwellii* (common name marsh club-rush) and the small sumpland plant *Villarsia*. Naturalised introduced sedges *Cyperus eragrostis* and *Cyperus tenuiflorus* were also mapped as their distribution also appears linked to water regime.

Depth to water table is a function of the elevation of the lake bed, the local water table gradient and the regional water table level. The distribution of emergent macrophytes is controlled by three principal factors (Froend *et al* 1993, Chambers *et al* 1995):

- Annual range (minimum-maximum water level)
- Period of inundation at any particular RL within the lake basin
- Sediment type (typically sand, peat or clay)

Within the shallow saucer like form of Perth Coastal Plain wetlands, these three criteria define concentric zones around the shore where sand grades to silt-clay substrate and where the degree and duration of seasonal waterlogging and inundation vary. Dredging and reclamation of the shorelines has resulted in extensive areas of sandy substrate around portions of both lakes (Figures 3.6 a&b). At Perry Lakes the principal factors controlling the distribution of *Baumea* and *Typha* appears to be their differing preferred range and mean annual water levels (Table 3.1). Therefore *Baumea* occurs in the deeper portions of the basins where there is a longer or permanent period of inundation while *Typha* occurs on higher ground where inundation is sporadic.

Table 3.1 Water level criteria, dominant emergent macrophytes

	Tolerable WL Range	Preferred Mean WL
Baumea articulata	+400 to -400mm	+250mm
Typha orientalis	+100 to -300mm	0 *i.e.* waterlogged

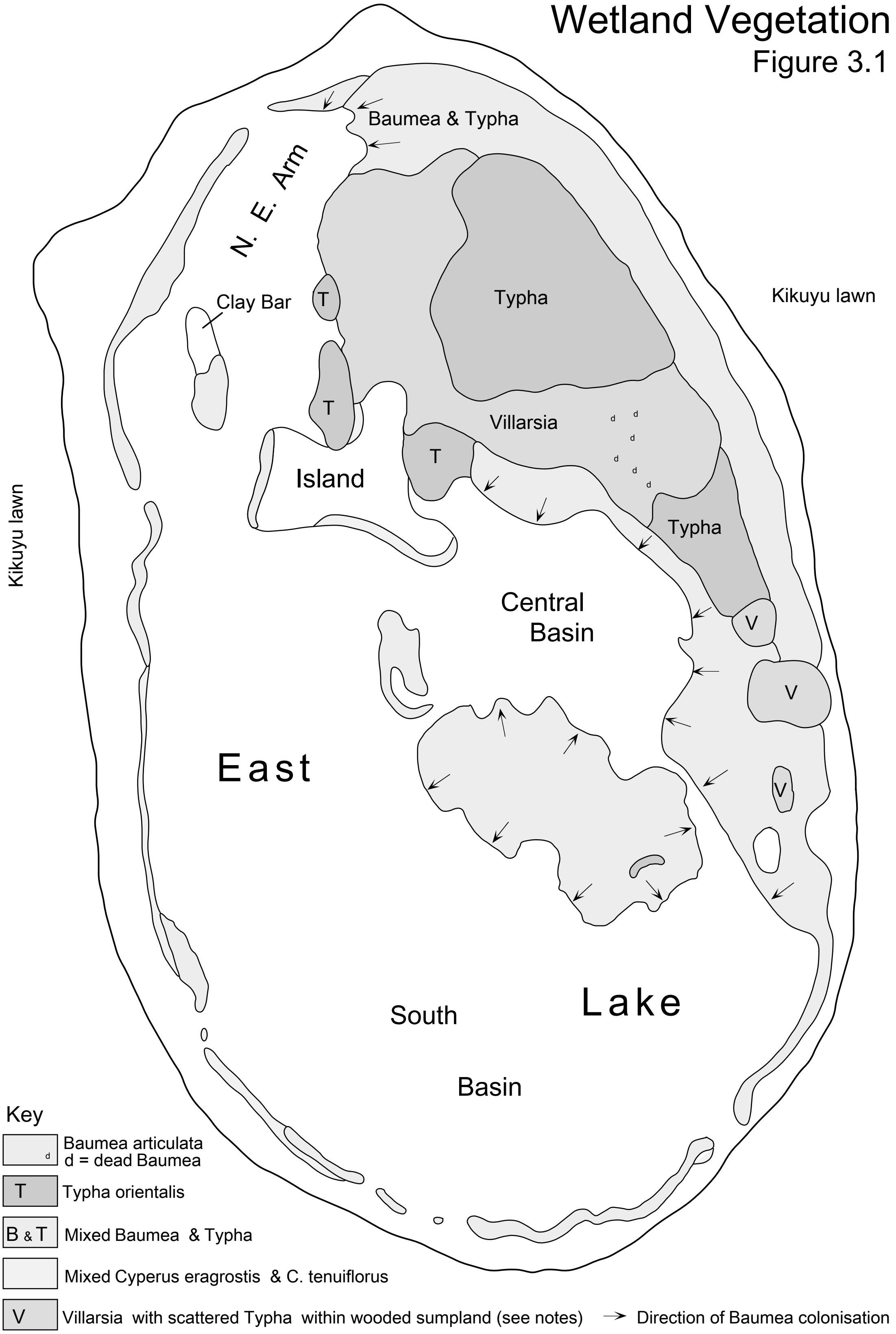
Mapping was controlled using 10x20m surveyed grids established for topographic and sediment isopach surveys. In East Lake, mapping was completed simply to document the vegetation distribution as it existed at the completion of the water balance field work in early 1998. In West Lake mapping was completed during the summers of 1995, 1996 and 1997 specifically to document the vegetation changes associated with the transition from permanent to seasonal innundation.

3.1.2 East Lake

Prior to dredging in 1962, East Lake appears to have been dominated by extensive stands of *Baumea articulata*, but with open permanent water always present in the South Basin. Since about 1970, water levels have declined and there has been a steady progression from permanent open water over the entire basin to permanent open water (artificially maintained over summer) in the South Basin only. Figure 3.1 shows the distribution of vegetation and open water or seasonal mud flats as of January 1998. *Baumea* is now actively expanding into the South, Central and N. E. Arms while *Typha* is expanding in the higher northeast quarter of the basin where there is only occasional inundation. Remnants of dead *Baumea* are common in the *Villarsia* sumpland (Figure 3.1) reflecting a recent site of *Baumea* colonisation. These colonies have probably died within the past five years.

Wetland Vegetation

Figure 3.1



Notes

1: Outer margin of lake basin defined by the 5m AHD contour

2: Kikuyu lawn grass (Pennisetum clandestinum) occupies steep bank between 5m contour and outer margin of wetland vegetation

3: Typha and Villarsia in N.E. quadrant of basin occur within wooded sumpland of Flooded gum (Eucalyptus rudis) and paperbark (Melaleuca spp.)

4: Bolboschoenus caldwellii not identified in East Lake

Scale: 1:2000

Mapped January 1998

3.1.3 West Lake

West Lake dried completely (apart from the small sump adjacent to the staff gauge) for the first time in recent years in the summer of 1995. Anecdotal evidence (Chapter 2) suggests that within historic times occasional summer drying had occurred previously, but probably not to the same extent. Since 1995, West Lake has been dry every summer from approximately January until June or July. It has become a seasonal wetland or 'sumpland' as defined by Semeniuk (1987). Vegetation distribution was mapped in detail in February of 1995, 1996 and 1997. During this period:

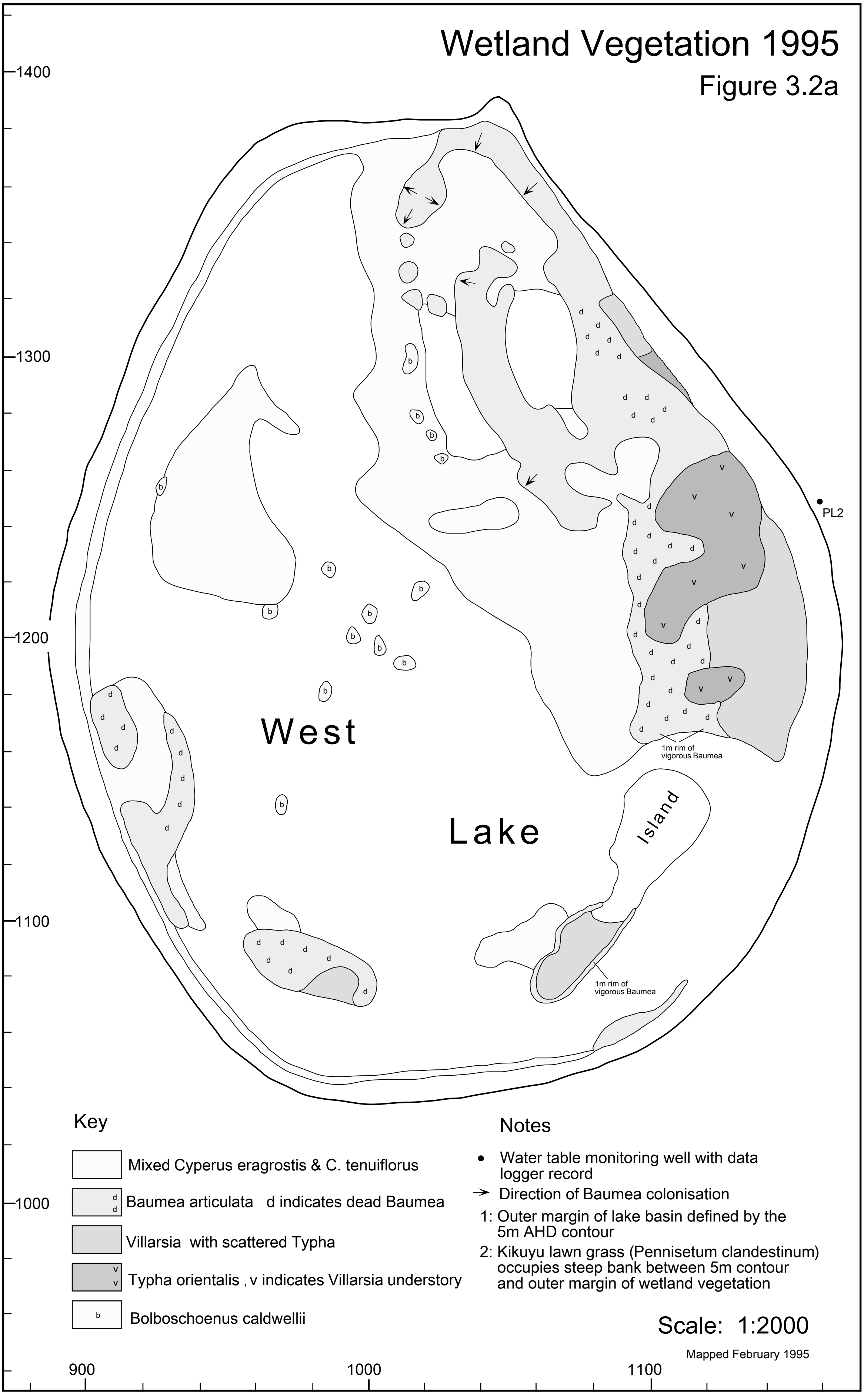
- Mean depth and period of winter inundation decreased
- Depth to water table over the summer increased

In a lake the piezometric head at the lake bed is everywhere equal to the elevation of the water surface. The water surface constitutes a horizontal water table. When a lake dries out however, the regional water table gradient is re-established beneath the lake bed. Therefore despite having the same elevation, different points around the lake bed will be at differing vertical distance to the water table. In West Lake, the regional gradient traverses the lake from northeast to southwest (Figure 3.3). Therefore over summer when the lake is dry, distance to the water table in the southwest corner of the lake basin will be greater than in the northeast corner.

Figures 3.2 a&b demonstrate the principal changes delineated over the two years from February 1995 to February 1997. These fringing emergent macrophytes constitute dynamic communities which respond quickly to exploit a modified water regime. The principal changes observed over 24 months were:

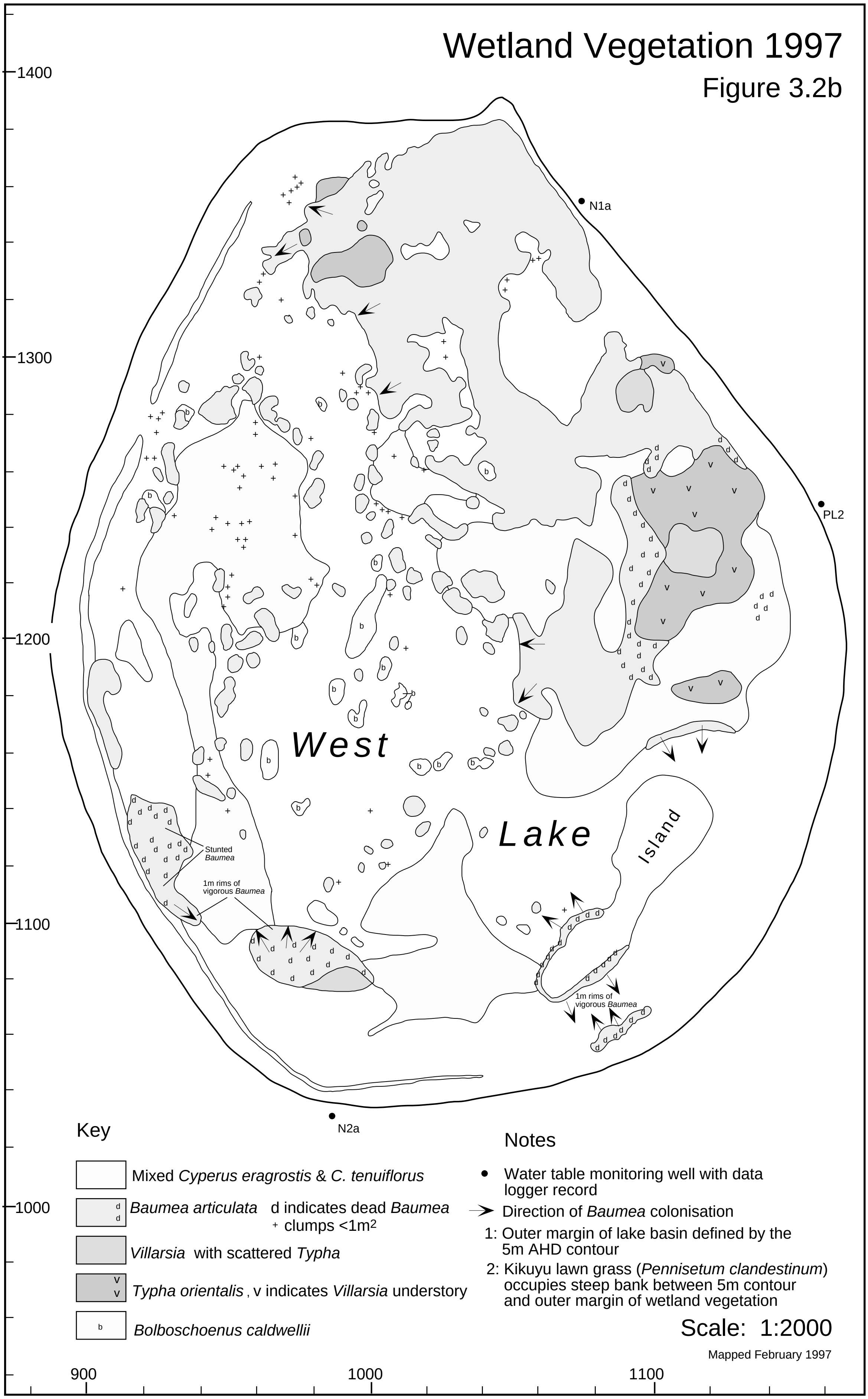
- an explosive expansion of *Baumea articulata* into the deeper western and southern portions of the basin including the establishment of numerous isolated outliers
- expansion of *Typha orientalis* into the northern section of the basin
- a decrease in vitality or death of *Baumea* and *Typha* at various locations around the higher periphery of the basin
- death of *Villarsia* along the higher eastern margin of the basin
- rapid expansion of *Cyperus* and *Bolboschoenus* into the deeper portions of the basin

Examining the vegetation distributions in conjunction with the lake bed topography (Figure 3.10b) demonstrates the effects of topography combined with seasonal re-establishment of a water table gradient beneath a seasonally dry lake. In 1995 vigorous *Baumea* tended to occur between the 3.2 and 3.0m RL while plants situated between 3.2



Wetland Vegetation 1995

Figure 3.2a



Wetland Vegetation 1997

Figure 3.2b

Key

- ☐ Mixed *Cyperus eragrostis* & *C. tenuiflorus*
- ▨ d d *Baumea articulata* d indicates dead *Baumea*
  + clumps <1m²
- ▨ *Villarsia* with scattered *Typha*
- ▨ v v *Typha orientalis* , v indicates *Villarsia* understory
- ☐ b *Bolboschoenus caldwellii*

Notes

- ● Water table monitoring well with data logger record
- → Direction of *Baumea* colonisation

1: Outer margin of lake basin defined by the 5m AHD contour

2: Kikuyu lawn grass (*Pennisetum clandestinum*) occupies steep bank between 5m contour and outer margin of wetland vegetation

Scale: 1:2000

Mapped February 1997

and 3.4m were stunted and in part dead (Figure 3.2a). This was largely a topographic effect only representing annual differences in range and period of inundation. Between 1995 and 1997 *Baumea* expansion was largely confined to the northern half of the lake basin between 2.9 and 3.0m RL. Despite the fact that large portions of the southern half of the basin lay within the same elevation range these remained uncolonised, due to the water table gradient effect. *Baumea* cannot colonise these southern portions of the basin because the depth to water over summer is too great. The data demonstrate the rapidity of vegetational response to major changes in wetland water regime.

3.1.4 Aquatic Flora

Watson (1958) describes *Potamogeton pectinatus* in East lake in 1957 and *Nitella sp* in flood ponds on present day Alderbury Flats. Lantzke (1986 unpublished) noted abundant submerged aquatic plants in 1974 including *Najas marina*, *Triglochin procera* and *Potamogeton pectinatus*. Approximately two decades later Dames and Moore (1992) reported only sparse distributions of *Chara sp* and possible *Nitella sp* with abundant epiphytic growths. No aquatic flora were noted over the period 1996-1998.

3.1.5 Algae

The available historic evidence suggests that algae are a natural part of the Perry Lakes ecology. Seasonal growth of algae appears to be a natural part of Swan Coastal Plains wetland ecology and possibly precedes European occupation. Hodgkin & Vicker (1987) for example make such a suggestion in respect to the Swan River. Watson (1958) noted a heavy growth of filamentous green alga in East Lake over winter 1957. Lantzke (1986 unpublished) reported similar alga in both lakes over the period 1975-1984 as did Dames & Moore (1992) in 1991 along with abundant *Chara sp* in West Lake.

Samples of alga collected from East Lake in October 1995 were identified as *Zygnema sp* (J. Nowell pers com), a filamentous non branching green alga. Blooms of this species were observed each October during 1995 to 1998. Each year blooms grew slowly over several weeks and then collapsed quickly suggesting nutrient limiting in either nitrogen or phosphorous. Blooms of blue-green algae have been reported during 1976-77 (Lantzke 1986 unpublished) and in West Lake only in 1991 by Dames & Moore (1992). None were observed over the period 1995 to 1998.

3.2 AQUIFER GEOLOGY

3.2.1 Geomorphology

Perry Lakes are situated within the Pleistocene Spearwood Dune System of McArthur & Bettenay (1960). Immediately to the west within Bold Park, calcareous coastal dunes of the Holocene Quindalup system (McArthur & Bettenay 1960, Semeniuk, Cresswell & Wurm 1989) encroach as far east as Camel Lake.

Sands of the Spearwood Dune System while principally yellow, include white, light grey and brown sands. They are predominantly quartz, with colour derived from a coating of kaolin and goethite (Glassford & Killigrew 1976). These siliclastic sands overlying the Tamala Limestone have been generally interpreted to represent *in situ* decalcified Tamala Limestone (Prider 1948, Lowry 1977). The Spearwood Dune System has generally been accepted to represent an aeolian reworking of this material from the west (McArthur & Bettenay 1960). Petrographic data (Glassford & Killigrew 1976) and stratigraphic evidence (Glassford & Semeniuk 1990) suggest an aeolian continental provenance for these yellow quartz sands representing extensive desert phases co-incident with periods of middle Pleistocene glaciation in higher latitudes. Interdigitating deposits of limestone and yellow sand may therefore represent alternating periods of coastal aeolian and continental desert aeolian sedimentation (Semeniuk & Glassford 1987).

Perry Lakes are probably of Holocene age. The lakes occupy small interdunal depressions. Their shape (and distribution of palaeo-sediments within them) suggests that they formed in deflation basins of the style described by Hutchinson (1975) associated with extreme aridity at the end of the Pleistocene. Lake basin sediments are therefore Holocene to Recent in age. Lacustrine geology is described in detail in Section 3.3.

3.2.2 Hydrogeology

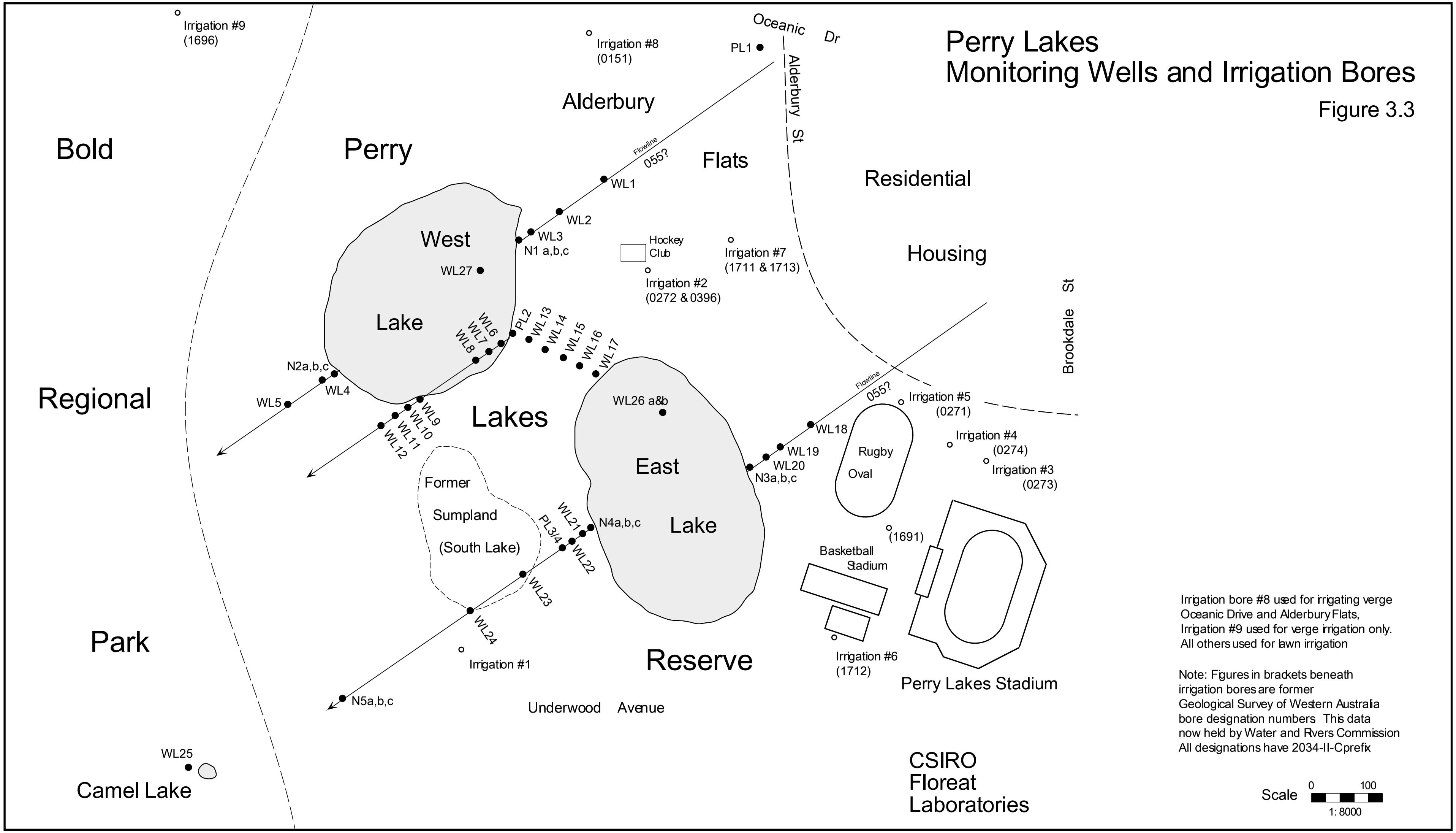
Superficial aquifer geology and hydrogeology is based on data from three sources:

- production bore hydrogeological records
- CSIRO drilling conducted for this project
- geophysical records

Hydrogeological records (now held by the Water and Rivers Commission) were located at the Geological Survey of Western Australia (GSWA) for some of the current and former production bores within Perry lakes Reserve. Production bores for lawn irrigation were first drilled in 1962 (Somerford pers com). The situation is confusing because all bores

Perry Lakes
Monitoring Wells and Irrigation Bores

Figure 3.3



Irrigation bore #8 used for irrigating verge Oceanic Drive and Alderbury Flats, Irrigation #9 used for verge irrigation only. All others used for lawn irrigation

Note: Figures in brackets beneath irrigation bores are former Geological Survey of Western Australia bore designation numbers This data now held by Water and Rivers Commission All designations have 2034-II-Cprefix have been periodically replaced, some have been relocated and bore designations have changed. Available logs commence in 1971. The interpreted locations (Figure 3.3) are based on street location, Perth City Council (PCC) bore designation and depth to static water level. Most were drilled by cable tool, which provides uncontaminated samples and accurate depth information. These logs therefore provide the stratigraphic framework for the aquifer sections (Figures 3.4 a&b). Drill logs are included as Appendix 3.1. Nested piezometers N1c-N5c drilled for this project using hollow stem augers provide good contact definition between sand or weakly consolidated calcarenite and hard limestone.

A local stratigraphy has been erected comprising 'Upper Sand', 'Limestone' and 'Lower Sand':

Upper Sand:

> Medium grained yellow to white quartz (plus minor carbonate), 8-15m thick. Grain size analysis and detailed logs (Appendix 3.2) from the nested piezometers provide additional detail. The Upper Sand thins to the west of both lakes where it forms a thin veneer over the limestone. The Upper sand is principally a residual weathering product of the underlying limestone. Thin bands and fragments of limestone are common within this unit.

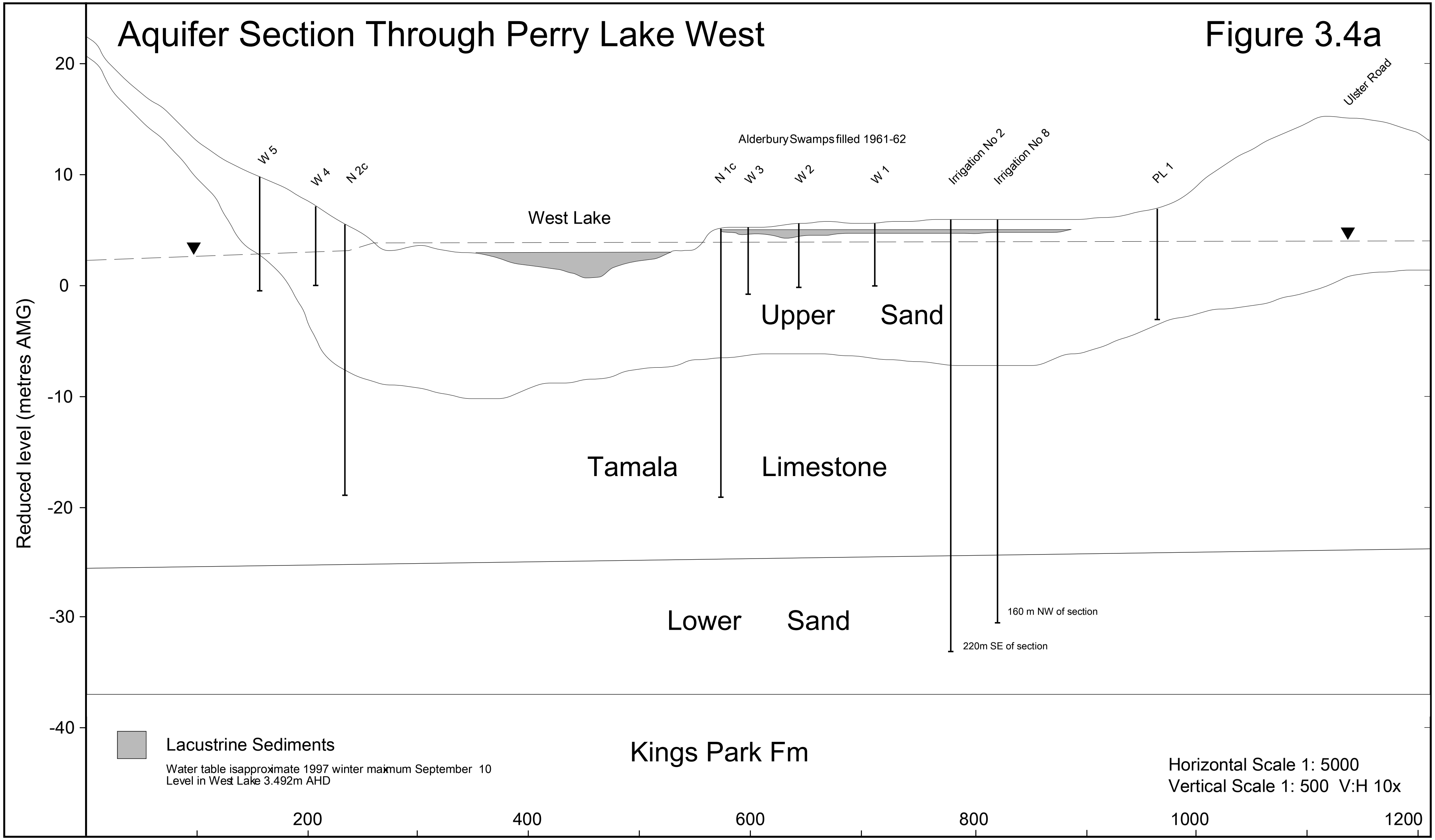
Limestone:

> Sheet like, 10 to >20m thick beneath the lakes, thickening to the west where it outcrops within Bold Park. The upper surface is irregular reflecting varying degrees of degradation to quartz-carbonate sand. The limestone is principally a weakly cemented quartz carbonate sand interspersed with harder centimetre to metre scale bands of grainstone (quartz grains in carbonate matrix), extremely hard vuggy calcrete and centimetre scale bands of beige to grey carbonate rich clay. The lower portions of the limestone frequently contain shells. The grainstone and calcrete bands are often impenetrable using an auger drill.

Lower Sand:

> This unit is known only from driller's logs which suggest a predominantly coarse, well sorted sand with occasional limestone rubble. All irrigation bores at Perry Lakes are screened within this unit. Gray clay representing degraded shale and siltstone of the Kings Park Fm. forms an aquitard and base to the superficial aquifer.

Total saturated thickness of the superficial aquifer is 35 to 39m below Perry Lakes Reserve.

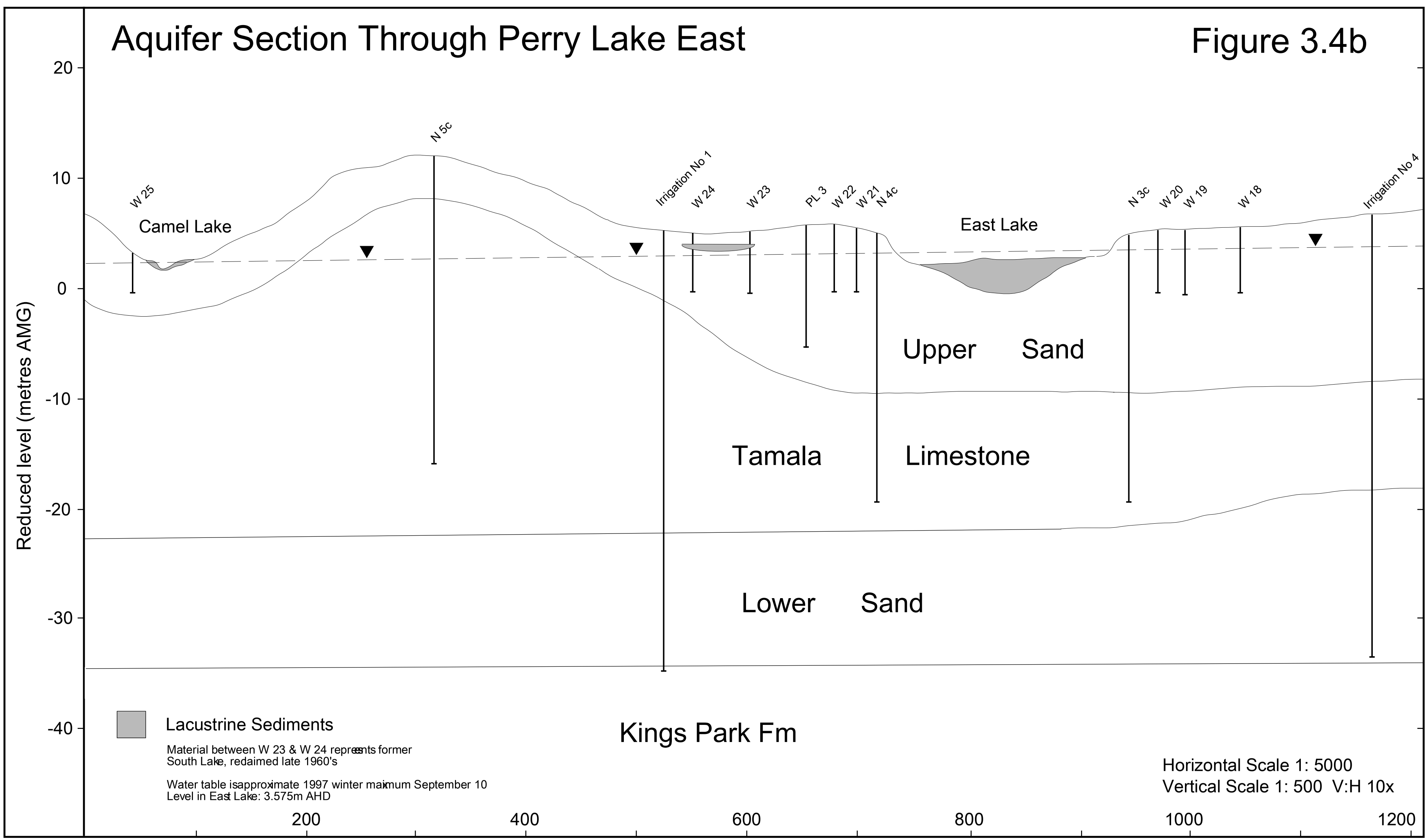


Aquifer Section Through Perry Lake West

Figure 3.4a

Aquifer Section Through Perry Lake East

Figure 3.4b



▨ Lacustrine Sediments

Material between W 23 & W 24 represents former South Lake, reclaimed late 1960's

Water table is approximate 1997 winter maximum September 10
Level in East Lake: 3.575m AHD

Horizontal Scale 1: 5000
Vertical Scale 1: 500 V:H 10x

3.2.3 Bore Hole Geophysics

Natural gamma ray logging can be used to detect layers of clay within the aquifer (Guyod 1975, Telford *et al* 1976). Gamma emitting radioisotopes normally found in sediments are potassium 40 and the myriad daughter products of the uranium and thorium decay series (Killeen 1975). Potassium is abundant in feldspars and micas. These weather to clays which in general have a much higher natural gamma activity than sands and carbonates (Keys & MacCarey 1971). Sands and carbonate comprise the principal lithologies within the superficial aquifer.

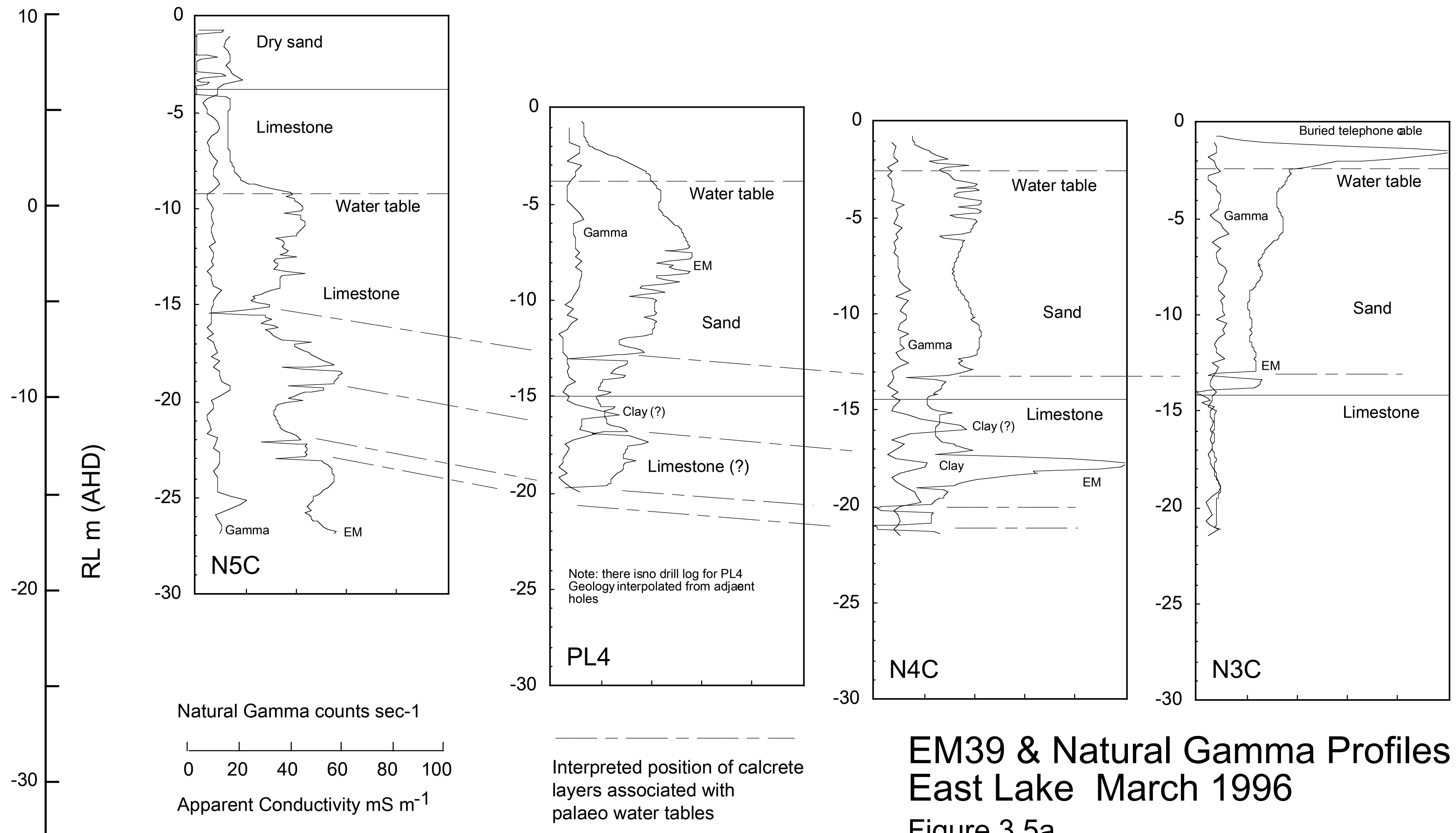
Frequency domain inductive electromagnetic (EM) methods utilise probes with two coils. The transmitter coil induces eddy currents in conductive formations. These generate secondary EM fields which are detected in the receiver coils, this induced signal being proportional to the conductivity of the formations surrounding the borehole, conductivity being the reciprocal of resistivity (Keys & MacCarey 1971). Highly resistive material will display low conductivity and vice versa. In the superficial aquifer clays will display high conductivity and strongly lithified material such as grainstone or calcrete will display low conductivity. These responses will be superimposed on a background level which varies in response to the conductivity of the pore water.

Bore hole logging was carried out in piezometer nests N1c-N5c and PL4 to test for clay units and resistive lithologies. Instrumentation comprised:

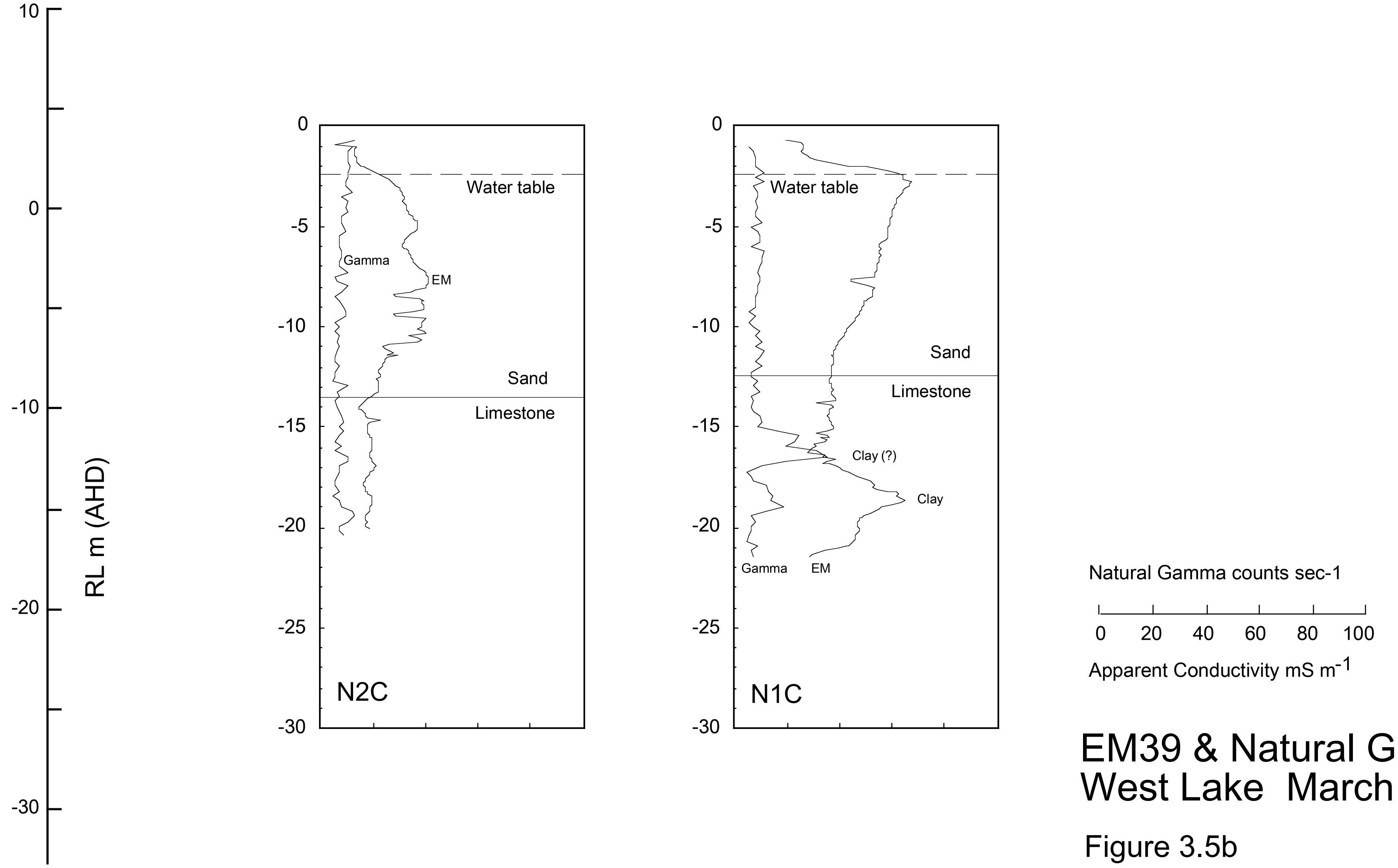
Natural gamma logging:	Mt Sopris 1000 total count natural gamma logger and probe
Apparent conductivity:	Geonics EM39 borehole conductivity logger and probe

Gamma, apparent conductivity and simplified geology are compiled as profiles in Figures 3.5 a&b. Geological logging and grain size analysis located organic rich lacustrine sediments to the east end of both lakes (piezometers N1c and N3c). These are plotted on the cross sections. The grain size analysis (Appendix 3.2) shows that these sediments contain only 12-30% silt and clay, the remainder being sand. Neither returned a gamma or conductivity response. All holes on the East Lake profile display a narrow (<1m) sharp conductivity low between approximately RL -5 to -9m AHD. Similar features are apparent at other levels, particularly in N5c. Two such features 1m apart may correlate with similar features in N4c.

The Tamala Limestone is of late Pleistocene age. Radiometric dating suggests that initial deposition commenced about 140 000 years ago, with further deposition and reworking continuing into the early Holocene (Teichert 1967, Playford *et al* 1976, Playford 1988). The conductivity features may define thin calcrete layers developed through the process of



EM39 & Natural Gamma Profiles
East Lake March 1996
Figure 3.5a



EM39 & Natural Gamma
West Lake March 1996

Figure 3.5b

capillary rise (Semeniuk & Meagher 1981) associated with a Pleistocene palaeo-water table under arid conditions. The Pleistocene was a period which included intense high latitude glaciation coupled with widespread aridity in southwest Western Australia (Glassford & Killigrew 1976, Wyrwoll 1979, Semeniuk & Glassford 1987, Glassford & Semeniuk 1990). This interpretation is consistent with driller's records which indicate predominantly soft limestone with interspersed thin hard bands. Gamma and co-incident conductivity peaks are interpreted to be carbonate clays.

3.3 LACUSTRINE GEOLOGY

3.3.1 Lacustrine Sediment Isopachs

Sediment thickness was measured by probing with a 6mm diameter brass rod 3.5m long. The rod was found to penetrate clays easily. At the clay-sand contact penetration becomes difficult. The technique, checked by hand auger was found to be accurate to within 5cm. Typical station spacing was 10x20m (Appendices 3.3 a&b).

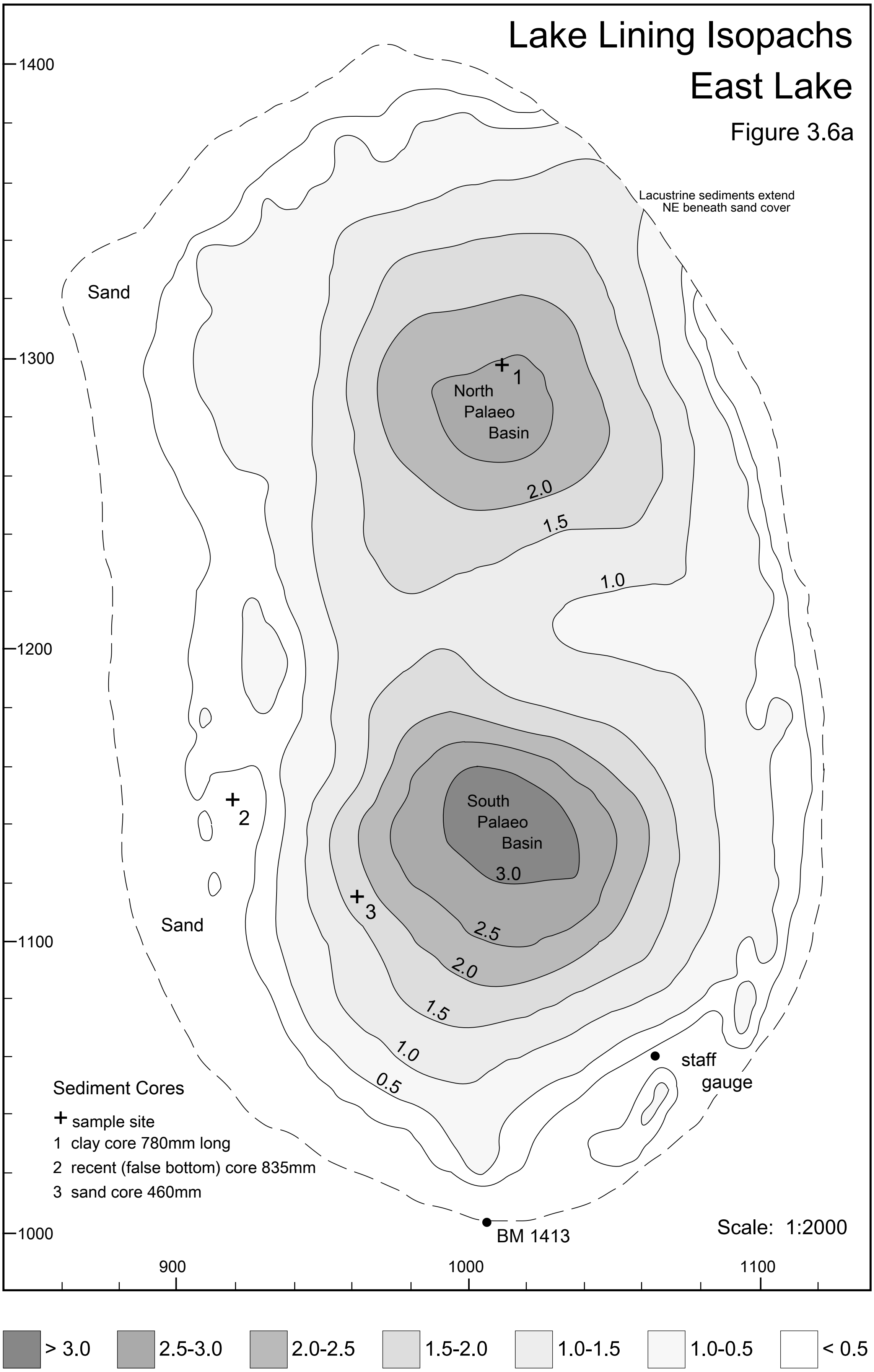
East Lake (Figure 3.6a)

The north, west and south margins of the basin have a sand floor (this includes sand with less than 20cm of false bottom sediment). The bird nesting island (Figure 3.10a) comprises sand and limestone fill dumped over the original lacustrine lining. The palaeo-lake was originally two separate ponds. As sedimentation continued, these palaeo-basins coalesced. Megirian (1982) found a similar pattern at Bibra Lake which coalesced from three smaller lakes. The data suggests that later stages of the lake extended to the northeast beneath what is now sand cover. In the South Basin, recent false bottom material comprises up to 0.5m of the sediment thickness.

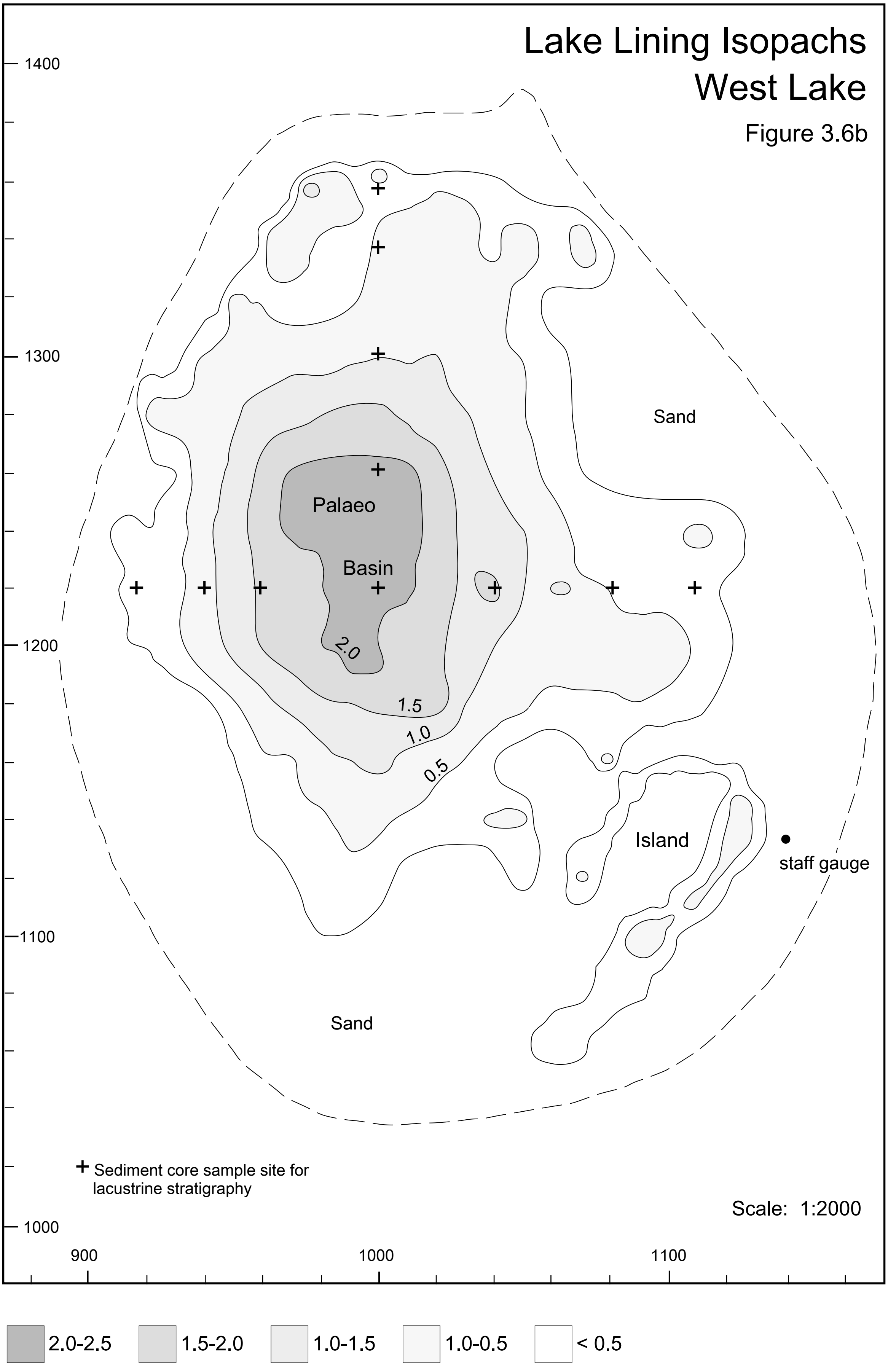
West Lake (Figure 3.6b)

The palaeo-lacustrine sediments are concentrated in one palaeo-basin. The bird nesting island was formed by bulldozing a deep arcuate basin along the south shore. Recent false bottom sediments fill this basin. The island is not therefore underlain by older lacustrine sediment. Recent sediment also fills elongate basins along the north and east margins of the lake formed when the lake was deepened and the banks extended in the early 1960's. Approximately 30% of the basin floor consists of sand with no lacustrine sediment lining.

At Perry Lakes the areas of permanent water that existed prior to modification in 1962 (Figure 2.2), did not overlie the deepest portions of the palaeo-basins which contain most of the sediment and must therefore have been the principal flooded portion of the lakes for



East Lake lacustrine sediment isopach contours generated from 497 soundings (Appendix 3.3a)
Dashed line is 5m surface contour (approximate limit of lake basin)



Lake Lining Isopachs
West Lake
Figure 3.6b

West Lake lacustrine sediment isopach contours generated from 646 soundings (Appendix 3.3b)
Dashed line is 5m surface contour (approximate limit of lake basin)

most of their history. These palaeobasins are the original wind deflation hollows which became flooded as the water table rose.

3.3.2 Lacustrine Stratigraphy and Palaeo-geography

A framework for lake basin lacustrine stratigraphy was compiled using a combination of coring and hand augering. Cores were collected specifically for the purpose from West Lake which was dry and readily accessible from the summer of 1995 onwards. Observations from hand augering were also compiled during lacustrine sediment isopach mapping on both lakes. Cores representing partial sections were collected from East Lake for vertical hydraulic conductivity and specific yield measurements and studies on the recent sediments within the South Basin.

In West Lake 11 cores were collected (Figure 3.6b). Lengths of 40mm PVC were bevelled inwards and driven to the lacustrine sediment-sand contact and then withdrawn using a tripod and hand winch. Inward bevelling forces an oversize sample into the tube, ensuring that the sample core is not partially withdrawn by suction when the PVC is removed. The technique is essentially that of Megirian (1982). The tubes were opened by cutting longitudinally using an angle grinder. Cores were sectioned lengthwise as stratigraphically younger material is dragged over older material around the pipe periphery, obscuring contacts. The lacustrine sediments have a low specific gravity, and compress when driven into the PVC. In the deepest holes, sample length was about 42% of original. Megirian (1982) found the compaction rate to be variable depending on depth and sediment type (maximum compression in clays and minimum compression in sands). In this case sediments were all clays. Contacts were adjusted assuming a uniform compaction rate. Due to the short lengths involved, compaction rate of all West Lake cores was assumed to be constant. Cores collected from East Lake at W26 and the South Basin were uncompressed. Sampling methods are described elsewhere in this chapter.

Radio carbon dating of wetlands on the Swan Coastal Plain suggests that lacustrine sedimentation commenced around 8000 years B.P. (V. Semeniuk pers com) with initiation of the present interglacial and associated Flandrian transgression (Flint 1967). Sea level rose rapidly to levels at and exceeding its current level accompanied by and in response to a significant global warming (Sturman & Tapper 1996). The previous 100Ka were characterised by extensive high latitude glaciation and in southwest Western Australia widespread aridity and high winds (Glassford & Killigrew 1976, Wyrwoll 1979, Semeniuk & Glassford 1987, Glassford & Semeniuk 1990). The driest conditions and lowest sea level (-130m AHD) occurred about 15-20Ka (Sturman & Tapper 1996) when the coast was approximately 50km west of Perry Lakes (present distance 2.5km). At this time groundwater levels would have been much lower than at present. Calcrete layers (Section 3.2.3) may define fossil water table levels during this arid climatic regime. Wetlands associated with a regionally homogeneous aquifer on a narrow coastal plain will be intimately linked to climate, principally rainfall and recharge (Allen 1981), vegetation and evapotranspiration (Congdon 1985) and sea level (Semeniuk 1986).

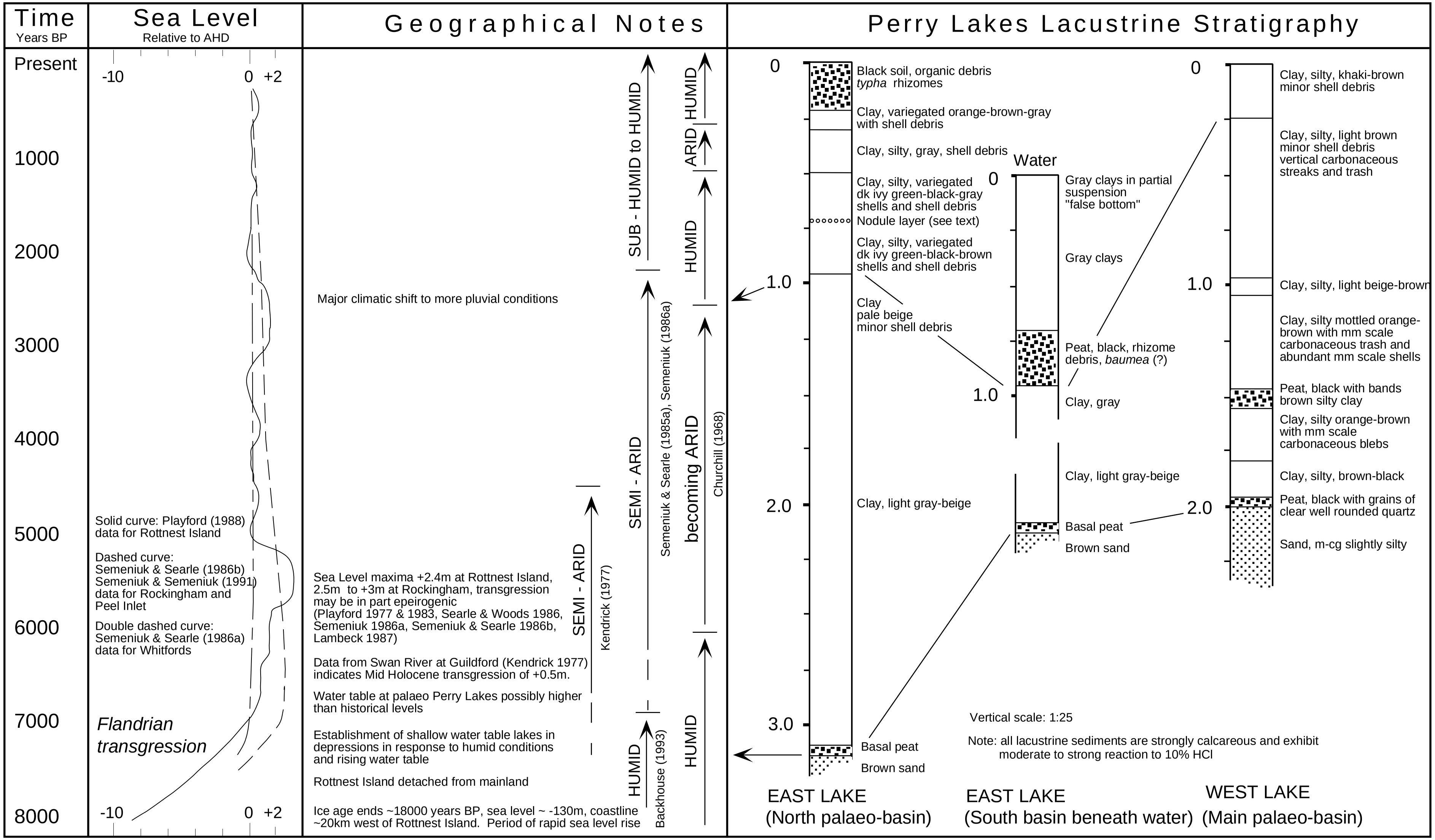
Proposed Holocene climate regimes on the Swan Coastal Plain are summarised in Figure 3.7. There is a general consensus that there was a rapid climatic amelioration at the beginning of the Holocene. Botanical evidence (Churchill 1968) suggests rainfall may have been similar to the present climate, with a trend towards aridity about 6000 years B.P. This is corroborated by peat radiocarbon dated at 7200 years B.P. and pollen and aquatic mollusc data from Barker Swamp, Rottnest Island (Backhouse 1993). However pollen data for Loch McNess (Newsome & Pickett 1993) indicated Eucalyptus woodland interspersed with wetland sedge communities and showed little change in vegetation from 9000 years B.P. to the present. Kendrick (1977) using radiocarbon dated mollusc data from the Swan River advocates a period of semi-arid climate (saline conditions in the Swan up stream to at least Guildford and little winter flooding) from at least 6700 years B.P. to at least 4500 years B.P. Mid Holocene aridity from at least 7000 to about 3500 years B.P. is also advocated by Semeniuk (1986) on the basis of water table related calcrete in beach and dune sands. Rainfall increase to modern era values may have occurred only in the past 2000-3000 years (Semeniuk (1986). Churchill (1968) suggests a recent dry phase from about 1300-500 years B.P.

Figure 3.7 includes sea level curves. In a regionally homogeneous aquifer on a narrow coastal plain sea level and the water table will be intimately linked (Semeniuk 1986). The sea forms a nearby constant head boundary and changes in sea level will be reflected in nearby groundwater levels . There is a marked variability in Holocene sea level curves for areas close to Perry Lakes. Local curves, (Figure 3.7) have been constructed from coastal geology (fossil platforms and notches) and radiocarbon dating. They include Rottnest Island (Playford 1988), Whitfords (Semeniuk & Searle 1986a), Rockingham (Semeniuk & Searle 1986b) and Peel Inlet (Semeniuk & Semeniuk 1991). These differences are ascribed to local epeirogeny (Playford 1977 & 1983, Searle & Woods 1986, Semeniuk 1986, Semeniuk & Searle 1986b, Lambeck 1987). The data however are similar to regional curves for Holocene sea level change for much of the southern hemisphere and southeast Asia (Bird 1993).

In summary, Perry Lakes are considered to be Holocene features, formed when sea level stabilised and climate approached modern era conditions about 8000 years B.P. During much of their history however a somewhat more arid climate may have prevailed.

Lacustrine Stratigraphy and Holocene Palaeogeography

Figure 3.7



Lacustrine sedimentary records for Swan Coastal Plain wetlands are scarce. Megirian (1982) obtained cores from Bibra and North Lakes (part of the East Beeliar chain of wetlands) and was able to define a coherent stratigraphy comprising 3 sedimentary cycles defining eutrophication and rejuvenation, with the present lakes comprising part of Cycle 3. Maximum sediment thickness recovered was about 3m (exclusive of recent ooze). The base of the deepest portions of each lake basin were not tested. The predominant lithology in each cycle was white-light grey clay, variably diatomaceous. Each cycle terminates in a thin peat layer. Perry Lakes and the East Beeliar wetlands are considered to be of a similar age and have similar thicknesses of preserved sediment.

In Perry East a 2cm thick sheet of ferruginous nodules underlies part of the basin (Figure 3.7). These nodules are 2-3cm in diameter, somewhat irregular in shape and yellow-brown in colour. They comprise principally clay and silt and include mm scale bivalves and gastropod shells. They may represent a period when most of the basin was uniformly vegetated. Nodular 'bog iron' (impure hydrous iron oxides) is a common wetland phenomenon forming through atmospheric oxidation or the oxidising action of algae and iron bacteria (Hackett & Lehr 1985). Nodules or plaques may form around the roots of wetland plants with well developed aerenchyma (such as *Typha*) where oxygen diffusion to the roots is sufficient to oxidise adjacent anoxic sediment containing reduced iron (Taylor *et al* 1984, Crowder & Macfie 1986).

Small wetlands typically exhibit sedimentation patterns reflecting progression from an oligotrophic to eutrophic state. In extremely shallow wetlands within a homogeneous aquifer close to the ocean progression from open water to swamp will occur in response to:

- sedimentation alone
- a lowered water table brought about by climatic change
- a lowered water table brought about by sea level decline or a combination of all these factors

Closed lakes accumulate sediments readily but have no mechanism for sediment removal. Therefore sediment cyclicity in Swan Coastal Plain wetlands is most likely a climatic feature superimposed on a more or less steady rate of sedimentation. If climate (and hence water table level) remain more or less constant, the lakes will tend towards a eutrophic state on the basis of sedimentation alone. Rejuvenation can only occur if the water table rises or sediment is removed. The high water levels of the 1950's were a natural climatic rejuvenation brought about by increased rainfall (augmented artificially through the introduction of storm drains). A second totally artificial sedimentological rejuvenation occurred when the lakes were dredged in 1962. The current rapid transition to eutrophication involves natural climatic changes (reduced rainfall) and artificial climatic changes (reduced groundwater levels through bore extraction). The sediment record suggests that since early Holocene wetland initiation there have been at least two cycles of eutrophication (probably reflecting aridity) followed by rejuvenation. It is important to note however that each rejuvenation requires a more extreme climatic change (higher water table) to overcome the build up of sediment in the basin.

In summary the palaeo-sea level, climate and sedimentary record suggests that:

- maximum water levels may have occurred shortly after wetland initiation in response to sea level and climate
- the lakes have oscillated between predominantly open water and vegetated sumpland in response to sediment accumulation and climate
- the lakes are now approaching a eutrophic state brought about by water table decline in response to natural (rainfall decline) and artificial (groundwater extraction) climatic change

3.4 AQUIFER HYDROLOGY

3.4.1 Grain Size Analysis

Unlike pumping tests which can provide large scale values of aquifer characteristics integrated over large volumes of an aquifer, grain size methods rely on small, disturbed samples to provide point source data. Where no other aquifer information is available however they can provide useful estimates of hydraulic conductivity (Kresic 1997).

Aggregate 1m samples were collected from surface to the upper contact with limestone in piezometers N1-N4. Samples were dried and sieved after the method of Allman & Lawrence (1972). Hydraulic conductivity was calculated using grain size distributions calculated from cumulative frequency curves (Folk 1966). Average values for samples below 2m (the wetted section of the aquifer) are summarised in Table 3.2. Details regarding methodology and results are included as Appendix 3.2.

Table 3.2 Hydraulic conductivity Upper Sand (m day^{-1}) surface to 7m

Method	d_{10}	d_{50}	σ_I	Sk_I	K_G	-1-	-2-	-3-	-4-	-5-	-6-	-7-
N1c	0.084	0.212	1.13	+0.26	1.40	6.2	4.0	6.0	7.2	3.7	11.1	4.8
N2c	0.101	0.207	0.80	+0.03	0.93	8.9	5.7	7.0	10.7	5.4	10.7	8.3
N3c	0.086	0.231	1.22	+0.37	1.65	6.6	4.2	6.1	7.6	4.0	12.8	6.5
N4c	0.132	0.331	0.71	+0.44	1.05	15.3	9.8	13.7	17.8	9.2	23.1	14.9

Key

1: Hazen (1893)
2: Harleman *et al* (1963)
3: Masch & Denny (1966)
4: Breyer cited Kresic (1997)
5: Uma *et al* (1989)
6: Shepherd (1989)
7: Alyamani & Sen (1993)

d_{10}: grain size(mm) at 10 cumulative percent (effective grain size)
d_{50}: grain size(mm) at 50 cumulative percent (median grain size)
σ_I: Inclusive graphic standard deviation (Folk & Ward 1957)
Sk_I: Inclusive graphic skewness (Folk 1968)
K_G: Graphic kurtosis (Folk 1968)

The upper sand unit in N4 is sedimentologically and hydrologically different to sands encountered in the other 3 piezometers. It has a larger effective and median grain size and is better sorted (smaller σ_I). Material on the east side of both lakes (N1 and N3) are poorly sorted while those on the west side (N2 and N4) are better sorted, N2 being moderately sorted and N4 moderately well sorted using the classification of Folk (1968). Skewness is a measure of curve asymmetry. The sands tend to be positively skewed indicating tails of fine material. Kurtosis measures the ratio between sorting in the tails and central portion of the grain size distribution. Material from N2 and N4 have average kurtosis values which approach unity, the value for a normal Gaussian distribution whereas N1 and N4 are >1 indicating better sorting or 'peakedness' in the central portion of the distribution curve. The differences are clearly evident in the histograms (Appendix 3.2). Sorting, skewness and kurtosis as measures of how closely the grain size distribution approaches the normal Gaussian probability curve provide geological clues regarding a sediment's genealogy (Folk & Ward 1957). For example dune sands tend to be positively skewed and beaches negatively skewed (Friedman 1961). The characteristics of the upper sand are consistent with its derivation from an aeolianite.

The grain size analyses (Table 3.2) suggest that the hydraulic conductivity in the upper sand unit around N4 is about double that measured else where around Perry Lakes. Grain size methods which take into account the overall grain size distribution are more likely to provide useful estimates of hydraulic conductivity for heterogeneous poorly sorted sediments (Appendix 3.2). The data (Table 3.3).suggest (but due to limited sample distribution do not prove) there is a significant difference in the hydraulic conductivity of the upper sand west of East Lake.

Table 3.3 Hydraulic conductivity range (m day^{-1}), Upper Sand

Piezometer	N1	N2	N3	N4
Hydraulic conductivity range	6-11	7-11	6-13	14-23

3.4.2 Pump Test Analysis

Pump tests are considered the most accurate measure of aquifer parameters because they provide *in situ* measurements averaged over a large aquifer volume (Freeze & Cherry 1979). In unconfined aquifers, analysis of pumping test data, particularly at early times is complicated by the delayed drainage of unsaturated material above the receding water table and vertical flow components (Webb & Watson 1979). Measurement of hydraulic conductivity is also highly scale dependent. Experiments by Rovey & Cherkauer (1995) using effective test radii of <1 to >10 000m show that hydraulic conductivity increases approximately linearly with test radius to a range between 20 and about 200m after which it is constant with scale. Small scale field methods such as slug tests will typically under estimate regional hydraulic conductivity by up to an order of magnitude (Bredehoeft *et al* 1983) while laboratory tests such as permeameters may yield values a further order of magnitude smaller (Ptak & Teutsch 1994, Millham & Howes 1995).

Results from Pump Tests on the Swan Coastal Plain

Pump tests provide the best estimates of horizontal hydraulic conductivity (K_h) within the superficial aquifer in the Perth metropolitan area. These are summarised in Table 3.4. In all cases the superficial aquifer is strongly anisotropic. Data from these tests fit solutions for semi-unconfined to semi-confined aquifers as defined by Kruseman & de Ridder (1990). Pump tests generally provide an averaged estimate of hydraulic conductivity over the entire aquifer section. Martin & Baddock (1989), using pump tests on the Jandakot Mound, estimated K_h in five units with distinctly different hydraulic properties (Table 3.4). Further resolution on the basis of grain size and the degree of sorting, suggested at least 12 layers with estimated K_h in the range 0.1-150m d^{-1}. This sort of variability is probably typical of the superficial aquifer. Anisotropy results from differing grain size, sorting, orientation, packing of framework grains, cementation and sedimentary bedding (Pettijohn *et al* 1972). In situ samples of sands from the superficial aquifer typically exhibit 10-15 visually recognisable layers per vertical metre (M. Martin, Water Corporation, pers com). In the Gnangara sands, individual bedding is recognisable down to the mm scale (S. Appleyard, Water and Rivers Commission pers com). Estimates of vertical hydraulic conductivity calculated using the solution of Walton (1962) are included in Table 3.4. They suggest that within the Superficial aquifer K_z:K_h is in the range 0.002 to 0.0004. Aquifer characteristics appear to be strongly influenced by the hydrogeology of the Tamala Limestone:

- limestone comprising unconsolidated to weakly cemented carbonate and quartz sand will display aquifer characteristics similar to other sand units within the superficial formations but with generally greater hydraulic conductivity.
- where initial porosity has been destroyed or reduced through duricrusting or vadose zone processes, the limestone may act as an aquitard, inhibiting vertical groundwater movement. Where such limestone comprises a significant portion of the aquifer section overall transmissivity of the aquifer will decrease.
- limestone containing karst features may exhibit cavernous flow conditions and extremely high transmissivities. At Kwinana (25km south of Perry Lakes) transmissivities of up to 20,000m^2 d^{-1} have been reported (Layton Groundwater Consultants 1979). These high transmissivities are believed to reflect zones of karst development and cavernous flow conditions.

On a regional scale, transmissivity within the superficial aquifer is estimated to rise sharply from 600 to 1000m^2 d^{-1} in a narrow band along the coast commencing with the appearance of outcropping Tamala Limestone (Davidson 1995). Perry Lakes are situated on this transitional zone. The range of regional transmissivities equate to expected hydraulic conductivities of approximately 16-27m d^{-1} at wetted thickness of 37m. A

Pumping Test Summaries Perth Metropolitan Area

Table 3.4

Area	Aquifer Geology				Aquifer Characteristics	T	K_h	K_z	S
(Reference)	Formation	Depth (m)		Lithology		($m^2 d^{-1}$)	($m d^{-1}$)	($m d^{-1}$)	
					Semi-unconfined				
Lake Jandabup	Bassendean Sand	0.0	27.0	sand, fine-coarse	Lower portion of aquifer initially responds as	328-541	18-27		
(Wharton 1981a)		27.0	27.5	clay, carbonaceous	a confined aquifer, as gravity drainage occurs				
	Gnangara Sand	27.5	54.0	sand, fine-medium, minor gravel	response follows type curves for unconfined	av: 410	av: 23		
		54.0	58.5	limestone, calcareous sand	aquifer with delayed yield (Boulton 1963) or				
	Poison Hill			-unconformity-	leaky artesian aquifer (Hantush & Jacob, 1955)				
Lake Gnangara	Bassendean Sand			15 bores, Bassendean sand to max	Unconfined with delayed yield	271-1100	5.3-22		
(Balleau 1971)				51.8m, with persistent layers of	Analysed using methods of Theis (1935)				
				clay and limestone	Cooper & Jacob (1946), Boulton (1963)	av: 544	av: 11.6		
	Poison Hill			-unconformity-					
Thompson Lake	Bassendean Sand	0.0	31.5	sand, fine-coarse	Unconfined to semi-unconfined	270-312			
(Wharton 1981b)	Guildford Clay	31.5	34.5	clay, dark grey					
	Gnangara Sand	34.5	43.5	sand, medium-coarse	groundwater is unconfined in the upper sands	av: 300	av: 19		$2.6x10^{-4}$
		43.5	45.0	sand, fossiliferous, very coarse	but is semi-unconfined beneith the clay at				
	Ascot Fm	45.0	48.0	limestone, with gravel	31.5m. The lower sands display drawdown				
		48.0	51.0	sand, fossiliferous, fine-v. coarse	response for leaky artesian aquifers				
	Osborne Fm			-unconformity-	(Hantush & Jacob, 1955)				
Thompson Lake	Bassendean Sand	0.0	5.0	sand, fine-coarse	Semi-unconfined to semi-confined				
(Deeney 1985a)	Gnangara Sand	5.0	41.0	sand, fine-coarse clay/silt at base					
				sand and gravel, poorly sorted &	lower sands fit solution of Walton (1962) for	170-214	8-15	$1.0x10^{-3}$	$4.0x10^{-4}$
	Ascot Fm	41.0	67.0	highly fossiliferous, minor clay	semi-confined aquifers, K_z is for mid level silt			to	
				and limestone	which forms an aquitard			$2.0x10^{-3}$	
	Osborne Fm			-unconformity-	Estimated K_z for entire aquifer $1.3x10^{-2}$ to $6.0x10^{-3}$				
Forrestdale Lake	Bassendean Sand	0.0	5.0	sand, fine to coarse	Semi-unconfined overall				
(Deeney 1985b)	Gnangara Sand	5.0	33.0	sand, fine to coarse, clay base	Aquifer comprises 4 distinct units, 1-4 from top			$1.1x10^{-2}$	
	Ascot Fm	33.0	42.0	sand and gravel with limestone,	units 1 & 3 are aquitards			to	
				highly fossiliferous	Unit 4 forms a semi-confined aquifer and fits	172-200	16-20	$8.5x10^{-3}$	
	Osborne Fm			-unconformity-	solution of Walton (1962)				
Jandakot	Bassendean Sand	0.0	5.0	sand, fine to coarse	Highly anisotropic, unconfined	Unit 1	20	Bassendean Fm	
(Martin & Baddock 1989)	Gnangara Sand	5.0	23.0	sand, fine to very coarse	Aquifer comprises 5 units with distinctly	2	5	Coffee Rock	
	Ascot Fm	23.0	44.0	fine sand to gravel, thin limestone	different hydraulic conductivities, analysed	3	10	Gnangara Fm	
				highly fossiliferous	using the method of Neuman (1975)	4	50	Gnangara Fm	
	Osborne Fm			-unconformity-		5	8	Ascot Fm	

summary of the geological and hydrogeological character of the Tamala Limestone is included as Appendix 3.4.

Tracer Tests on the Swan Coastal Plain

Bromide tracer tests in sands from two locations 12-15km northeast of Perry Lakes indicated groundwater velocities varying from 40-100 m yr^{-1} to 100-150m yr^{-1} (Salama *et al* 1989, Thierrin *et al* 1993). Within the Tamala Limestone velocities of 85-335m yr^{-1} have been reported (Barber *et al* 1990 cited Davidson 1995).

Description of the Pump Test

A 50 hour pump test was carried out using irrigation bore No.1. This utilises a submersible pump, with a rated *irrigation* capacity of about 900m^3 d^{-1}. Output from the bore was routed via the 6 inch (150mm ID) irrigation ring main into East Lake through the south (100mm ID) flow meter (Figure 5.1a). Figure 3.8 shows well locations and measured drawdown. The pumping rate rose slowly from 1.842m^3 min^{-1} (2652m^3 d^{-1}) at the start of the test to 2.011m^3 min^{-1} (2896m^3 d^{-1}) at the end. These figures are about three times the rated irrigation capacity and reflect the fact that output was restricted only by the flow meter. The low initial rate probably reflects filling within the extensive irrigation ring main system. Dataflow capacitive water level loggers operating at 1 minute intervals were installed in observation wells W22, W23 and W24. These are spaced about 1, 2 and 4 aquifer thicknesses from the pumped well as recommended by Lohman (1972) and Hazel (1975), details in Table 3.5 and Figure 3.8a. W22, W23 and W24 are water table monitoring wells, screened over 1m approximately 2m below the water table (Figure 3.8b). The pumped well is believed by the Town of Cambridge to be screened over 18m representing about 48% of aquifer thickness.

Table 3.5 Observation well locations

Observation Well	W24	W23	W22	N5c
Distance to pumped well (m)	38.2	81.7	153.5	205.0
Distance as aquifer thicknesses	1.0	2.2	4.1	5.5

The test was carried out May 27-29 1997, one week after all lawn irrigation and lake maintenance pumping had ceased (Figure 3.8c). Total test time was limited by the Town of Cambridge (on the basis of electricity costs) to 2 days. Total pumping time was 2916 minutes (2.025 days). Loggers were operated for a further 2.5 days to record recovery. During the recording period, 14mm of rain was recorded at Perry East. Combined with water from the pumped well, this produced a 150mm rise in lake level. The rain event is evident in the drawdown curve for W22, but was not recorded in W23 or W24.

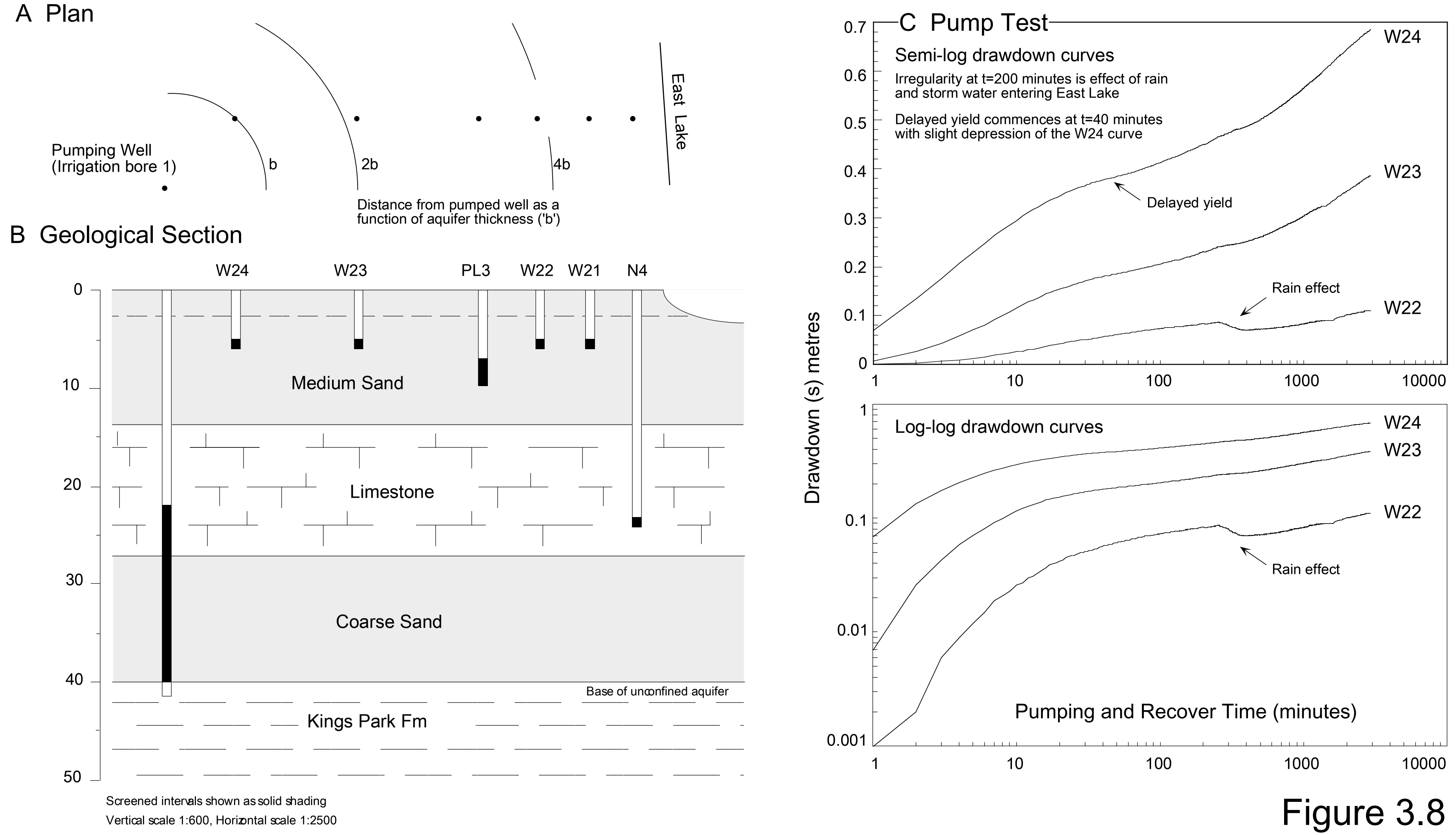
Aquifer Geology of the Test Site

Aquifer geology in the test area is summarised in Figure 3.8b, based on sieve analysis of the upper sand from N4 and the driller's log for irrigation bore No.1. In N4, distinctive dark green (possibly glauconitic) silty sands were intersected from 12-15m and 0.5m calcareous clay from 18.5-19.0m. N4c was drilled to bit refusal at 24m after passing through alternating bands of hard and soft limestone. Little is known of the lower sand unit. Driller's logs for irrigation bores around Perry Lakes generally describe it as coarse grained sand with occasional shells and limestone. It almost certainly represents sandy units within the Tamala Limestone but may also include Bassendean Sand (Figure 1.2). In summary the aquifer would be expected to be highly anisotropic. The limestone in particular varies from weakly cemented calcareous silica sand to strongly indurated grainstone and calcrete which is impenetrable using a light rotary auger drill rig. These units may form local aquitards.

Results

Approaches using non-steady and steady state solutions produced widely differing results. This test satisfied few of the basic assumptions underlying pumping test solutions. Neither the pumped well nor any of the observation wells were fully penetrating and no observation well was screened at the same depth, or within the same lithology as the screen within the pumped well. Pump test analysis of unconfined aquifers, even under ideal well configurations is complicated, particularly at early times, by delayed drainage and vertical flow components. Type curves for partially penetrating pumping and observation wells in unconfined aquifers developed by Moench (1993) suggest that for the range of K_h and K_z typically reported for the superficial aquifer, early time drawdowns will be much greater than the Theis type curve. Therefore we would expect that transient solutions will produce unrealistically high estimates of transmissivity. It is important to remember that pump test solutions are non-unique. Pump test data may match a theoretical curve, but that alone is meaningless unless the aquifer fits the assumptions used to generate the curve (Freeze & Cherry 1979).

Up to approximately t = 720 minutes (12 hours) curves exhibit very rapid initial drawdowns and the sigmoid pattern typical of delayed yield. Late stage curves however approach Theis type curves for unconfined aquifers exhibiting no delayed yield (Boulton 1963). Therefore reliable estimates of transmissivity might be expected only from the late time steady state results since they represent a much larger volume of the aquifer, sampled over a much longer period of time, and where the early time complexities induced by partial penetration are minimised.



A Plan
Pumping Well
(Irrigation bore 1)
b
2b
4b
East Lake
Distance from pumped well as a function of aquifer thickness ('b')
B Geological Section
W24
W23
PL3
W22
W21
N4
0
10
20
30
40
50
Medium Sand
Limestone
Coarse Sand
Base of unconfined aquifer
Kings Park Fm
Screened intervals shown as solid shading
Vertical scale 1:600, Horizontal scale 1:2500
C Pump Test
Semi-log drawdown curves
Irregularity at t=200 minutes is effect of rain and storm water entering East Lake
Delayed yield commences at t=40 minutes with slight depression of the W24 curve
Delayed yield
Rain effect
W24
W23
W22
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
Drawdown (s) metres
Log-log drawdown curves
Rain effect
W24
W23
W22
1
0.1
0.01
0.001
1
10
100
1000
10000
Pumping and Recover Time (minutes)

Figure 3.8

Transient Methods

Experiments using partially penetrating observation bores at Jandakot showed that anisotropy results in calculated transmissivities which increase with increasing distance from the pumped well (Martin & Baddock 1989). At Perry Lakes (Table 3.6) similar results were obtained using both the Boulton and Cooper-Jacob methods (where pumping and observation bores are assumed to be fully penetrating) and the Moench method (for partially penetrating wells). The apparent transmissivities however are unreasonably high when compared to other superficial aquifer pump test data (Table 3.4).

Table 3.6 Pump test results using transient methods

Method	Technique	Transmissivity m^2 d^{-1}			Hydraulic Conductivity m d^{-1}		
		W24	W23	W22	W24	W23	W22
Boulton	Manual curve match	2176	2857	7620	58	77	205
Cooper-Jacob	Manual curve match	1975	2628	7100	53	71	192
Moench	Computer	2995	4377		81	118	
Recovery[1]		2628			71		

Note: aquifer thickness *b* taken as 37m
1: method of Theis (1935)

The Moench type curve method (Moench 1993, Hall 1996) generates type curves for partially penetrating pumping and observation wells including observation piezometers. Field data is curve matched to the type curves, generated using computer software (Hall & Chen 1994).

Steady State Methods

Hantush (1956 & 1964) presented a solution for leaky aquifers utilising the final drop of the piezometric surface s_f (the equilibrium drawdown) in a number of observation wells located at different distances r from the pumped well. The pumped well is located within the lower sand unit which may be thought of as a leaky confined aquifer receiving water from the overlying limestone and sand units. Using data from W22-W24, s_f was calculated at the end of the pumping test $t = 2916$ minutes (2.025 days) and with t extrapolated to 10 000 minutes (6.95 days). The Hantush method also allows the limits of the radius of influence to be estimated ($s_f = 0$). Results are tabulated as Table 3.7.

Table 3.7 Pump test results using the steady state method of Hantush

Time (d)	$s_f = 0$ (m)	Transmissivity m^2 d^{-1}			Hydraulic Conductivity m d^{-1}		
		W24	W23	W22	W24	W23	W22
2.025	262	1256	1364	1492	33.9	36.8	40.3
6.950	280	1096	1124	1365	29.6	30.4	36.8

Aquifer thickness b taken as 37m

Similar results were obtained using the Thiem and Thiem-Dupuit equations for steady state flow in an unconfined aquifer (Hazel 1975, Bouwer 1978). These methods utilise ratios of drawdown and distance to the pumped well in adjacent observation bores. Results are tabulated as Table 3.8.

Table 3.8 Thiem and Thiem-Dupuit steady state pump test results

Method	Time (d)	Transmissivity m^2 d^{-1}		Hydraulic Conductivity m d^{-1}	
		W23/24	W22/23	W23/24	W22/23
Thiem	2.025	1121	1303	30.3	35.2
	6.950	1053	1010	28.5	27.3
Thiem-Dupuit	2.025	1119	1302	30.2	35.2
	6.950	1051	1009	28.4	27.3

Aquifer thickness *b* taken as 37m

Summary Comments

Estimates of transmissivity decrease with increasing time and increase with increasing *r*. This suggests that true steady state was not achieved and that the effects of aquifer anisotropy are still present. Mean horizontal hydraulic conductivity of the aquifer at Perry Lakes is estimated to be somewhat less than the estimates determined from the pump test and probably lies in the range 20-30m d^{-1}.

3.4.3 Specific Capacity Tests

Specific capacity data from irrigation bores No. 2 and 8 was used to provide estimates of transmissivity and hydraulic conductivity (Table 3.9) using the method of Razack & Huntley (1991) where

$$T = 15.3 \left(\frac{Q}{h_0 - h} \right)^{0.67} \qquad (3.1)$$

Table 3.9 Transmissivity estimates from specific capacity

Bore	Q m^3 d^{-1}	Drawdown (m)	T m^2 d^{-1}	K m d^{-1}
Irrigation No 2	2094	12.20	480	13.0
Irrigation No 8	1309	1.72	1300	35.1
	1702	2.44	1230	33.2
	2291	3.66	1144	30.9

Aquifer thickness *b* taken as 37m

Well logs (Appendix 3.1) suggest a similar aquifer geology in both wells. The excessive drawdown in No 2 bore suggests that the well was not sufficiently developed when the test was conducted at the time the bore was constructed. These estimates are for the Lower Sand unit and are similar to the steady state pump tests for irrigation bore No 1.

3.5 LAKE LINING HYDROLOGY

3.5.1 Physical Character of the Recent Sediments

The lake lining consists of three sediment types:

- Sand (the exposed top of the Pleistocene Upper Sand unit)
- Clays (lacustrine sediments of Holocene age)
- Recent sediments comprising a false bottom over the older clays and sand

Transition from false bottom sediments to clay appears to be completely gradational. The false bottom consists of a suspended soupy mass of carbonate rich mud, colloidal sludge and organic material. A worker standing bare foot in this material typically sinks about 0.6m. When exposed at low lake stages, these bottom sediments shrink producing mud cracks. In recent years all of West Lake and much of East Lake have been dry for extended periods each summer. Where the false bottom sediments have dried and shrunk over an entire summer, the false bottom does not re-establish during winter inundation. West Lake first dried up completely over the summer of 1994-95. The bottom then remained firm over the following winters.

Bulk density is defined as the oven dried mass of a sample W_d divided by its field volume V_t. Bulk density may also be expressed as

$$(1-n)\rho \tag{3.2}$$

where n is the porosity and ρ is the density of the solid phase, taken to be 2.65g cm^{-3} for most clays (Deer, Howie & Zussman 1967). Clays typically have porosities of 40-70% (Freeze & Cherry 1979) which equates to a bulk density range of 1.59-0.79.

Bulk density measurements were made on an uncompressed core of this material from East Lake collected at 1120N 960E (Table 3.10 & Figure 3.6a). The core was collected by vibrating a 0.9m length of 90mm ID PVC pipe into the lake bed. The base of this sample tube was fitted with a 10m length of sash cord. Water depth was only about 5cm which allowed the height of sediment in the sampler to be compared with the undisturbed lake bed, thereby ensuring no compression of the sample. When fully inserted, the top was capped, and the base rotated to the surface by pulling on the sash cord from a distance of about 5-6m. This sheared the contained sample flush with the bottom of the sampler, with no loss of sample. After capping, the sample was frozen and cut into 10cm lengths then oven dried at 105° to constant weight.

Table 3.10 Bulk density measurements, false bottom sediments

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-83.5
Bulk density	0.199	0.238	0.249	0.255	0.264	0.304	0.241	0.217
Geology	mud	mud	mud	mud	mud	mud	mud & peat	mud & peat

The bulk density increases by about 50% from the sediment water interface to 60cm depth where it is still 50% or less than that of typical clays. Analysis of similar material in Figure 3.9 by Carbon *et al* (1988) confirms that organic material comprises up to 52% (dry weight) of these sediments.

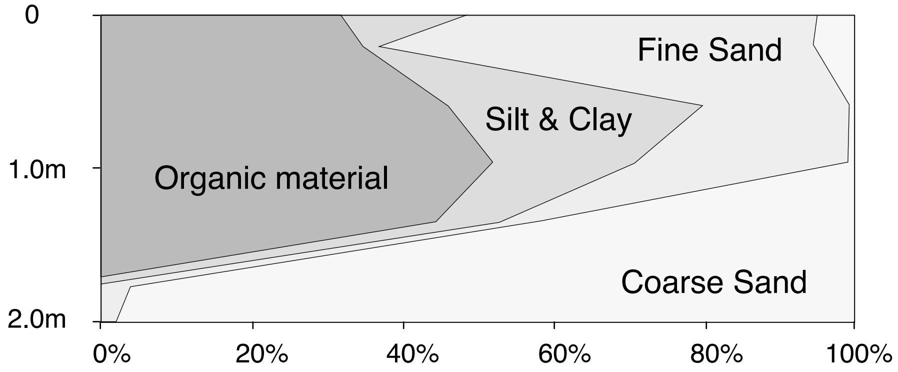


Figure 3.9 Sediment composition in lake lining core, East Lake. Initial dry weight determined by drying at 105°C, organic material determined by weight loss after further drying at 600°C. Sand fractions determined by sieve analysis, silt and clay by difference. Adapted from published and unpublished data of Carbon *et al* (1988).

Where the lake is permanently inundated, the water-sediment interface is therefore a transitional zone. Where the lake is seasonally inundated, the false bottom sediments shrink and compact forming a well defined sediment-water interface.

3.5.2 Hydraulic Conductivity of Lake Lining

Permeameter Tests

Vertical *in situ* cores of lake bed sand and clay were collected from East Lake. These were run as permeameters and estimates of vertical hydraulic conductivity (K_z) determined.

Sand Core: L: 460mm D: 100mm Location : 1150N 920E
Mean of 6 falling head tests: 9.5m day^{-1} (run times 1 to 10 hours)

Clay Core: L: 780mm D: 100mm Location: 1300N 1017E
Mean of 43 fixed head tests: 1.08cm day^{-1} (run times 12 to 72 hours)

The clay core was run in an unheated building during winter. Data were corrected for absolute water viscosity by logging day and night time water temperature. Methodology, geology of the cores and detailed results are summarised in Appendix 3.5.

3.5.3 Specific Yield of Lake Lining

Specific yield was determined on the saturated sand and clay cores using the methods modified from Johnson *et al* (1963) and Prill *et al* (1965). Principal modification was the use of undisturbed cores collected *in situ* as opposed to cores comprising repacked sediment. True specific yields can only be estimated using temperature controlled columns and test runs of hundreds of days, however Piper (1939) cited Prill *et al* (1965) found that increasing the time to hundreds of days increased specific yield by only 1 to 3 percent. The data presented here is therefore considered to represent reasonable estimates of specific yield.

Columns were allowed to drain until flow ceased. Specific yield at t = 24 hr was calculated for use in evapotranspiration estimates using water table fluctuations (Chapter 11).

Sand core: S_y 0.136 S_y at t = 24 hr: 0.134

Clay core: S_y 0.0243, S_y at t = 24 hr: 0.0069

Details are included as Appendix 3.6.

3.6 DEPTH-AREA-VOLUME RELATIONSHIPS

Stage-area-volume curves define the relationship between lake stage (easily measured) and lake area and lake volume (difficult to measure directly). Area and volume are essential to water balance studies. In very small, shallow wetlands where area and volume vary by several hundreds of percent over a season, accuracy in these relationships is crucial.

3.6.1 Methods

Methodology was similar for both lakes. Local metric grids with central baseline were established (Appendix 3.7 a&b) using wooden survey pegs on 10x20m centres. Surveyed points were typically 10m apart, decreasing to 5m or 1m where additional detail was required Grid orientations were:

East Lake: baseline (1000E) bearing 350° true (surveyed January 1998)

West Lake: baseline (1000E) bearing 040° true (surveyed February 1995)

Standard optical levelling techniques (Bannister & Raymond 1984) were employed with each station levelled to ±1mm. All levels are in metres AHD, tied to the following bench marks:

WEMBLEY 7 (Corner Oceanic Drive & Ulster Road)	12.790m
MWB 1413 (Perry East flood remediation pump station)	5.518m
Australian Survey Office Plan A0-495 control point 27 (West Lake)	6.127m

Water and Rivers Commission staff gauges were checked against these bench marks. The East Lake gauge is considered accurate to ±1mm. The West Lake gauge was checked twice. A 12mm discrepancy was recorded with control point 27 in February 1995 and a 16mm discrepancy in January 1998, (gauge reads low). This suggests that the West Lake gauge is slowly sinking. Recorded water levels in West Lake have been corrected by adding 14mm.

West Lake was completely dry when surveyed apart from a 20x50m pool around the staff gauge. East Lake was dry apart from the south basin which contained a pool of water measuring approximately 100x100m. The submerged portion of the lake bed was surveyed by measuring water depth to the water-sediment interface. This interface (which appears optically to be clearly defined), is in reality a gradational or 'false bottom' (see Section 3.5). Depth measurements were converted to AHD by subtracting from the lake stage height. Readings accurate to 1 mm were possible as the maximum water depth was only 26cm (lake stage 2.938m). Stations at the periphery of the submerged area were also surveyed optically a few days later. Elevations for these duplicate stations were typically 20mm lower, reflecting compaction of the sediment upon draining and partial drying. Elevations at these tie points, obtained using both survey methods, were averaged.

3.6.2 Historical Note

The basic morphology of the lake basins appears similar to that inferred from aerial photographs prior to the 1962 dredging (Chapter 2). East Lake generally sloped from shallow in the northeast (N. E. Shelf in Figure 3.10a) to deep in the southwest. This general form remains. A distinct trough immediately adjacent to the eastern bank was created during bank reclamation. The deepest water still occurs in the South Basin, just as it did prior to dredging (Plate 2.1). A central, southeast trending curvilinear ridge colonised by *Baumea* remains today just as it did in the 1940's and 1950's. This combined with the fossil tree stump and old fence data (Chapter 2) suggest that the dredging probably removed false bottom 'muck' but very little of the denser clay lining. Somerford (pers com) believes that very little dredging was actually carried out in the northeast section of the basin and suggested that the present basin contours (apart from the bank reclamation) closely mimic the original lake basin.

In West Lake the effects of bank reclamation are also evident around most of the lake perimeter. The overall morphology however mimics that evident in 1942 (Plate 2.1). The S.W. Basin remains the deepest natural portion of the lake with deeper artificial sections close to the island. The shallow east - west trending bar immediately to the south is a remnant of the original south basin margin, the present bank having been dug out south of it. The gentle sloping shelf forming the eastern margin of the lake basin is largely natural and is evident in Plates 2.1 and 2.2.

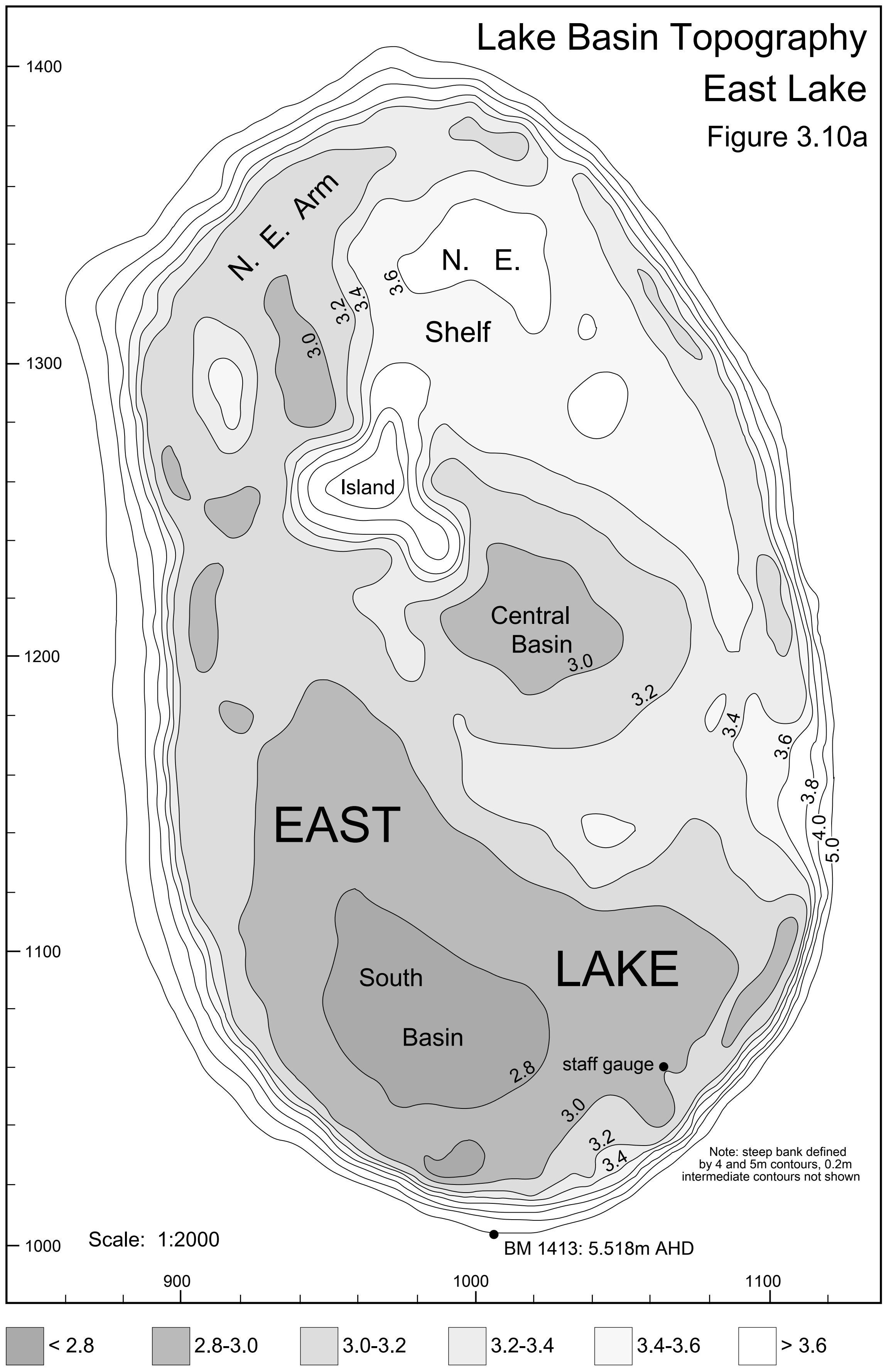
3.6.3 Generation of Contour Maps and Depth-Area-Volume Curves

Lake basin contours, and stage-area -volume relationships were computer generated for both lakes using SURFER. The underlying grid was generated by kriging using 2x2m nodes. Stage-area-volume data was generated directly from this grid. Smoothing routines have been applied to produce the presentation contour maps Figures 3.10 a&b. Stage-area-volume tables were computed for both lakes at 1mm stage intervals and are presented in graphical form as Figures 3.11 & 3.12 and as tables in Appendices 3.8 a&b. Volume calculations were checked manually using the formula of Welch (1948)

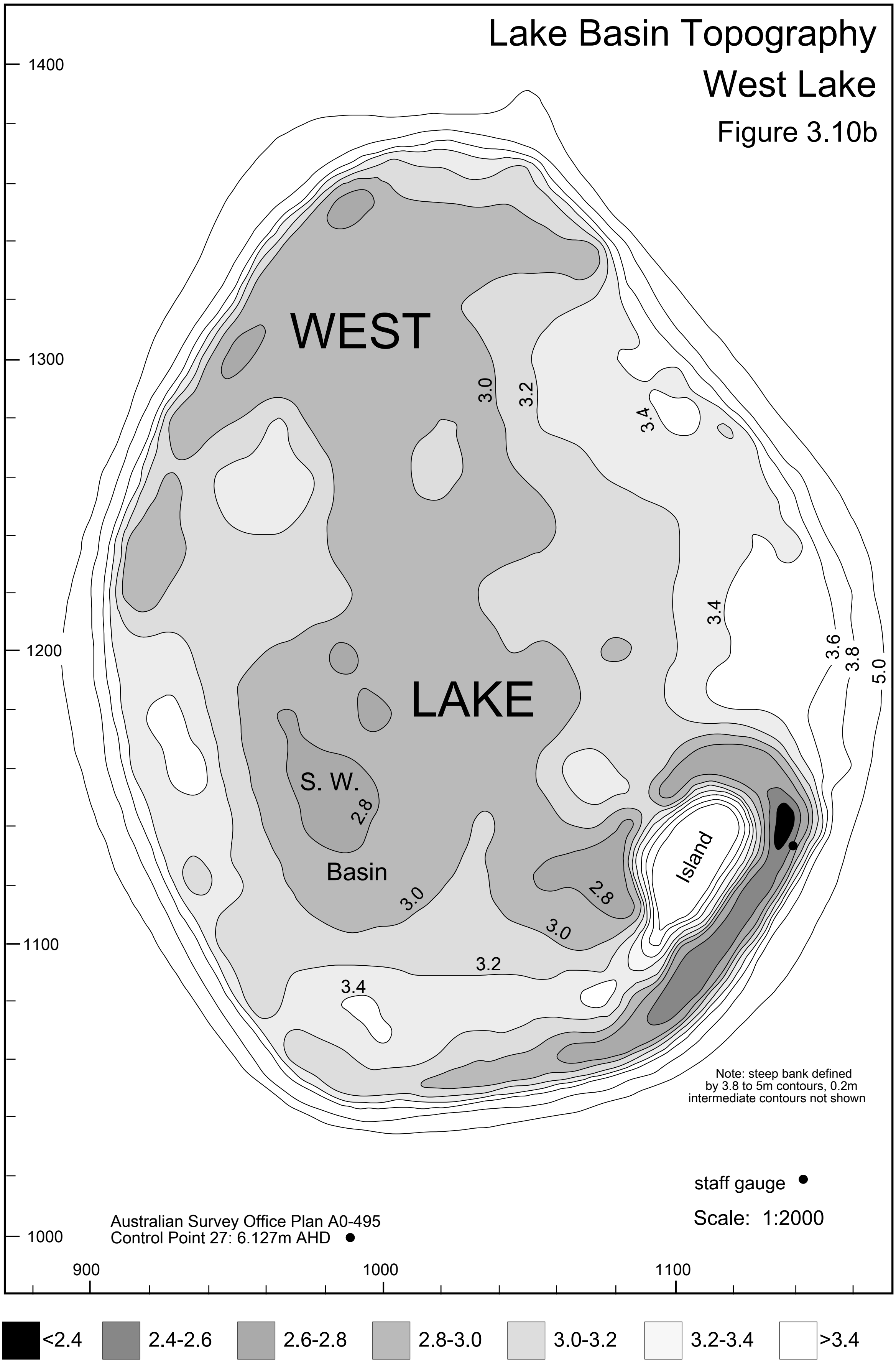
$$Volume = \frac{h}{3}(a_1 + a_2 + \sqrt{a_1 a_2}) \tag{3.3}$$

where a_1, a_2 are top and bottom area of frustra, and h its height. Manual calculations were within 1% of the computer generated values.

In water balance studies, stage is the quantity measured, area is required for quantifying rainfall, evaporation and heat (solar radiation) and volume is the mass of water or 'storage' in the lake. The stage-area (hypsographic) curves both have a distinct change of slope at the point where the irregular basin floor becomes completely flooded and the lake is contained by the steep basin walls. The curves are representative of concave lake basins using the classification of Hakanson (1981). During the course of this study, neither basin floor was ever completely flooded. The basin floors take the form of very shallow irregular saucers where small changes in lake stage produce large changes in lake area.



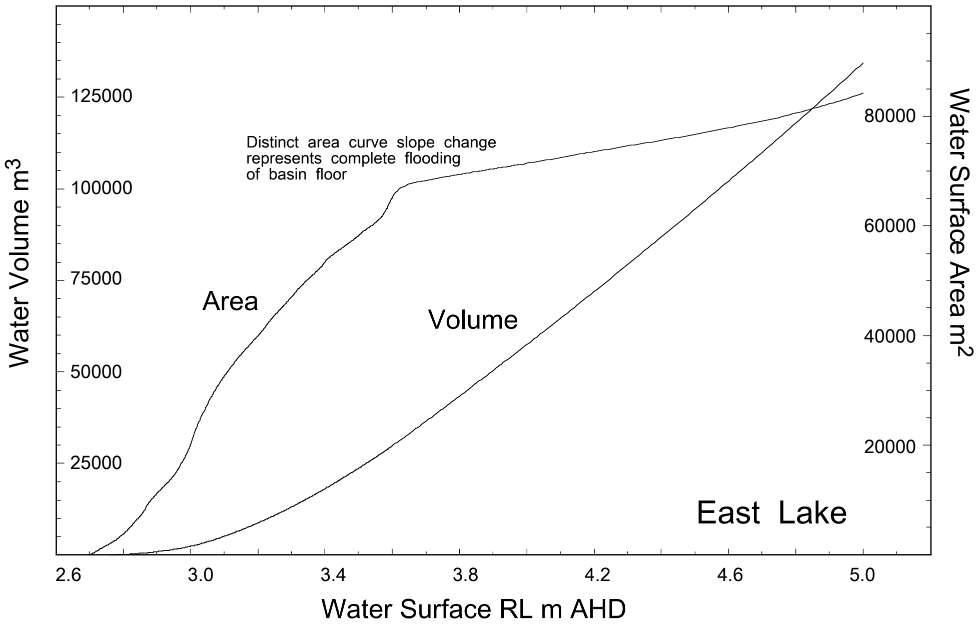
East Lake basin topography generated from 1080 survey points (Appendix 3.7a)
Outer basin margin defined by 5m contour
Contour interval: 0.2m.



Lake Basin Topography
West Lake
Figure 3.10b

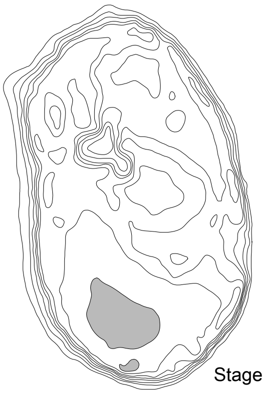
West Lake basin topography generated from 1086 survey points (Appendix 3.7b)
Outer basin margin defined by 5m contour
Contour interval: 0.2m.

Volume - Area Curves



Distinct area curve slope change represents complete flooding of basin floor

Incremental Stage Flood Maps

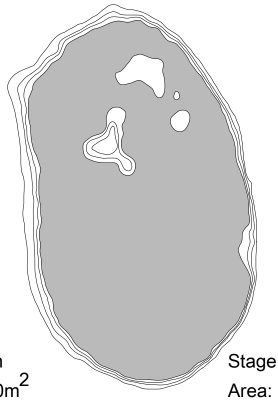


Stage: 2.8m
Area: 3834m^2
Volume: 180m^3

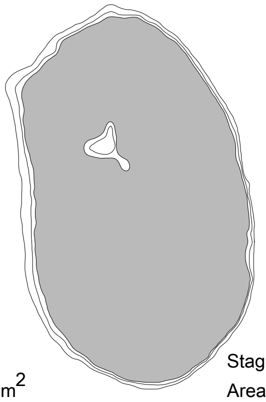
Stage: 3.0m
Area: 20110m^2
Volume: 2404m^3

Stage: 3.2m
Area: 39920m^2
Volume: 8760m^3

Stage: 3.4m
Area: 53440m^2
Volume: 18140m^3



Stage: 3.6m
Area: 65120m^2
Volume: 29825m^3



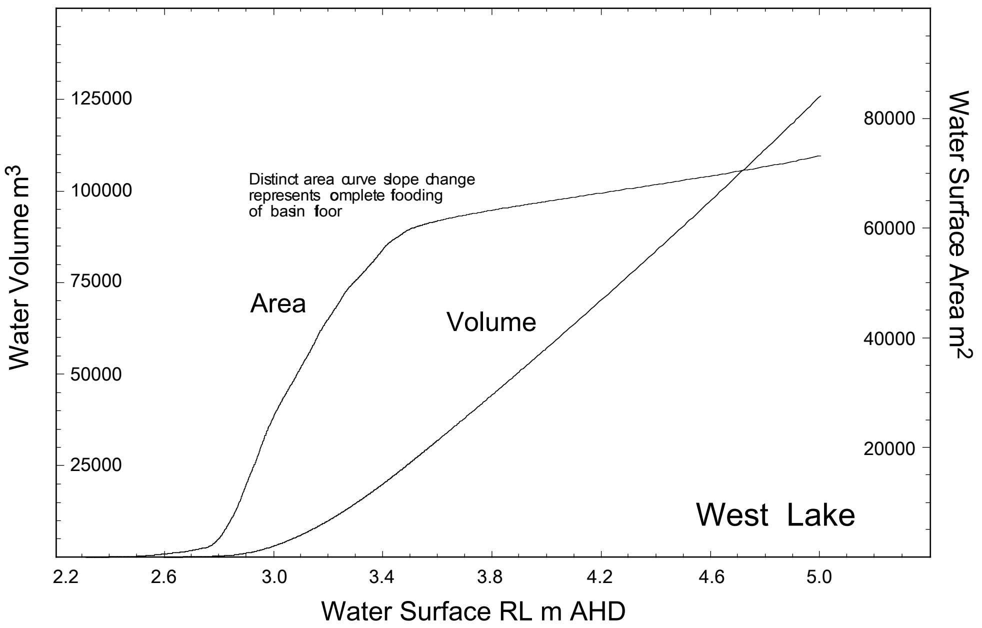
Stage: 3.8m
Area: 69320m^2
Volume: 43435m^3

Notes

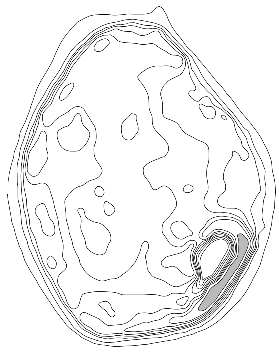
Lake stage-area and stage-volume curves for water surface stage 2.6 - 5.0m AHD
Flooding outside lake basin occurs above approximately 5m
Data plotted at 1mm stage resolution.
Thumbnail maps show water surface at stages between 2.8 - 3.8m AHD

Area - Volume
East Lake
Figure 3.11

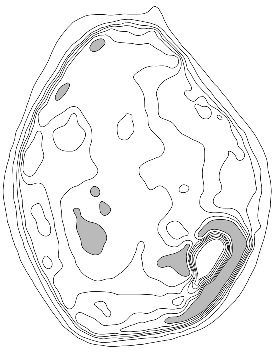
Volume - Area Curves



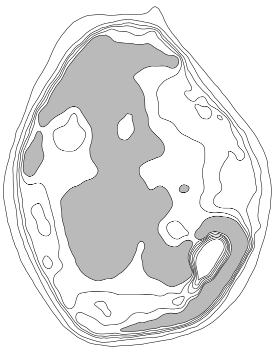
Incremental Stage Flood Maps



Stage: 2.6m
Area: 600m^2
Volume: 56m^3

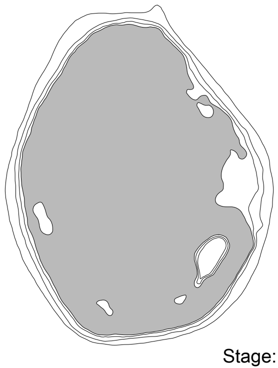


Stage: 2.8m
Area: 3628m^2
Volume: 348m^3

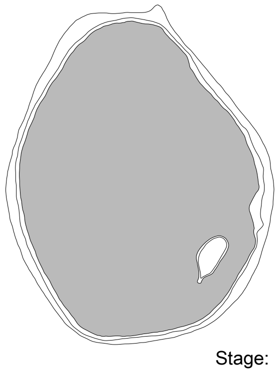


Stage: 3.0m
Area: 25940m^2
Volume: 3145m^3

Stage: 3.2m
Area: 43660m^2
Volume: 10135m^3



Stage: 3.4m
Area: 56280m^2
Volume: 20200m^3



Stage: 3.6m
Area: 61295m^2
Volume: 32095m^3

Area - Volume

West Lake

Figure 3.12

Notes

Lake stage-area and stage-volume curves for water surface stage 2.2 - 5.0m AHD
Flooding outside lake basin occurs above approximately 5m
Data plotted at 1mm stage resolution.
Thumbnail maps show water surface at stages between 2.6 - 3.8m AHD

CHAPTER
4

WATER BALANCE CONCEPTS

4.1 INTRODUCTION

A water balance is an accounting of all inputs and losses of water from a hydrologic system, balanced against the change in water stored within that system. It must account for all inputs, losses and interactions between atmospheric, surface, subsoil and aquifer water. A water balance may be calculated at any spatial scale from global such as the worlds oceans to regional such as an aquifer system to local such as a small pond. A water balance can be calculated at any temporal scale; a day, week, month, year or longer. A balance may comprise water mass or other components including dissolved chemical species such as salts or nutrients, isotopes or heat. In the case of wetlands such as Perry Lakes a simple water balance may be thought of as:

$$\text{Water In - Water Out = Change in Water Storage} \qquad (4.1)$$

Water balances are extremely important in that they form the underlying basis of wetland hydrological modelling (Townley *et al* 1993a).

4.2 REGIONAL BALANCE ON THE SWAN COASTAL PLAIN

The Swan Coastal Plain may be thought of as a hydrological system. Most shallow lakes within it occur where the regional unconfined aquifer (hosted by predominantly sandy sediments) intersects the undulating land surface. Exceptions occur (particularly along the Darling Scarp) where clay soils (or clay lenses within sands) may trap precipitation and surface run-off (Hill *et al* 1996). The elevation of the water table in a general sense follows regional surface topography. In the case of Perry Lakes, groundwater flow originates 30-40km to the north east on the Gnangara Mound (Figure 1.2) and terminates at the Darling Fault, Swan River or Indian Ocean which collectively form the system boundaries (Figure 4.1a). Over this distance the elevation of the water table drops by only about 50m so that for practical purposes the water table and groundwater flow gradient may be thought of as being essentially horizontal. Rainfall recharges the aquifer over its entire area although the amount of recharge varies greatly from area to area depending on surface land use. Natural bush intercepts large amounts of precipitation in the canopy and that which enters the soil may be subsequently re-evaporated or transpired via deep rooted vegetation. Whereas natural bush may recharge anywhere from nil to around 13% of rainfall, cleared farmland and urban areas may recharge much more. Much rainfall is lost in evaporation from the soil and transpiration from plants. Close to wetlands water may be evaporated directly from the water table via capillary rise and transpired by phreatic vegetation. Most water leaves the aquifer system by discharging directly into rivers and the ocean however large amounts are also extracted from bores. This may be treated as potable water and then exported to elsewhere in the system where it may be recharged as lawn and garden irrigation or in the case of irrigation bores, applied in situ. The aquitard forming the base of the unconfined aquifer is seldom completely impermeable. Water may be lost to or received from deeper confined aquifers.

Before urbanisation the unconfined aquifer would have been in a state of dynamic equilibrium or balance. The water table would move up and down seasonally in response to winter recharge and summer evapotranspiration. Urbanisation creates a new set of conditions. The clearing of deep rooted native vegetation reduces canopy interception and evapotranspiration from the vadose zone. Recharge to the aquifer increases markedly. Shallow rooted vegetation such as lawns recharge an increased amount of rain. Impervious shedding surfaces such as roofs and roads shed rainfall either directly to the aquifer via soak wells or via storm drains to infiltration basins and wetlands. Bores and drainage ditches extract water directly from the aquifer. The original natural 'dynamic balance' is upset. Given enough time a new balance is established which may result in a water table higher or lower than that which prevailed under natural conditions.

The final factor which affects the water balance under both natural and urban conditions is the climate. Long term climate change, both temperature and rainfall, affect recharge and evapotranspiration. As the climate slowly changes so too the regional water balance slowly adjusts.

4.3 URBAN BALANCE CONCEPTS

Urbanisation has significant impacts on the local water balance. In central business districts impervious shedding surfaces comprise almost 100% of the land surface. Most of the rain which falls is intercepted. In the Perth CBD this is channelled by drains directly into the Swan River. Recharge below the CBD is minimal. Figure 4.1b illustrates the principal components of the local urban water balance in suburban areas which make up the vast bulk of the Perth metropolitan area.

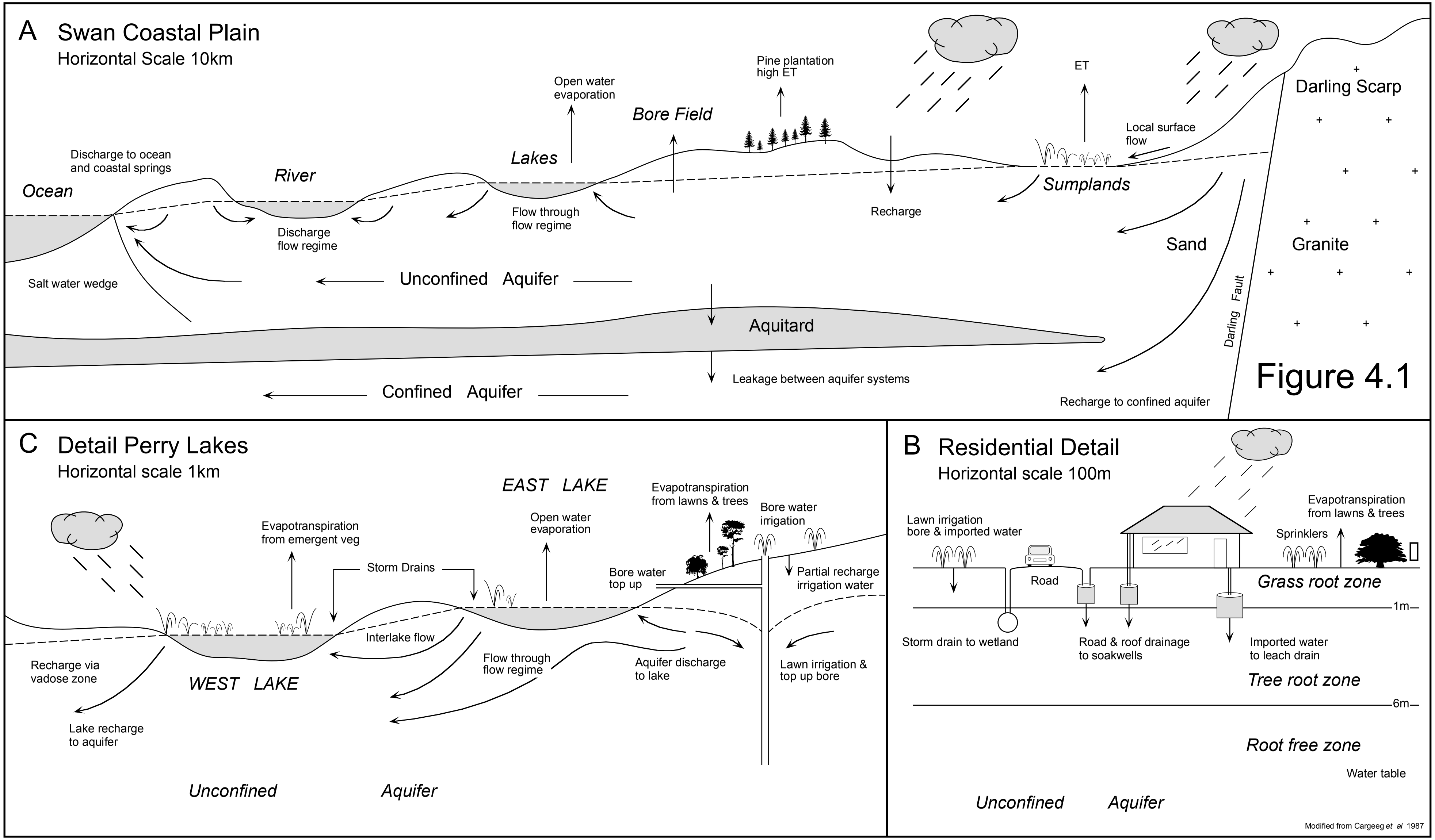
Depending on housing density impervious shedding surfaces may comprise typically 20% to 40% of the land surface. Roofs may direct rain either directly to the vadose zone via soak wells (where most is recharged) or into storm drains. These in turn direct water (including water from roads and car parks) either into infiltration basins (where most is recharged to the unconfined aquifer) or into wetlands. In some areas domestic septic tanks channel sewage and grey water into leach drains which also add recharge to the aquifer. Shallow rooted lawns and ornamental gardens are key features of the suburban landscape. Natural rain quickly infiltrates past the shallow root zone so that a much greater proportion is recharged compared to natural bushland. In summer excess lawn irrigation may exceed usage and also be recharged. This may be either local groundwater extracted from a domestic bore and effectively 'recycled' or scheme water imported from elsewhere. Trees are frequently shallow rooted ornamental species which intercept water only from the shallowest portion of the vadose zone. Compared to native bushland, canopy interception by lawns and shrubs is much less.

4.4 WETLAND WATER BALANCES

Wetlands on the Swan Coastal plain outside the urban area have very simple water balances. Most wetlands are simply deflation hollows which lie below the level of the local water table. Rainfall recharges the water surface directly and is recharged through the sandy soils surrounding the lake. These wetlands typically have no riparian inputs or losses and nil surface run off. Water is lost from the system via direct evaporation from the water surface and evapotranspiration from emergent and phreatic fringing vegetation. The lakes both receive groundwater on the up gradient side as discharge and return water on the down gradient side as recharge. As such they are termed 'flow through' lakes (Nield *et al* 1994).

Wetlands in urban areas have a more complex suite of balance components (Figure 4.1c). Additional water inputs may include storm water channelled directly into the wetland via storm drains or open ditches, run off from adjacent impervious shedding surfaces such as car parks, and 'top up' water to maintain levels over summer. This may be local water from the unconfined aquifer pumped into the lake from nearby bores or imported water from a confined aquifer. Additional losses may include water extracted directly from the lake for lawn irrigation, or water pumped out to prevent winter flooding. The local water table may be affected by heavy local groundwater extraction for ornamental lawns. These water bodies also function as flow through lakes; however, during periods of heavy rain (and subsequent storm drain flow) discharge from the aquifer may cease. Under these conditions the lakes recharge water back to the aquifer until equilibrium levels are re-established.

Figure 4.1



Modified from Cargeeg *et al* 1987

At first glance, calculation of a water balance appears deceptively simple. In fact all of the components of the balance are difficult to measure accurately with the result that all components plus the resulting balance are subject to considerable error. Groundwater components are arguably one of the most difficult balance components to quantify (Hunt *et al* 1996). As a result groundwater is frequently simply estimated as the residual in the balance (Winter 1981, Carter 1986) or is simply ignored. Alternatively, only net groundwater contribution to the lake is estimated or either groundwater inflow or outflow is arbitrarily set to zero, allowing the other to be estimated (Rinaldo-Lee & Anderson 1980, Crowe 1993). Winter (1981) provides an overview of these difficulties and demonstrates how errors in the measurement of each component can be compounded, resulting in a very large uncertainty in the residual. Over time many of these errors cancel, therefore the longer a water balance survey is, the more accurate it is likely to be. Rigorous measurement of each component in the balance eliminates some of the gross errors associated with calculating one component as a residual. Even so, because some components of the balance are disproportionately large compared to others, small errors in their calculation become significant. In Perth, for example, evaporation is the largest single factor contributing to water loss from wetlands. In dry years evaporation may exceed by three times the precipitation, yet evaporation remains very difficult to measure accurately. Even using energy budget techniques, annual errors may exceed 10% (Winter 1981). Such discrepancies can represent very large volumes of water and significant proportions of the water balance.

Also evident when examining flow-through lakes are the reasons why a rigorous determination of the groundwater component is essential. Large volumes of water may enter and leave a lake through its bottom sediments over the period of a year. If however the lake level does not change, this groundwater flux will remain unaccounted for in simple balances because the lake volume shows no apparent change. Clearly where we are dealing with water quality and nutrient balance issues, such uncertainties are unacceptable. We know that the proportions of water discharged to the lake may be markedly different to that being recharged back to the aquifer and that these proportions will vary seasonally, annually and between wetlands.

All balances attempted so far for Swan Coastal Plain wetlands have been non-rigorous. This is inevitable because groundwater inflow and outflow are extremely difficult to measure. At Lake Jandabup, groundwater components were estimated as the residual in a combined mass-solute (chloride) balance (Congdon 1985). Such residuals are highly prone to error since they include the sum of all other errors in the balance (Winter 1981). In most studies balances were determined annually between identical lake stages so that the change in storage ΔS did not have to be determined. Lake storage involves knowing accurately the stage-area-volume relationships of the lake. It represents a significant field work undertaking. Table 4.1 summarises balance results for other Swan Coastal Plain lakes.

Table 4.1 Simple Annual Mass Balances Swan Coastal Plain Lakes

Lake and Reference	Years	±GW	±ΔS	+P	+S_i	-E
Bibra Lake (Megirian 1982)	1972-1981	+0.71	+0.01	+0.65	+0.02	-1.37
Jandabup (Allen 1979)	1977-1978	+3.43	+0.12	+2.04	+0.00	-5.87
North Lake (Megirian 1982)	1977-1981	+0.32	0.00	+0.32	+0.12	-0.76
Joondalup (Congdon 1985)	1979-1980	+0.77	0.00	+3.37	+0.90	-5.04
Mariginiup (Hall 1985)	1979-1980	+1.00	0.00	+1.10	+0.10	-2.20

All quantities x$10^6$$m^3$, GW groundwater, ΔS change in storage, P precipitation,
Si Surface inputs, E evaporation,

4.5 MULTIPLE SIMULTANEOUS BALANCES

On the basis of a mass balance alone, groundwater can only be differentiated as a net input or loss. There is no way to differentiate or quantify groundwater discharge to the lake or lake recharge to the aquifer. All earlier workers were aware of groundwater flows. Nested piezometers (Allen 1979, Hall 1985) and seepage meters (Congdon 1985) clearly showed water to be entering and leaving. Allen (1979) attempted to estimate the groundwater components for Lake Jandabup using the Darcy equation and (vertically exaggerated) equipotentials. These suggested that only the upper portion of the aquifer was interacting with the lake. Subsequently it was shown that the entire aquifer section was interacting with the lake (Townley *et al* 1993a). While the detail of Allen's interpretation was incorrect, he was able to confirm the earlier observation of Balleau (1973) that groundwater chloride concentrations increase to the west of lakes on the Swan Coastal Plain. A similar result (with a similar misrepresentation of equipotentials) was obtained for Lake Mariginiup by Hall (1985). All of these simplified balances indicate that there is a net surplus of groundwater entering these lakes. They are over the longer term evaporative sumps. What the balances cannot do is accurately quantify groundwater discharge and lake recharge. Lakes highly modified by urban drainage may show the opposite effect. McFarlane (1984) found that in Mason Gardens and Shenton Park Lake, recharge of storm water back to the aquifer was the largest component of the annual balance.

This leads directly to the importance of simultaneous multiple rigorous balances. These are rigorous in the sense that (within practical limitations) every effort is made to measure *every* component of *each* balance. They are simultaneous in the sense that solute and isotope balances are calculated along with simple water mass. Integrating the balances allows the elusive groundwater flux components to be teased out. The detail on just how this is accomplished forms a large portion of Chapter 6. At Lake Joondalup for example, Congdon (1985) was able to demonstrate that where mass balances indicated a net monthly input (discharge) of groundwater, chloride balances simultaneously showed a net loss of chloride, *i.e.* a flow-through lake with recharge exceeding discharge.

Biologically conservative solutes have been widely used as water flow tracers (Allison & Hughes 1978, Allison & Leaney 1980). Chloride (as a solute balance) has been widely employed in combination with mass balances of Swan Coastal Plain lakes (Allen 1979, Hall 1985) and the unconfined aquifer (Davidson 1981 & 1995). Chloride is described as a conservative solute because its behaviour is simple and predictable and it does not fractionate during evaporation. Evaporating a closed body to half the original volume simply doubles the Cl content. Diluting the body with water of known Cl concentration permits the final concentration to be accurately predicted. Isotopes such as deuterium and oxygen 18 on the other hand are non conservative in that evaporation removes some of the isotope of interest. In a lake-aquifer system, isotope ratios are stable everywhere except at a lake surface where fractionation and enrichment occurs during evaporation (Gat 1981 d&e). This behaviour or 'isotope effect' (Gat 1981 a&b) is governed by well defined rules (Chapters 6 & 12) which when applied allow these isotopes to be used in a similar fashion to conservative solutes. Knowing the isotopic ratio within the system components, mass balance equations can be solved to estimate the groundwater component in lake water balances (Dinçer 1968, Turner *et al* 1983, Krabbenhoft *et al* 1990, Turner *et al* 2000). Krabbenhoft & Webster (1995), demonstrated the temporal variability of groundwater inflow-outflow including the transition from flow-through to recharge status using solute balances (calcium) and stable isotopes.

Other methods can be employed to provide independent clues about lake-aquifer coupling and interaction. These include nested piezometers, in-lake piezometers, water table contours and flow nets (Chapter 7) as well as thermal patterns in the lake sediments (Chapter 9).

4.6 PERRY LAKES

Townley *et al* (1993a) provide the theoretical framework for integrating mass, solute and isotopic balances to tease out the groundwater components of wetland water balances. This study represents a field validation of the theory. At Perry Lakes direct measurement of all components except groundwater flux has been combined with solute (chloride) and isotope (deuterium) techniques to allow all the groundwater components of the balance to be determined. These concepts are expanded in Chapter 6 while in Chapter 7 the balance data is combined with regional hydrologic data to elucidate lake-aquifer interaction under natural and artificially induced conditions.

The final execution and synthesis of any water balance is a compromise. Expense, available labour and the field site itself (availability of electric power, security, vandalism etc) all place restraints on what can and cannot be achieved. The Perry Lakes site had a number of distinct advantages which made it amenable to detailed water balance studies. In particular its location adjacent to CSIRO allowed highly labour intensive studies to be completed. Much of the data gathering was done manually on a daily basis. The provision of a secure compound immediately adjacent to East Lake with 240 volt power available was essential for the isotope experiments. The UWA Field Station immediately adjacent represented another secure area where evaporation pan experiments could be conducted.

Perry Lakes also had a number of distinct disadvantages. It is very heavily used by the public including school field days. Vandalism is a problem. Monitoring equipment must be either inaccessible or not visible. Hydrologically the reserve is subject to excessive groundwater extraction for at least half the year. Pumping from multiple bores occurs every week day for lawn irrigation. On weekends these same bores are used to top up East Lake. None of the bores are equipped with flow metres and many draw their power from the common stadium supply without separate hour or watt meters. Bore usage relied on written logs maintained by park staff. This was often difficult as staff were rotated through other reserves. Simple bad luck also plays a role. A complete seasons worth of bore usage records was lost when a park staff ute was stolen along with the bore log. The vehicle was recovered but not the log.

At the early planning stages (1994-95) West Lake retained some water over summer. By the time all equipment was constructed and in place (1997-98) West Lake was dry for half the year and East Lake was being artificially maintained for at least 6 months of the year. This represented a unique opportunity to study two closely coupled lakes, one of which was allowed to dry out naturally and one in which artificial intervention played a dominant role.

CHAPTER
5

WATER BALANCE COMPONENTS

5.1 INTRODUCTION

This chapter describes the field techniques used to measure the principal water balance mass components or (in the case of groundwater discharge and recharge) sample their solute and isotopic values. Components measured are summarised in Table 5.1.

Table 5.1 Mass balance components

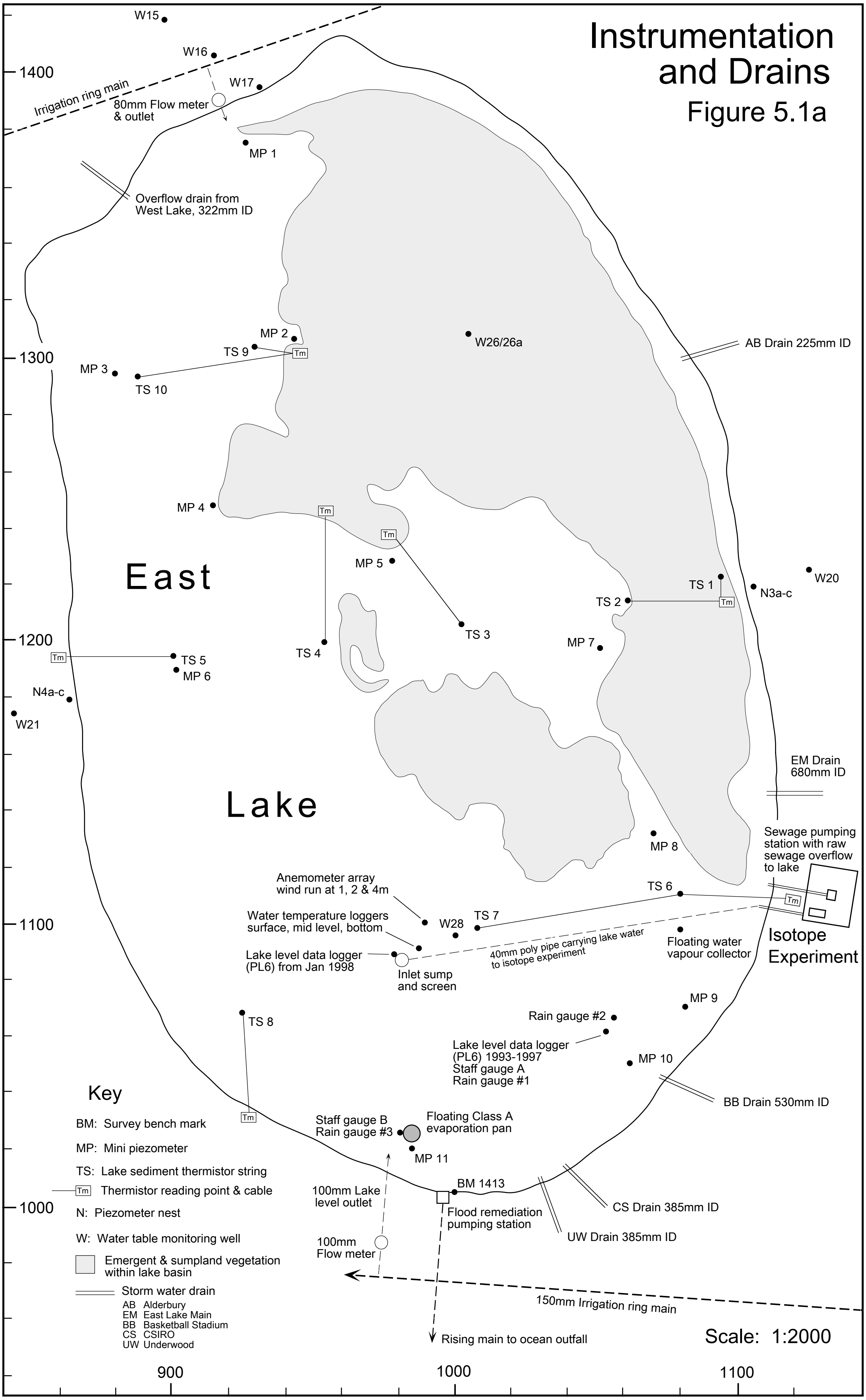
Component	Mass	Cl	^{2}H	Heat
Lake volume	X	X	X	X
Rainfall	X	X	X	X
Summer maintenance	X	X	X	X
Evaporation	X		X	
Transpiration	X			
Storm water	X	X	X	X
Groundwater discharge		X	X	X
Groundwater recharge		X	X	X

Thermal balance issues are addressed separately in Chapters 8 and 9. Evaporation is the subject of stand alone studies in Chapter 10. Transpiration is dealt with exclusively in Chapter 11 and isotope experiments to determine isotopic exchange parameters unique to Perry Lakes in Chapter 12. Lake volume, rainfall, summer lake level maintenance and evaporation proved to be relatively straight forward to measure. By far the bulk of this chapter is devoted to the storm drains. Their large number and highly varied construction necessitated a variety of monitoring techniques and custom built instrumentation.

Figures 5.1a and 5.1b detail the locations of all sampling equipment and infrastructure described in this and subsequent chapters.

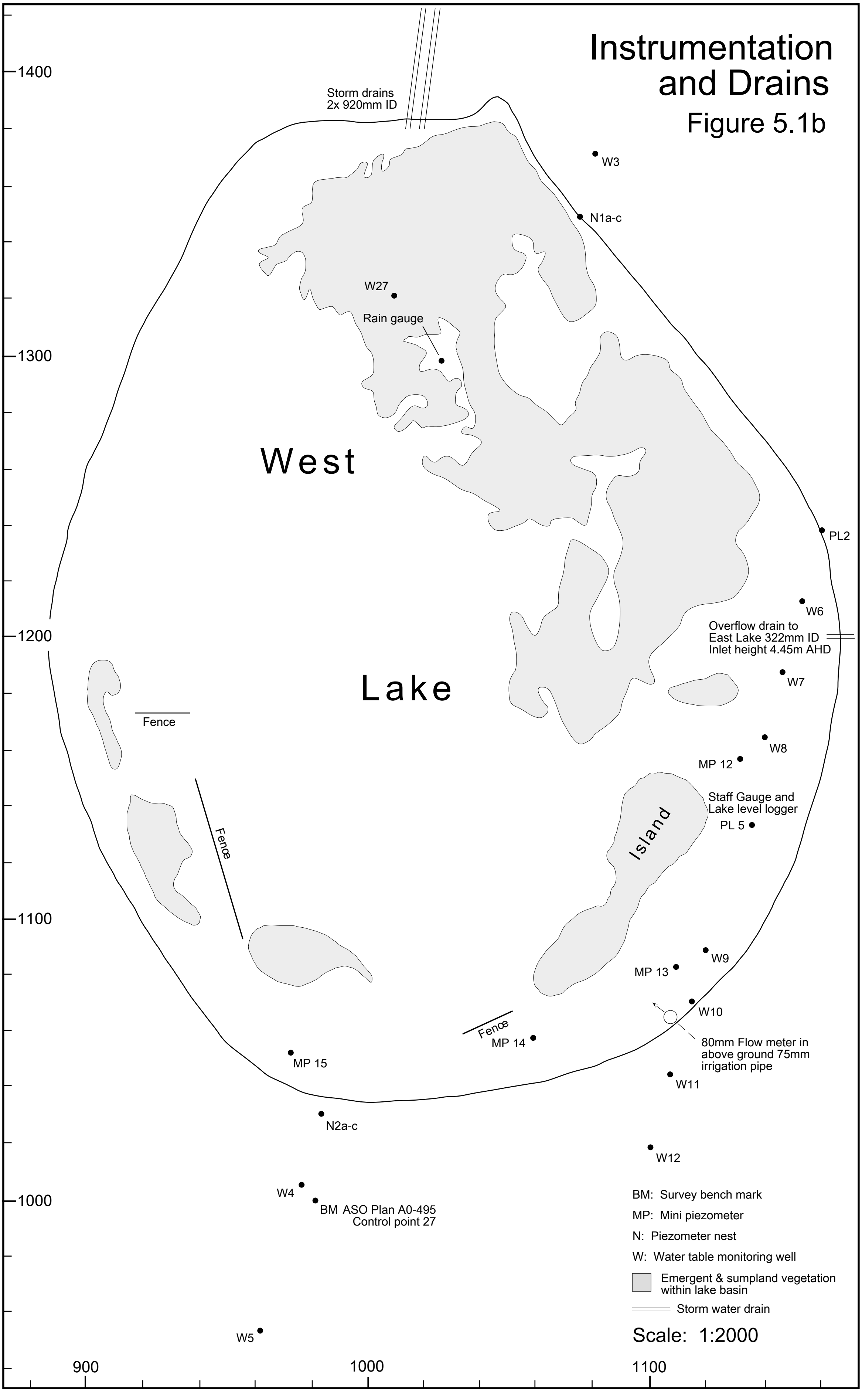
5.2 LAKE VOLUME

Lake volume was computed daily at 08:00 using depth-area-volume curves generated for each lake (Chapter 3) and manual readings taken from staff gauges in East and West Lake. The staff gauges are maintained by the Water and Rivers Commission (WRC) and read lake surface height in metres AHD. Gauges were read to 1mm accuracy. In windy weather a length of 300mm diameter PVC pipe was placed over each gauge to act as a stilling well.



Instrumentation and Drains

Figure 5.1a



Instrumentation and Drains

Figure 5.1b

In East Lake the WRC gauge is designated staff gauge 'A' in Figure 5.1a. This gauge has a 1m face plate reading from 3.0 to 4.0m AHD. As East Lake frequently fell below 3.0m, a second gauge was installed adjacent to the floating evaporation pan, designated staff gauge 'B' (Figure 5.1a). In West Lake the WRC gauge is located close to the deepest point in the lake and was useable all year round.

Capacitive water level loggers (Dataflow type 392) were installed on each staff gauge, designated PL5 in West Lake and PL6 in East Lake. These were used as a back up to the manual data and to plot details of lake level change between the daily manual readings. This was particularly useful when computing storm water inputs. The logger's data required constant calibration against the manual data. Damp debris (such as algal growth) on the capacitive element, and thermally induced electronic drift resulted in seasonal errors of over 0.1m. In East Lake persistent summer levels below 3m AHD necessitated moving PL6 to a deeper section of the lake in January 1998.

5.3 RAIN

Rainfall was measured manually every 24 hours using four inch (101.6mm) orifice gauges. In East Lake these are designated #1 to #3 in Figure 5.1a. In West Lake a single gauge was located in the northeast section of the lake basin. Sunken gauges flush with the ground surface are considered the least prone to wind induced error (Winter 1981). Gauges in the lakes were therefore mounted 0.5m above anticipated winter stage maximum. At the UWA Field Station Class A pan a fifth gauge was operated, mounted 0.5m above the ground. Rain gauges were read to 0.1mm accuracy at or close to 08:00 whenever there was rainfall in the preceding 24 hours. In East Lake, the three gauges generally read to within 0.1mm of each other although differences of up to 0.5mm were recorded when rain was accompanied by high winds. Rainfall was taken to be the greatest of the three readings.

5.4 SUMMER LAKE LEVEL MAINTENANCE

During summer, water was maintained in East Lake by adding groundwater pumped from any one (or combination) of eight irrigation bores within Perry Lakes Reserve (Figure 3.3). Water entered via an 80mm outlet at the north end of the lake and a 100mm outlet at the south, both fed by the irrigation ring main and controlled by independent gate valves (Figure 5.1a). Rebuilt, calibrated impellor type flow meters (purchased from Water Corporation of WA) were installed by the Town of Cambridge in both outlets. These were read every morning. Data was read to 0.1m^3 however the overall meter precision was plus or minus 4% (K. Lloyd, Water Corporation Instrument Workshop, pers com). West Lake was topped up occasionally via above ground 75mm aluminium irrigation pipe fitted with a second 80mm flow meter (Figure 5.1b).

5.5 EVAPORATION

The floating evaporation pan was sited in the South Basin of East Lake as this is the deepest part of the lake and the only part which does not dry out. The ideal site would have been adjacent to the anemometer array however this would have required daily boat access. A site close to the south shore appeared to represent the best trade off between accessibility (by wading from shore), minimal wind and solar shading and deep enough water to remain floating at low lake stages. The pan was sited on the south side of the lake to minimise shading. Some very late afternoon summer shading occurs (as it does over much of the lake). Vandalism problems precluded measuring wind run at the pan site which was 75m south of the anemometer array (Figure 5.1a).

Figure 5.2 outlines construction details. The literature on floating pans is generally concerned with very large raft mounted installations (refer discussion Chapter 10). All detail similar problems with floating pan installations, namely:

- necessity to stabilise the pan to prevent pan water slopping out and waves slopping in
- desirability of presenting minimal wind disturbance and solar shading around the pan (an almost impossible requirement with raft mounted installations)
- desirability of maintaining pan water level similar to lake level but with minimal pan lip height
- difficulty in detecting small leaks
- necessity for daily reading and maintenance
- tendency of pan to fill and sink during heavy rain
- difficulty in levelling and stabilising pan during readings

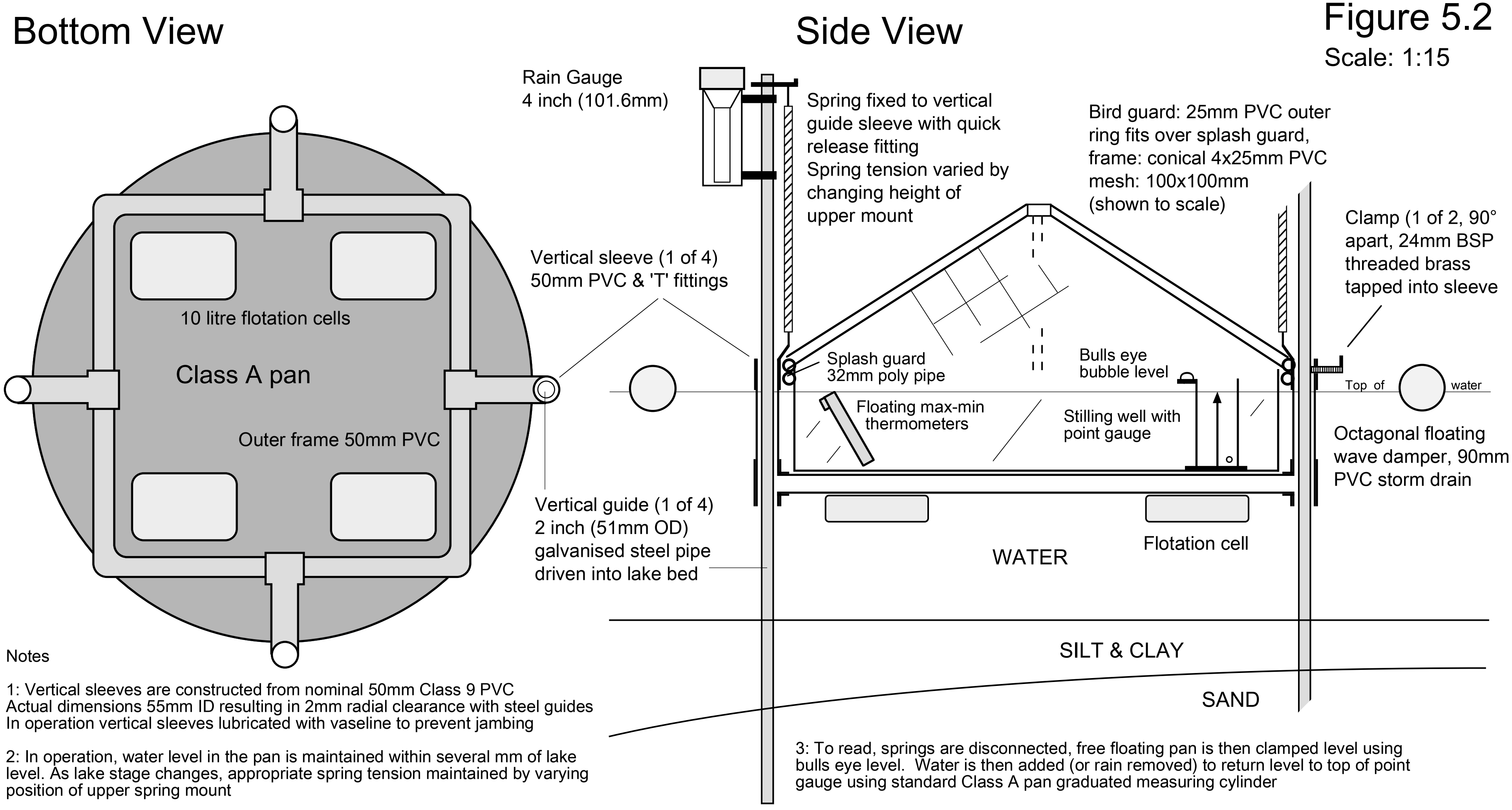
A Class A pan when filled with water to the standard depth (75mm below the rim) will float with a freeboard of about 50mm. In this configuration it is highly unstable and tends to list easily. It does however represent something approaching the ideal in terms of minimal wind disturbance and solar shading. The design adopted for Perry Lakes evolved over several months of experimentation. Its principal attributes include:

- absolutely minimal wind and solar shading
- stability without the use of rafts
- provisions to increase flotation when heavy rain is expected
- ease of levelling and stabilising pan during readings
- wave damping mechanism

Floating Evaporation Pan Detail

Figure 5.2

Scale: 1:15



Notes

1: Vertical sleeves are constructed from nominal 50mm Class 9 PVC
Actual dimensions 55mm ID resulting in 2mm radial clearance with steel guides
In operation vertical sleeves lubricated with vaseline to prevent jambing

2: In operation, water level in the pan is maintained within several mm of lake level. As lake stage changes, appropriate spring tension maintained by varying position of upper spring mount

3: To read, springs are disconnected, free floating pan is then clamped level using bulls eye level. Water is then added (or rain removed) to return level to top of point gauge using standard Class A pan graduated measuring cylinder

These attributes are achieved through a design in which the natural buoyancy of the filled pan is augmented by additional upward flotation from flotation cells below the pan and springs working in conjunction with anti-tilt guides. The guides incorporate locking devices to stabilise the pan during readings. Pans operating in Australia invariably require a screen to prevent interference from birds. The standard Bureau of Meteorology (BoM) bird screen consists of a 300mm high cylindrical frame covered with chicken wire. These screens attenuate monthly pan evaporation by 4% to 8% depending on climate and season (van Dijk 1985). Experiments with an unscreened pan confirmed that wood ducks find them attractive as mid lake roosts. A custom conical screen with very large mesh aperture (100x100mm) proved to deter roosting or other interference from all water birds. The very large screen aperture (100cm^2 versus 2.5cm^2 for chicken wire) has minimal attenuation of solar radiation and wind compared to a standard BoM bird screen.

One of the greatest disadvantages of floating pans is the fact that during heavy rain, the pan fills and rides lower in the water. High winds invariably associated with major frontal systems increase the likelihood of wave slop both into and out of the pan. In the Perry Lakes design these problems were circumvented in two ways. During winter when a frontal passage was forecast, spring tension was increased. This has the immediate effect of giving the pan greater freeboard, and preventing slop in. The pan was also equipped with an anti-slop ring or 'splash guard' around its rim and was surrounded by a floating wave damper (Figure 5.2). If significant rain was also forecast (>20mm), the water level in the pan was also lowered by 20-30mm prior to the frontal passage, preventing slop out. The spring assisted guides allowed the pan to move vertically through at least 0.5m in any 24 hour period, this being the typical lake stage change from storm water or summer top up. Over 13 months of continuous daily operation, only two days data were lost, once from flooding during an extreme rain event and once from flooding when the pan was inadvertently left in the 'locked' position after being read. Daily evaporation was read to 0.1mm using a standard Class A pan graduated measuring cylinder and adjusted for rainfall collected at the pan site (rain gauge #3 in Figure 5.1a).

5.6 STORM WATER

Empirical techniques such as those derived by Chezy and Manning can provide useable estimates of open channel flow in pipes using simple empirical equations (refer Chow 1959 and Hamill 1995 and references therein). Minimal requirements are:

- a long straight debris free pipe of constant diameter and gradient and uniform construction
- depth of water in pipe measured at discreet intervals

All such techniques include a pipe friction factor (Chezy's 'C', Manning's roughness coefficient 'n'). Extensive experimental observation, has allowed typical ranges of these coefficients to be calculated (see Chow 1959 p109). Final calibration (and determination of the pipe friction coefficient) is achieved by comparing computed pipe flows for multiple rain events against gauged flows (French 1985, West *et al* 1991). Where flow is into a closed lake, changes in lake volume can be used to calibrate pipe flow coefficients.

Winter frontal passages in Perth can be expected to drop 20-30mm of rain over several hours. Typically each front comprises a number of discreet rain bands or 'events'. These are characterised by a period of intense rain (possibly of 5-10 minutes duration) which then tapers off. Rainfall often ceases altogether before the passage of the next band. Storm drains within the Perry Lakes catchment are all above the water table. These drains are dry except during rain events. During a frontal passage drains may go from no flow to peak flow within 2-10 minutes, tapering rapidly back to no flow within several hours. Storm drains around Perry Lakes were intentionally under engineered as an economic expedient (P. Smith pers com). During extreme rain events they may operate fully charged. Figure 5.3 shows a typical drain response during a strong frontal passage.

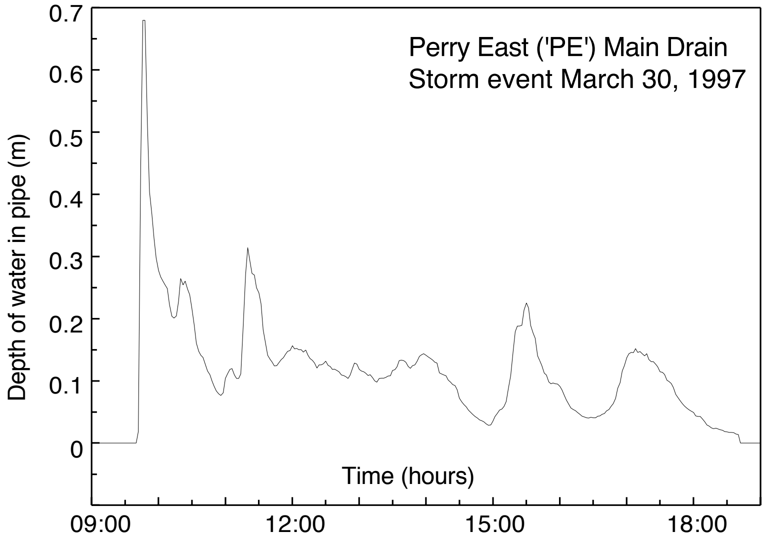


Figure 5.3 Drain response during strong frontal passage. Perry East Main Drain, data recorded every 2 minutes. In this particular case the pipe went from dry to full flow in just 4 minutes. In this event the pipe (diameter 680mm) flowed fully charged for 5 minutes. Four distinct 'events' of lessening intensity are evident. Measured rainfall was 43.5mm.

Balance studies of Swan Coastal Plain wetlands therefore require permanent monitoring of storm drains because they are capable of introducing very large volumes of water over a very short period of time. Earlier studies employing manual measurements almost certainly have underestimated storm water. At Lake Jandabup for example, Congdon (1985) used bi-weekly manual measurements in box section drains. Effects of individual storm events were ignored.

In circular pipes operating as open channels (*i.e.* flow driven by gravity only) velocity increases with depth. Maximum velocity occurs where depth of flow is 0.81 pipe diameters and maximum discharge at 0.95 pipe diameters (Hamill 1995). Depth-volume curves vary according to pipe diameter, gradient and pipe friction (Manning's 'n'). Depth-velocity and discharge curves for storm drains at Perry Lakes (Appendix 5.1) illustrate the relationship between depth, velocity and discharge volume. These curves were calculated for all flow depths up to fully charged. The data illustrate the inherent difficulty in accurately measuring drain flows. During intense rain events much of the flow occurs over an extremely short period of time, typically about 20 minutes. At high flows, the range of pipe friction coefficients typical of cast concrete pipes results in significant differences in computed volume. In the Perry West drains, the difference between 'n' of 0.010 and 0.012 at peak flow is about $9m^3$ per minute per drain.

Data loggers allow storm drain flows to be quantified. The simplest technique is to measure water depth in the pipe. In Perth, sampling rates of 1-5 minutes are typically employed to provide reasonable estimates of discharge volume (G. May & J. Cox, hydrographers with Water Corporation of WA, pers com, M. Kenny, Microcom Pty Ltd, pers com). Originally we envisaged monitoring all storm drain mass inputs directly using drain mounted instrumentation such as the Unidata UDI ultrasonic doppler logger. These loggers use an ultrasonic doppler technique to measure water velocity acoustically by doppler shift from suspended particulate matter in the water, and pressure transducers to measure water depth. They also measure water temperature to correct the doppler data for variations in the speed of sound due to changes in water density. This was attractive since storm water temperature was required for the thermal balance. Concurrent research in a similar setting at Shenton Park Lake (Sim 1995) suggested that the UDI loggers were probably not a practical solution to measuring storm drain flows at Perry Lakes. Data problems included spurious velocity data and debris build up on the doppler sensors and significant problems with instrument calibration (D. Herne pers com). At a practical level, the instrument must be pipe mounted at the downstream end of a straight section of pipe, with manhole access for mounting the logger and automobile battery which requires weekly maintenance. The pipe systems at Perry East are characterised by pipes of several diameters feeding a sediment trap, with discharge to a single larger pipe draining directly to the lake. The only suitable instrument location would be at the lake discharge however these provided no security for the logger or battery which would have to be mounted outside the pipe. The logistics alone of such a set up at Perry Lakes precluded their use.

At Perry West saddle traps (Figure 5.4) have been cut into the pipes. These allow access but preserve pipe form and flow characteristics. These are ideally suited to ultrasonic loggers which bounce an ultrasonic acoustic signal off the water surface and calculate distance to the water surface. Two Microcom DDT-200 ultrasonic depth loggers were installed in the West Lake drains in July 1996. The DDT 200 can resolve water height to 1mm. Associated flow conversion and analysis software can be used to convert water depth to discharge volume for given pipe diameters, gradients and values of Manning's 'n' over user specified periods of time (Appendix 5.1). These instruments have a large memory capacity and were capable of logging continuously at a 1 minute scan rate for 70 days. Because the DDT-200 has a 40-50cm 'dead' zone the transducer must be mounted at least 50cm higher than the highest anticipated flow level. The West Lake saddle traps provided just enough access height to allow pipe flows to 700mm depth to be logged. Unfortunately none of the pipe work at Perry East was amenable to measurement using the DDT-200 loggers.

Measurement of pipe flows at Perry East was rendered extremely difficult due to the following:

- there are 5 drains varying from 225mm to 680mm diameter (Figure 5.1a).
- none provide access to undisturbed flow (*i.e.* West Lake style saddle traps)
- most are too small to allow commercial instrumentation

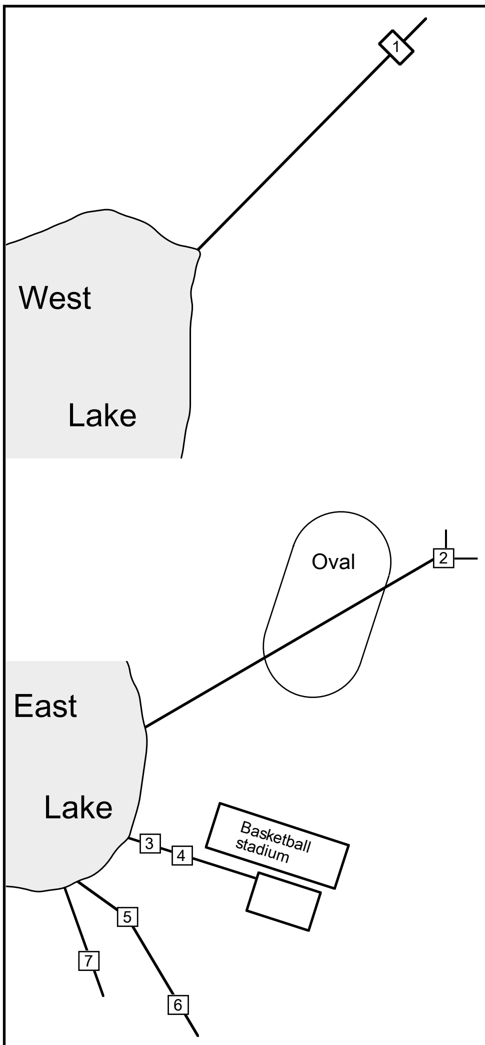
Pipe access is typically via small (1.0x1.5m) sediment traps (Figure 5.4). Water may enter the trap from a number of pipes of varying diameters and leaves via a single pipe, often of larger diameter. The sediment trap on the East Main Drain was observed during a typical storm event. While the level in the trap was clearly different to the level in the exit pipe, it was evident that there was probably some sort of simple relationship between water depth in the trap and depth in the exit pipe. Monitoring required a two fold solution. Depth in the trap could be easily monitored using a stilling well and capacitive water level logger. Pipe depth could then be calculated from the relationship between depth in trap and depth in pipe. This calibration was achieved in three ways:

- direct manual measurement during storm events
- use of crest-stage gauges
- construction of an in-pipe direct level logger

Direct measurement proved to be highly impractical although it provided an unequivocal comparison between trap and pipe water depths. The principal problem being that many high intensity storm events are of extremely short duration. Storm drain flows peak and

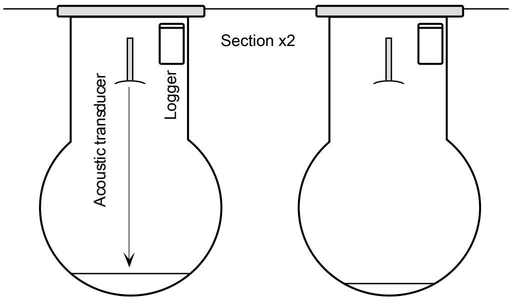
Storm Drains

Figure 5.4



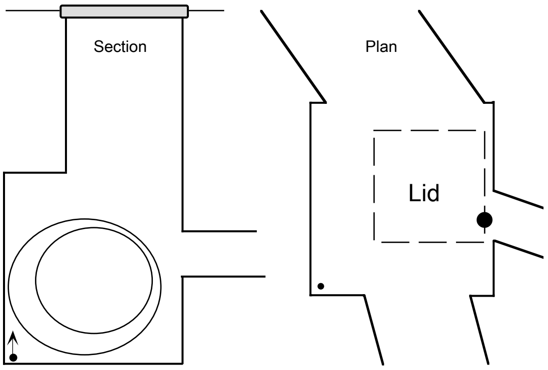
Trap 1 West Lake

Form: double saddle traps
Diameter: 920mm
Distance to West Lake: 266.2m
Gradient: (L) 0.00113, (R) 0.00116
Instrumentation: 2x Microcom DDT-200 acoustic loggers



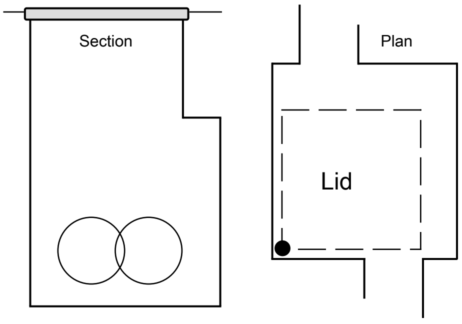
Trap 2 East Lake Main Drain 'EM'

Form: Square junction & sediment trap
Diameter: Inlets: 530 & 250mm, Outlet: 680mm
Distance to East Lake: 236.0m
Gradient: 0.00274
Instrumentation: 1m capacitive probe & LM35 T sensor, 2x Dataflow 392 loggers
Float arm logger at pipe exit to lake



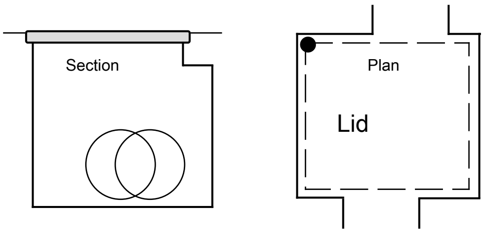
Trap 6 CSIRO Drain 'CS'

Form: Square sediment trap
Diameter: Inlet: 320mm Outlet: 320mm, Trap 5 to lake: 385mm
Distance to Trap 5: 91.3m, Trap 5 to lake: 56.5m
Gradient: Trap 5 to 6: 0.03698, Trap 5 to lake: 0.008265
Instrumentation: 0.5m capacitive probe & Dataflow 392 logger



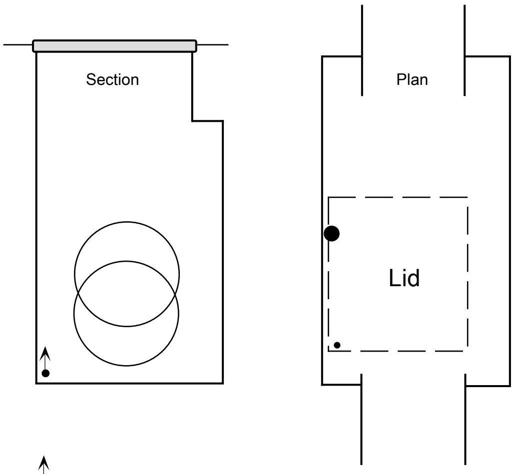
Trap 7 Underwood 'UW'

Form: Square sediment trap
Diameter: Inlet: 385mm Outlet: 385mm
Distance to lake: 45.8m
Gradient: 0.01582
Instrumentation: 0.5m capacitive probe & Dataflow 392 logger



Trap 4 East Lake Basketball Drain 'BB'

Form: Square junction & sediment trap
Diameter: Inlet: 530mm Outlet: 530mm
Distance to Trap 3: 27.7m
Gradient: 0.01083
Instrumentation: 1m capacitive probe & LM35 T sensor, 2x Dataflow 392 loggers
Float arm logger at pipe exit to Trap 3



• LM35 Temperature sensor

● Stilling well with capacitive water level probe wane over several minutes. Peak (crest-stage) can be measured using simple crest-stage gauges. These allow a simple direct measure of maximum stage for a single storm event. Six gauges were constructed (Figure 5.5) using a design modified from Harbeck & Kennon (1954). These were installed approximately 0.5m inside the lake exits of the West Lake drains and the EM, CS and UW drains at East Lake. In the BB drain the exit is partially submerged at winter lake stages. Here the crest gauge was installed in the pipe exit to trap 3 (Figure 5.4 & Appendix 5.1, Figure 2a). The data were frequently difficult to interpret unequivocally. These simple gauges register only flow peak. Therefore reliable data from multiple low through high flow events would be required to provide reliable calibration. In practice the crest gauges were found to have numerous practical disadvantages. They require constant maintenance after every storm, frequently became fouled by leaves and other debris and proved attractive to vandals.

It was clear by the end of winter 1996 that the electronic data being collected in the sediment traps could not be adequately calibrated using either direct measure or crest-stage gauges. The final solution was to design and build a sensor which would continuously monitor water height in a pipe and log it electronically over short (minute or two minute) intervals. Data from one or two major storm events would be sufficient to calibrate the sediment trap loggers. The final design (Figure 5.5) consisted of a counterweighted float and arm driving a potentiometer via a 1:4 gear train. The arm length was adjusted (depending on pipe diameter) such that flow at 0-90% of pipe diameter moved the arm through about 20° of rotation (thus maintaining the float horizontal to the water surface). Movement through this small rotational angle was multiplied via the gear train to provide increased resolution of small changes in depth. The counterweight was adjusted such that the float just skimmed the top of the water. The logger was too large to fit in the CS and UW drains. They were calibrated manually. Table 5.2 summarises storm drain instrumentation. Appendix 5.1 details individual drain calibration.

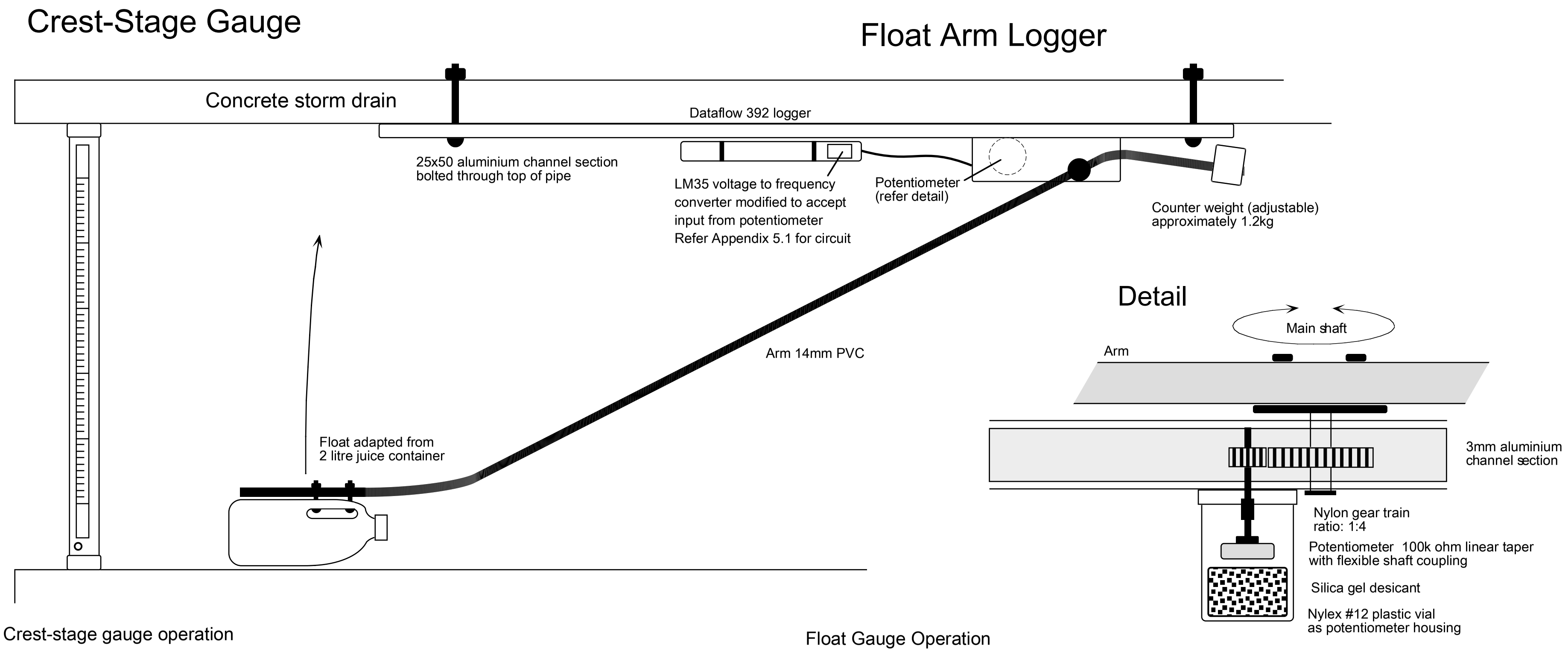
Table 5.2 Storm drain instrumentation

Drain	Manual	Crest Gauge	Capacitive 5 minute scan	Capacitive 2 minute scan	Float Arm 1 minute scan	Acoustic 1 minute scan
Perry East 'PE'	17/6/96	June 96	9/6/96-18/3/97	18/3/97-3/1/98	2/7/97-26/7/97	
Basketball 'BB'	17/6/96	"	"	"	13/8/97-22/11/97	
CSIRO 'CS'	1/9/97	"	17/6/96-18/3/97	"		
Underwood 'UW'	1/9/97	"	2/7/96-18/3/97	"		
West Lake (E)		"				7/7/96-3/1/98
West lake (W)		"				7/7/96-3/1/98

Initially capacitive loggers in the sediment traps were operated at a 5 minute scan rate due to their limited (32kb) memory capacity (Table 5.2). Initial analysis of this data for individual storm events was compared to data from West Lake where the acoustic loggers were providing 1 minute data. It was concluded that 5 minute data does not provide

Drain Loggers

Figure 5.5



Crest-stage gauge operation

Graduated wooden rule is fitted inside 40mm PVC stilling well
Stilling well is fitted with removable end caps
Powdered cork placed in base of well adheres to rule at stage crest
Well is held in place with semi-circular seats bolted into pipe (not shown)

Float Gauge Operation

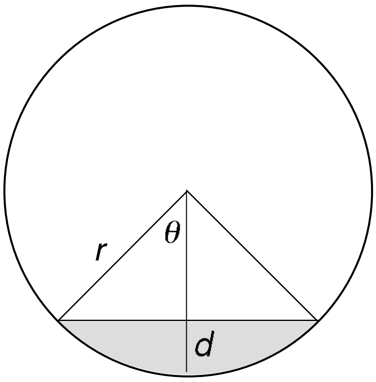
Counter weight is adjusted so float just skims top of water
Length of arm is adjusted depending on pipe diameter such that arm rotates through about 20° when pipe is half full, equivalent to 80° rotation of potentiometer shaft
Installation must be calibrated in situ
Logger typically scans every 1-2 minutes

sufficient resolution of the very short duration, high intensity events typical of frontal passages. The capacitive loggers were run for most of 1997 at a 2 minute scan rate which necessitated down loading about every 10 days but provided adequate resolution.

Calculation of Discharge Volumes East Lake

Where the swing arm logger had been used in the East Main and Basketball drains, the logger provided a direct measure of water depth in the pipe. This logger was operated at one minute logging interval and provides the most accurate measure of storm drain flow volumes. The logger also provided calibration data for the water height in the adjacent sediment traps. These 'depth in trap' values were then converted to equivalent 'depth in pipe' values. Manual data was used to calibrate the CSIRO and Underwood drains. Regardless of derivation these depth in pipe values were then used to calculate flow volumes using identical methodology.

In a drain operating from dry to full volume, with water depth d, and radius r, the following quantities were calculated after Lewitt (1949):



$$cos\,\theta = \frac{r-d}{r} \quad (\theta \text{ in radians}) \tag{5.1}$$

Area of the wetted section A is

$$A = r^2\left(\theta - \frac{sin\,2\theta}{2}\right) \tag{5.2}$$

and length of wetted perimeter P is

$$P = r2\theta \tag{5.3}$$

Hydraulic radius (R) is defined as $R = {}^{A}\!/_{P}$ (5.4)

Average velocity V within the pipe is obtained from the Manning Equation (metric form) where:

$$V = \left(\frac{1}{n}\right) R^{2/3} \sqrt{S} \qquad \text{(Hamill 1995) in units of metres/second} \qquad (5.5)$$

where S is the pipe gradient (dimensionless) and n is the Manning co-efficient ('Manning's n') defining pipe surface roughness with units $s / m^{1/3}$ where s is time in seconds and m is metres. Chow (1959) and French (1985) provide comprehensive details on the evaluation of Manning's n. Within old concrete pipes (straight, no debris) n ranges from 0.010 to 0.013 with 0.011 considered typical (Chow 1959). Flow volume (per second) is $Q = AV$ or per minutely recording interval $Q = 60AV$. Summing these minutely volumes is effectively integration by rectangles (Orvis 1996 p363). A minimal improvement was obtained using Simpson's one third rule (Lial *et al* 1993 p375).

Final choice of calibration involved using both methods to compute apparent pipe flow for storm events over July 5-7, 1997. This series of sharp distinct events allowed total drain flows using different calibration expressions to be compared to short term changes in lake volume (seepage losses being ignored for short periods of several hours). The Manning and similar expressions for drain velocity are empirical expressions and involve subjectively applied coefficients (Manning's 'n') which can significantly alter the final flow volumes (see Hamill p223). Volumes so derived are better considered as estimates only unless they can be calibrated against known discharge volumes. Final calibration of the Perry Lakes drains required finding separate coefficients for each drain such that the aggregate computed flow best matched observed lake volume change over a range of calibration rain events. Individual drain calibration is detailed in Appendix 5.1.

Final Calibration East Lake

Individual drains cannot be calibrated against any gauged discharge however the sum of the four principal drains can be compared to changes in lake volume. At Perry East there was uncertainty over both the optimum trap:pipe relationship for each drain and the most appropriate value of Manning's 'n'. The overall procedure is:

- compile aggregate drain discharge using various trap:pipe conversions and values of Manning's 'n'
- calibrate aggregate discharges against measured changes in lake volume for a variety of storm events

An 'ideal' calibration storm event has the following characteristics:

- sharply defined rain events with no prolonged periods of light rain or drizzle
- calibration event should be preceded and followed by dry periods of at least several days to allow pre and post event lake seepage and ET rates to be accurately computed

Table 5.3 and Figure 5.6 illustrate two of the nine calibration rain events and basic methodology.

Table 5.3 Computation of aggregate storm drain discharge

Event A	Stage	Area	Volume	Apparent ΔS	Seep+ET	Total In	Rain	Drains
	3.265	44650	11510					
	3.319	48370	14020	2509	630	3139	1099	2040
Event B	3.297	46800	12975					
	3.347	50100	15401	2426	658	3084	1102	1982

Apparent ΔS is change in lake volume, Seep + ET is total water lost from the lake as evapotranspiration and recharge to the aquifer, Total In is total computed inputs from rain falling directly on the lake and storm drain flow

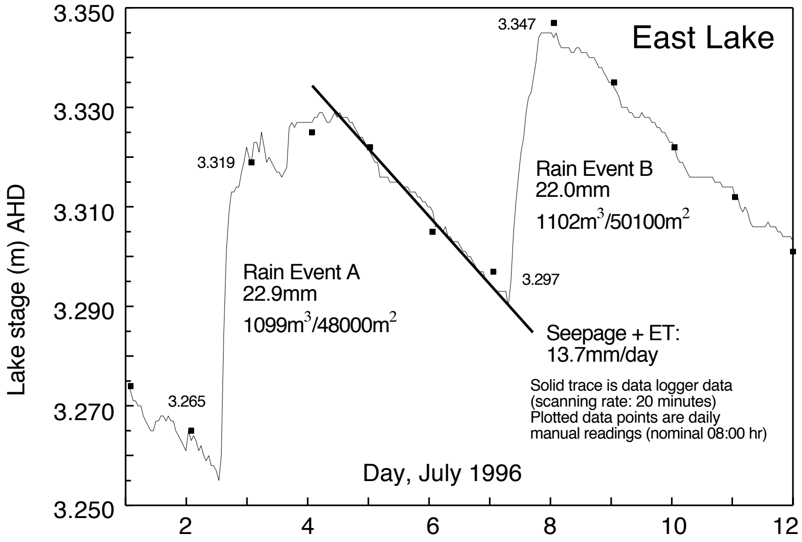


Figure 5.6 East Lake drain calibration events, July 1996. At this time during early winter, any inputs raise the lake above the surrounding water table (recharge flow conditions). Slope of the 'seepage' line represents a combination of recharge (seepage) and evapotranspirative losses. Inputs are direct rainfall on the lake surface plus drain discharge. Daily staff gauge data plotted as small squares.

For each drain a number of possible 'depth in sediment trap' to 'depth in pipe' co-efficients were computed based on manual and float arm data and other factors such as variable time lag in the PE drain where the float arm and manual data was collected over 200m from the trap site (Appendix 5.1). Aggregate discharge was described by a 'family' of 120 rating curves defined by the trap:pipe and pipe friction coefficients (Manning's 'n'). These are tabulated in Appendix 5.1. Aggregate discharge using all permutations of pipe discharge were plotted against data derived from lake volume changes for 9 rain events. A perfect match is defined by a line of slope =1 and y intercept of 0. Data combinations which appeared close using 'n' set at 0.011 were retested with 'n' set at 0.010 and 0.012. Appendix 5.1 includes examples of various 'close fits'.

Figure 5.7 is the final 'best fit' curve. It provided the best fit for average rain events producing 1000m^3 to 2500m^3 of aggregate drain flow but was slightly less accurate for extreme events of 4000m^3 to 5000m^3.

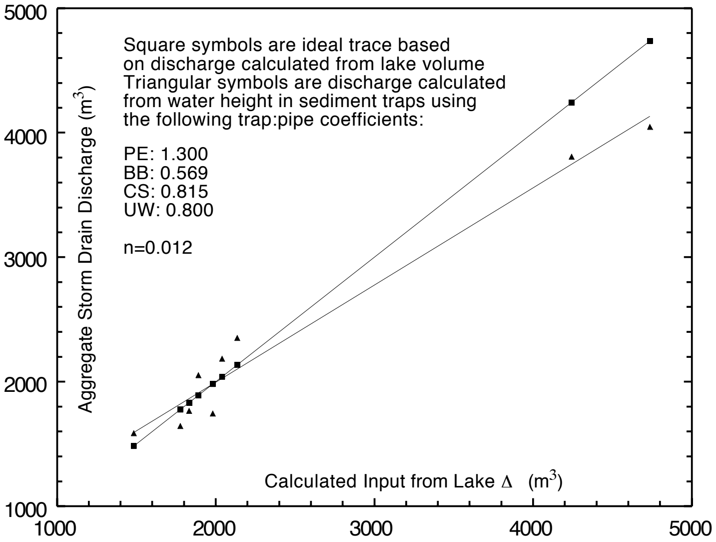


Figure 5.7 Aggregate PE, BB, CS & UW drain discharge plotted against estimates of drain discharge from lake volume change for 9 storm events. The figure includes the final trap:pipe coefficients used to compute all East Lake storm drain discharge volumes. Despite their frequent transition to supercritical flow the BB, CS and UW trap:pipe relationships were most accurately described by linear expressions which appeared to represent an averaging of both flow regimes (refer Appendix 5.1 Table 1). Appendix 5.1 details the calibration process and includes additional examples of other aggregate discharge 'close fits'.

Calibration of this sort is difficult. Only a limited number of distinct rain events were suitable for estimating drain discharge. During any given rain event, there will typically be a very high degree of areal variability (Chow 1964, Viessman *et al* 1989, Smith in Maidment 1993). Therefore for rainfall events of equal magnitude (as apparent discharge recorded at East Lake), the ratios of discharge between different drains will almost certainly be different. Our models account only for rainfall falling on the lake surface (lake area computed at post storm stage). During intense rain surface run-off was occasionally observed from the car parks around the southeast side of the lake and from mud flats on the lake. The small (225mm) AB drain (Figure 5.1a) receives run-off from Alderbury Street and was ungauged. Most if not all of its discharge never reaches the main body of the lake. These additional inputs are small and were ignored in the final calculations. The PE drain calibration had to accommodate inputs from Meagher Drive and the stadium car park which enter the pipe between the sediment trap and the lake. Similar rainfall was assumed for the drain catchment and Meagher Drive. Placing the float arm logger at the pipe exit therefore allowed these additional inputs to be included in the trap:pipe rating curve.

Undoubtedly the greatest single impediment to accurate discharge estimation was the extreme pipe gradients in the BB, CS and UW drains. There are cost advantages for engineers to use smaller diameter pipes at steeper gradients as opposed to larger diameter pipes at lower gradients (Cedergren 1989). Supercritical flow is also often used to ensure self cleaning (Lagvankar & Velon 1992). Where drains enter wetlands however high gradients and velocities induce unnecessary scour and erosion (Water and Rivers Commission 1998a). The use of smaller diameter pipes may reduce excavation costs and the higher velocities achieved at supercritical flow scour sediment from the system.

The BB drain carries significant amounts of water from the stadium complex. It comprises a complicated series of daisy chained sediment traps and pipe gradients which induce critical flows during many storm events. Calibration relied solely on the floating arm logger as access to the pipe network was impossible during storm events and the final outlet was below the level of East Lake (Appendix 5.1, Figure 2). Polynomial and linear expressions were used to estimate the average relationship between water depth in the sediment trap and the outlet pipe. In the final integrated calibration (Figure 5.7) a linear relationship was employed. Appendix 5.1 details the calibration during sub-critical and supercritical pipe flow.

Similarly the CS and UW drains (0.385m diameter), also oscillate between sub-critical and supercritical flows during typical rain events, however unlike the BB drain, they contribute only a small proportion of total drain input. Approximate trap:pipe coefficients were calculated from manual measurements and then adjusted in the final calibration.

Calculation of Flow Volumes West Lake

Computation of discharge volumes in West Lake utilised Microcom 'II Study' software employing Manning's equation. The software automatically computes total discharge for any given period, in this case each daily balance period. The optimal value for Manning's 'n' was determined from independent estimates of drain discharge computed manually using integration by rectangles. These were computed for 14 discreet rain events using the same lake volume change methodology applied at East Lake. Flows for the same events were computed using the 'II Study' software with Manning's 'n' set at 0.010 to 0.013. This calibration exercise indicated that for discreet events of less than 3000m^3, 'n' should be set at 0.011, corresponding to the 'normal' value for concrete pipes free of debris (Chow 1959). Discharge events exceeding 3000m^3, were calculated at 'n' of 0.010 corresponding to Chow's 'minimum' value for drains of this construction. Calibration details are included as Appendix 5.1.

Estimation of Missing Data

Balance periods 1-5 for East Lake and 1-6 for West Lake (Appendices 6.2 & 6.3) predate complete instrumentation of the drains. Estimates of total drain inputs for each lake for rain events during these balance periods were calculated using relationships derived from rainfall versus total measured drain flow (Appendix 5.2). In East Lake, estimated totals were also used to calculate UW drain volumes for rain periods 011-016 which preceded instrumentation of the UW drain and periods 085-092 where the UW measured volumes appeared too great, due to a fouled probe sensor.

5.7 SOLUTE AND ISOTOPIC SAMPLING

East and West Lake were sampled daily at 08:00. East Lake was sampled at a point in the centre of the South Basin by tapping water pumped continuously for the isotope experiments (Figure 5.1a). West Lake was sampled manually at a depth of 0.1m adjacent to the staff gauge. Two 10ml vials were collected from each lake daily. Details on the isotopic sampling of rainfall, top up water and groundwater appear in Chapter 6.

CHAPTER

6

WATER BALANCE INTEGRATION

6.0 INTRODUCTION

The theory of integrating measured mass components of the water balance with solute and stable isotope balances is introduced. The methodology by which this was achieved at Perry Lakes is discussed and integrated balance data presented. Groundwater recharge and discharge (which are the only components of the water balance not directly measured) are estimated.

6.1 SIMULTANEOUS MULTIPLE BALANCES

6.1.1 Theory

Chapter 4 discussed the uncertainties in measuring the mass components of any water balance. At Perry Lakes groundwater recharge and discharge are the only mass components which were not easily directly measured. Perry Lakes are not alone in this deficiency. As Winter (1981, p82) points out 'the interaction of lakes and ground water is the most elusive factor of all'. Table 6.1 summarises the water balance components and their associated solute and stable isotopic values measured at Perry Lakes.

Table 6.1 Water balance components measured

Component	Mass	Cl	^{2}H	Heat	Comments
Lake volume	X	X	X	X	Data logger (20 minutes), daily manual lake stage
Rainfall	X	X	X	X	Daily manual (4 in-lake) gauges
Storm drains	X	X	X	X	Continuous data logger (1 & 2 minute data)
Summer top up	X	X	X	X	Flow meters, read daily
Groundwater discharge		X	X	X	Estimated by integrated mass-solute-isotope balance
Groundwater recharge		X	X	X	Mass bal (R regimes) integrated bal (FT regimes)
Evaporation	X		X		Daily, floating Class A pan
Transpiration	X				Estimated by water table techniques, logger data

It is clear that while groundwater recharge and discharge mass could not be measured, their associated solute and stable isotope signatures were easily measured. This points out the advantage in simultaneous multiple balances. Stable solutes such as chloride are conserved during evaporation and transpiration, becoming concentrated in the lake waters. Stable isotopes on the other hand, fractionate during evaporation. Both impart different, but predictable signatures on the residual lake water.

Solutes and isotopes therefore provide complementary information on mass balance components (Townley *et al* 1993b, p30). In so doing they allow difficult to measure components (such as groundwater) to be better estimated.

6.1.2 Simultaneous Multiple Balances

The mass balance for East Lake may be written:

$$\Delta S = S_i + P + GW_i - S_o - E - E_t - GW_o \tag{6.1}$$

where

ΔS = change in surface water storage

S_i = all surface water inflows (storm drains, surface run-off)

P = precipitation

GW_i = groundwater discharge from the aquifer through the lake lining

S_o = all surface water outflows (there are none at Perry Lakes)

E = evaporation

E_t = evapotranspiration from emergent vegetation

GW_o = groundwater recharge from the wetland directly to the aquifer

Each mass balance comprised a time interval of 'one Perry Lakes day' which commenced and ended at 08:00 hr. Area and storage volume were calculated from the lake stage at the end of each balance period. Water volume (with units of m^3) was used as a proxy for mass. This was for computational convenience and was considered acceptable since over the annual observed water temperature range of 15˚C to 35˚C thermal expansion results in a stage increase of about 0.5mm at lake stage 3.0m. This lies within the reading error of manual stage measurement. It should always be remembered however that it is mass NOT volume which is actually conserved. In all formulae which follow 'mass' was measured as volume (ignoring temperature and density). Thermal expansion and water density effects are further explored in Chapters 7 & 10.

Under flow-through regimes all mass components except groundwater discharge and recharge were measured directly. When the lakes were in recharge, this component (recharge) was estimated as the residual in the mass balance.

Rearranging (6.1) and ignoring E_t the mass balance becomes:

$$\Delta S - [S_i + P] + E = GW_i - GW_o \qquad (6.2)$$

Expanded and expressed in words this becomes:

$$\left[\left(Vol_{final}\right) - \left(Vol_{initial}\right)\right] - \left[\left(drains\right) + \left(top\,up\right) + \left(rain\right)\right] + (evap) = \left(Gw_{in} - Gw_{out}\right) \qquad (6.3)$$

No groundwater discharge mass was measured directly. The term $-Gw_{out}$ is designated the 'apparent groundwater flux' in Appendices 6.2 and 6.3. It represents the residual in the mass balance. Under recharge flow regimes it represents an estimate of lake water recharged to the aquifer. Under flow-through conditions it is the difference between recharge and discharge. A mass balance alone, cannot differentiate groundwater flux components. Only by integrating complementary solute and isotope data can all components be estimated.

The chloride balance may be expressed as: (6.4)

$$\left[\left(Vol_{final}\right)*\left(Cl_{final}\right) - \left(Vol_{initial}\right)*\left(Cl_{initial}\right)\right] - \left[\left(drains\right)*\left(Cl_{drains}\right) + \left(top\,up\right)*\left(Cl_{outlet\,A}\right) + \left(top\,up\right)*\left(Cl_{outlet\,B}\right) + \left(rain\right)*\left(Cl_{rain}\right)\right] = \left[\left(Gw_{in}\right)*\left(Cl_{in}\right) - \left(Gw_{out}\right)*\left(Cl_{lake\,av}\right)\right]$$

Note that top up outlets have separate chloride values and that the recharge term $\left(Gw_{out}\right)$ has a chloride value equal to the lake average for the period. Each term has the form $mass\left(m^3\right)*Cl\left(mg\,L^{-1}\right)$ yielding units of grams of chloride. Values for all terms, including $\left(Cl_{in}\right)$ and $\left(Cl_{lake\,av}\right)$ are known. The only unknowns are the mass terms $\left(Gw_{in}\right)$ and $\left(Gw_{out}\right)$. Rearranging yields:

$$\left(Gw_{out}\right)=\left(Gw_{in}\right)*\left(Cl_{in}\right)-\frac{\left[\left(Vol_{final}\right)*\left(Cl_{final}\right)-\left(Vol_{initial}\right)*\left(Cl_{initial}\right)\right]-\left[\left(drains\right)*\left(Cl_{drains}\right)+\left(top\,up\right)*\left(Cl_{outlet\,A}\right)+\left(top\,up\right)*\left(Cl_{outlet\,B}\right)+\left(rain\right)*\left(Cl_{rain}\right)\right]}{Cl_{lake\,av}} \tag{6.5}$$

For any given balance period, (6.5) defines a family of chloride balance solutions where for any value of $\left(Gw_{in}\right)$, a value of $\left(Gw_{out}\right)$ can be defined.

Chloride is a conservative solute. It is essentially non reactive and not influenced significantly by biological or chemical proccess (in particular evaporation) within a watershed or water body (Schwartz & Gallup 1978). Therefore (6.5) requires no evaporation term. On the other hand deuterium and other isotopes such as oxygen 18 are non conservative. Various physiochemical processes including changes of state, and chemical and biochemical transformations can result in isotopic fractionation (Clark & Fritz 1997). In water balance studies evaporation is the principal fractionation process of interest (Townley et al 1993b) so an evaporation term must be included in the balance equation. Again $\left(Gw_{out}\right)$ has a deuterium value equal to the lake average for the period. Each deuterium term takes the form $mass\left(m^{3}\right)*\left(1+\delta\right)$ and the deuterium balance becomes:

$$\left[\left(Vol_{final}\right)*\left(1+\delta_{final}\right)-\left(Vol_{initial}\right)*\left(1+\delta_{initial}\right)\right]-\left[\left(drains\right)*\left(1+\delta_{drains}\right)+\left(top\,up\right)*\left(1+\delta_{outlet\,A}\right)+\left(top\,up\right)*\left(1+\delta_{outlet\,B}\right)+\left(rain\right)*\left(1+\delta_{rain}\right)\right] \tag{6.6}$$
$$+\left[\left(evaporation\right)*\left(1+\delta_{E}\right)\right]=\left[\left(Gw_{in}\right)*\left(1+\delta_{Gw\,in}\right)-\left(Gw_{out}\right)*\left(1+\delta_{lake\,av}\right)\right]$$

Rearranging:

$$\left(Gw_{out}\right)=\left(Gw_{in}\right)*\left(1-\delta_{in}\right)- \tag{6.7}$$
$$\frac{\left[\left(Vol_{final}\right)*\left(1+\delta_{final}\right)-\left(Vol_{initial}\right)*\left(1+\delta_{initial}\right)\right]-\left[\left(drains\right)*\left(1+\delta_{drains}\right)+\left(top\,up\right)*\left(1+\delta_{outlet\,A}\right)+\left(top\,up\right)*\left(1+\delta_{outlet\,B}\right)+\left(rain\right)*\left(1+\delta_{rain}\right)\right]+\left[\left(evap\right)*\left(1+\delta_{E}\right)\right]}{\left(1+\delta_{lake\,av}\right)}$$

An isotope (deuterium or ^{18}O) balance is simply a variation of the chloride balance but has a particular quirk with the use of the delta ('δ') notation, defined as the relative difference in the ratio (R)of deuterium (or ^{18}O) to the more abundant light isotope, measured relative to the reference ocean water VSMOW (Clark & Fritz 1997):

$$R = ratio\left[\frac{^{2}H}{^{1}H}\right] \quad \text{or} \quad R = ratio\left[\frac{^{18}O}{^{16}O}\right] \tag{6.8}$$

In the case of deuterium (^2H) is 155.76‰ VSMOW. This notation may be thought of as being the gram atoms of deuterium per litre. Using delta notation:

$$\delta_{sample} = \left[\frac{R_{sample} - R_{VSMOW}}{R_{VSMOW}}\right] \tag{6.9}$$

or, written per mille (‰) becomes:

$$\delta_{sample} = \left[\frac{R_{sample}}{R_{VSMOW}} - 1\right] * 1000‰$$

(6.10)

This means that

$$1 + \delta_{sample} = \frac{^{2}H_{sample}}{^{1}H_{VSMOW} + ^{2}H_{VSMOW}}$$

(6.11)

which is the grams of deuterium per grams of hydrogen (protons and deuterons) in the water. The process may be visualised by converting delta notation to ppm deuterium. The R value of VSMOW is equivalent to 155.76 ppm deuterium ($\delta = 0‰$). Therefore when water has a delta value of 0.00‰, we are simply describing water with an isotopic ratio equal to VSMOW. Substituting into (6.10):

$$\delta = \left[\frac{155.76}{155.76} - 1\right] * 1000‰ \quad = 0‰$$

(6.12)

What should be clear however is that the $(mass)*(1 + \delta)$ notation is describing water with deuterium greater or less than 155.76 ppm, the range of natural waters being approximately 90-165 ppm (Clark & Fritz 1997). For any given balance period, (6.7) defines a family of deuterium balance solutions where for any value of discharge (Gw_{in}), a value of recharge (Gw_{out}) can be defined.

6.2 METHOD

All balances were completed within a strict framework of balance 'periods' (refer Appendices Chapter 6). Each period was 12, 16 or 20 days long and consisted of 3, 4 or 5 sub-balance periods of exactly four days. A balance 'day' started and ended at exactly 08:00 hours. The division between balance periods was dictated by rainfall and storm drain flow. Each period starts and ends in a dry period.

Mass balances were computed daily. Water from both lakes was sampled daily but deuterium and chloride analyses were completed only every four days. Mass, chloride and deuterium were integrated for each of these four day 'sub-balance' periods. The chloride and deuterium were therefore known at the start and end of each four day period, allowing an 'average' figure to be calculated for recharge. They appear in the denominators of Equations (6.5) and (6.7).

In East Lake four day integrated mass-solute and isotope balances were completed from balance periods 4 to 50 (146 sub-balances). East Lake was in a recharge condition for balance periods 1 to 3 which were computed by mass balance only. West Lake chloride was analysed from August 1996 to March 1997 only, covering the transition from lake (winter maximum) to residual sump (summer minimum). Integrated balances cover periods 11-19A only. In West Lake chloride was analysed every 12 days (start and end of each balance period) while deuterium was analysed every four days. Four day sub-balances (using interpolated Cl estimates) and twelve day balances are included in Appendix 6.3. The two methods result in only small differences in estimated groundwater flux. Figure 6.1 shows the 50 balance periods and the distribution of mass, deuterium and chloride measurements.

Equations (6.5) and (6.7) were applied to each four day sub-balance period (Appendices 6.2 and 6.3). For each equation a range or 'family' of estimates of groundwater recharge was used to calculate a corresponding range of values for groundwater discharge. These estimates of recharge and corresponding discharge plot as straight lines. The deuterium solutions comprised two solution 'sub-families', computed using δ_E derived experimentally specifically for Perry Lakes from pan experiments (Chapter 12), and δ_E calculated empirically using experimentally determined values of δ_A (refer also to Chapter 12) and Equation 23 of Craig & Gordon (1965). The groundwater flux estimates presented in Table 6.2 and Appendices 6.2 and 6.3 all utilise the experimentally derived values of δ_E . Final balance integration was done both graphically and algebraically by solving for the intersection of the two linear equations (6.5) and (6.7). The intersection of the chloride and isotope curves indicates a unique solution for discharge and recharge. Solutions calculated using empirically and experimentally determined δ_E typically varied by less than 2%. In the examples shown in Figure 6.2, the differences range from 0.07% (recharge sub-balance 33B) to 1.8% (discharge sub-balance 33E). At transition to flow-through (Figure 6.2b) calculated groundwater discharge figures are sometimes very small, in sub-balance 33D for example, being 22 and 25m^3. Here the apparent differences can become larger however when compared to the other inputs (in this case rain and storm water totalling 3440m^3) such differences become insignificant.

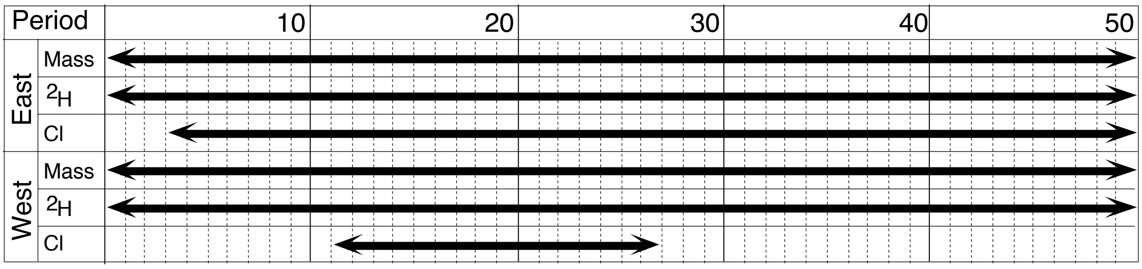


Figure 6.1 Distribution of mass, deuterium and chloride balances over 50 balance periods (vertical lines). Integrated mass - solute - isotopic balances were completed for all balance periods where all three components were measured.

Three basic flow regime states were identified.

Recharge Regimes (Figure 6.2a)

Lake water is recharged to the aquifer. No groundwater is discharged into the lake. The mass balance therefore contains only one unknown (recharge) which is solved as the residual of the mass balance. Similarly chloride and deuterium are solved for zero discharge. The chloride and deuterium solutions plot as parallel (or near parallel) lines, their y intercepts being recharge. Here mass, solute and isotope balances provide three independent estimates of recharge, allowing an average 'best estimate'.

Transition to Flow-through (Figure 6.2b)

The transition between regimes is marked by oscillation between weak flow-through and recharge. These are common over winter when heavy rain and storm drain inputs push the lake into or close to recharge. The temporal resolution of our integrated balances was four days. At this scale it was not possible to resolve short term detail.

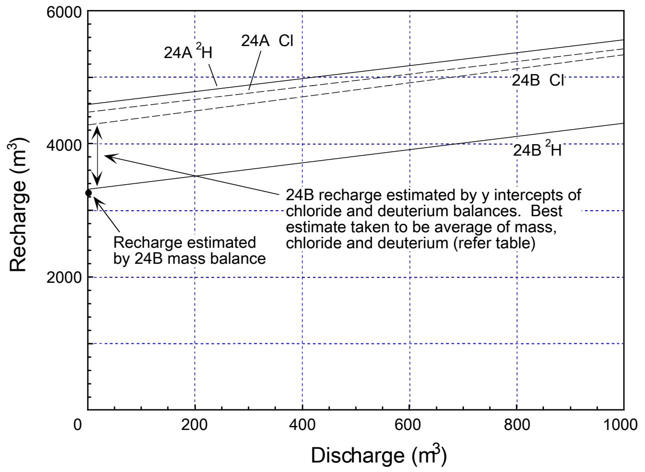
Flow-through Regimes (Figure 6.2c)

Groundwater is discharged into the lake and lake water is recharged to the aquifer. The mass balance therefore contains two unknowns and cannot be solved. Chloride and deuterium balance solutions plot as intersecting lines. The intersection (representing the solution to two linear equations) describes a unique solution satisfying the conservation of both chloride and deuterium.

Mass, Solute & Isotope Data Graphical Integration

Figure 6.2

A Recharge Regime

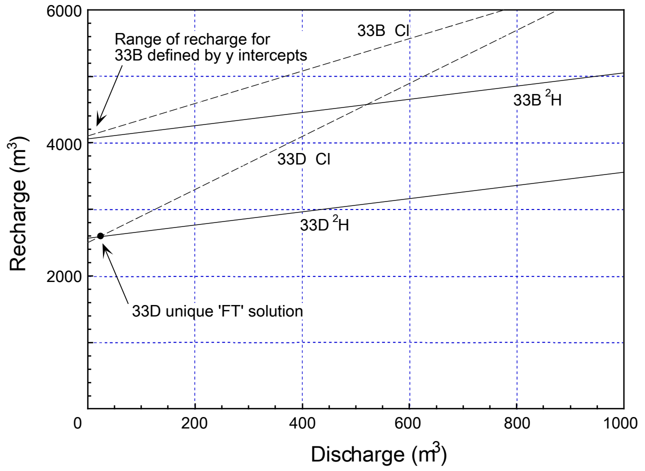


Under recharge ('R') regimes only groundwater recharge occurs. Discharge = 0. Each line represents solutions for groundwater recharge & discharge however we only consider the 'y' intercept which provides independent chloride and deuterium balance solutions for discharge. The mass balance provides a third solution.

Discharge (Gw IN) & Recharge (Lw OUT), m^3

Sub-balance	24A	(Feb 97)	24B	(Feb 97)
	Gw IN	Lw OUT	Gw IN	Lw OUT
Mass	0	4647	0	3293
Chloride	0	4490	0	4274
Deuterium	0	4602	0	3339
Deuterium*	0	4632	0	3362
Average		4579		3635

B Transition to Flow-through

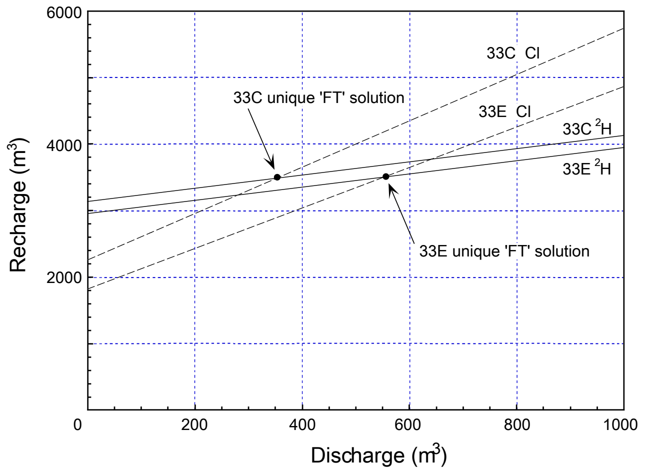


Transition between regimes is frequently marked by oscillation between weak flow-through ('FT') and recharge ('R'). Sub-bal 33 is 'R' but with 'FT' about to commence (Sub-bal 33C below). This in turn oscillates around the transition in 33D, which is very weakly FT.

Discharge (Gw IN) & Recharge (Lw OUT), m^3

Sub-balance	33B	(Jun 97)	33D	(Jun 97)
	Gw IN	Lw OUT	Gw IN	Lw OUT
Mass	0	4049	0	2568
Chloride	0	4102		
Deuterium	0	4057	22	2607
Deuterium*	0	4060	25	2621
Average		4069		

C Flow-through Regime



Each Cl & deuterium line represents an infinite family of possible solutions. Their intersection is a unique solution satisfying both balances.

Balance 33 marked the 1997 transition from summer recharge regimes to winter flow-through regimes.

These data represent typical FT results

Discharge (Gw IN) & Recharge (Lw OUT), m^3

Sub-balance	33C	(Jun 97)	33E	(Jun 97)
	Gw IN	Lw OUT	Gw IN	Lw OUT
Mass	0	3194	0	2970
Chloride				
Deuterium	355	3502	554	3513
Deuterium*	357	3511	564	3543

Key to graphs

- - - - - - - - Chloride

——————— Deuterium & Deuterium*

'Deuterium' solutions calculated using $\delta_{E(lake)}$ calculated from pan experiments at Perry Lakes

'Deuterium*' solutions calculated using Equation 23 of Craig & Gordon (1965)

6.3 RESULTS

Results are summarised by balance period in Table 6.2 and graphically in Figures 6.3 to 6.5. Appendices 6.2 and 6.3 contain daily mass balance and four day integrated balance calculations. They include all of the information required to complete each balance including solute and isotopic data.

Water balance studies generally are subject to incomplete data sets (Winter 1981). Most are mass only or mass and solute or mass and isotope balances. The single factor which makes the Perry Lakes study unique is the degree to which individual mass, solute and isotopic components have been independently measured. At Perry Lakes ALL mass components and their associated solute and isotopic signatures have been individually measured or experimentally derived including δ_A and δ_E (refer Chapter 12) Under flow-through regimes ONLY the mass of groundwater discharge and recharge are unknown. Under recharge regimes lake water recharged to the aquifer is the residual of the mass balance. This combined with independent solute and isotopic balances provides a highly accurate 'best estimate' average. In other words under recharge conditions there are really no unknowns although the recharge component is not directly measured. The integrated balances were not applied 'blindly'. Much additional information provided independent clues to likely lake-aquifer relationships. These include detailed lake stage and water table measurements, nested piezometers, in lake 'mini piezometers', irrigation pumping records and storm water and top up records. These are explored in detail in Chapter 7.

The single most significant result of the integrated balances is the non symmetrical nature of East Lake under flow-through conditions. It was assumed that groundwater discharge and recharge would be similar, more or less balancing each other. The data (Figure 6.3) shows that recharge always exceeded discharge. This pattern was established early in the winter and prevailed over both 1996 and 1997. The pattern was more pronounced in 1996 (when heavy lake maintenance top up commenced early in the summer) as compared to 1997 (when the lake was allowed to approach dryness naturally). Data for West Lake in 1996 (Figure 6.5) is similar to East Lake.

The ratio of recharge to discharge $Gw_{out}:Gw_{in}$ is one of a number of dimensionless ratios useful in describing flow regimes. Mathematical models (Nield *et al* 1994) have been restricted to $Gw_{out}:Gw_{in}$ in the range -2.0 to +2.0 (Nield *et al* use the notation U-:U+). These are more fully explored in Chapter 7. Table 6.3 shows that East and West Lake largely operated outside that range. This indicates that for most of each winter the lakes were always close to or approaching recharge status. The dividing stream line lay close to the up gradient shore in each lake, an observation confirmed experimentally using mini piezometers (Chapter 7).

Table 6.2 Integrated Balance Summary

East Lake

Bal	Start Date	Days	Med Area	Med Vol	Evap	Rain	Drains	Top Up	Gw IN	GW Out	Total Flux
1996											
1	April 22	12	43650	11072	1358	35	27	23265	0	26963	51648
2	May 04	12	40397	9025	930	923	3165	12175	0	14483	31676
3	May 16	12	42855	10459	996	128	222	25850	0	23198	50394
4	May 28	12	39690	8748	965	1496	2344	14075	0	22722	41602
5	June 09	16	40108	9040	820	5414	11718	0	600	10738	29290
6	June 25	12	46115	12514	968	3396	5994	0	421	8030	18809
7	July 07	12	47747	13620	1145	2923	4951	0	1146	7059	17224
8	July 19	20	52517	17852	2149	6495	10623	0	835	8552	28654
9	August 08	12	55973	20963	1395	2086	2859	0	216	5194	11750
10	August 20	12	55415	20238	1335	1759	2311	0	499	4083	9987
11	September 01	12	56191	21224	1679	2681	4103	0	396	3029	11888
12	September 13	12	57565	22949	2317	2357	3379	0	532	3689	12275
13	September 25	12	57430	22778	2216	1164	1702	0	1148	3176	9406
14	October 07	12	55577	20506	2397	435	419	60	787	2470	6568
15	October 19	12	55257	20110	2952	2081	2730	4714	55	4269	16801
16	October 31	12	56293	21382	3140	748	1005	5129	1069	4685	15776
17	November 12	12	55276	20139	3142	2250	3592	538	722	7110	17354
18	November 24	16	53162	18015	2788	267	265	12931	867	13277	30395
19	December 10	12	49732	15271	4062	327	390	8905	0	9206	22890
1997											
20	December 22	12	44775	11672	3728	0	0	8477	0	8156	20361
21	January 03	12	40989	9336	3356	0	0	13038	0	11285	27679
22	January 15	12	38921	8175	2840	12	0	11957	0	10479	25288
23	January 27	12	28627	4978	2092	0	0	5728	0	9170	16990
24	February 08	12	25887	3702	2060	10	0	17267	0	12668	32005
25	February 20	12	38300	8093	1489	41	45	21923	0	14466	37964
26	March 04	12	26336	5826	1548	7	0	2017	0	10911	14483
27	March 16	12	17723	2028	1292	174	570	17420	0	13563	33019
28	March 28	12	31420	5034	1468	3291	7235	10251	0	15136	37381
29	April 09	12	36197	6666	1209	542	947	21079	0	14413	38190
30	April 21	12	31634	5120	801	427	864	4896	0	8473	15461
31	May 03	12	27173	3555	645	62	247	7489	0	6940	15383
32	May 15	12	26389	3385	658	845	2004	7650	0	9872	21029
33	May 27	20	35832	7906	1361	6264	12389	9558	931	18103	48606
34	June 16	12	41610	9841	726	338	303	95	230	5975	7666
35	June 28	12	38650	8037	769	1957	4229	0	265	3773	10993
36	July 10	12	39593	8566	772	876	1806	0	176	3037	6667
37	July 22	12	38661	8014	941	1079	1778	0	315	2402	6515
38	August 03	16	43803	11248	1615	4088	7763	77	1582	5154	20279
39	August 19	12	48688	14266	1381	758	1226	0	1455	2602	7422
40	August 31	12	54920	20856	1645	6665	11965	0	1489	4757	26521
41	September 12	12	60060	25909	2198	47	31	0	790	2334	5400
42	September 24	12	57074	22255	2644	154	138	0	1510	2767	7213
43	October 06	12	55180	19962	2948	1523	2298	0	1716	3609	12094
44	October 18	12	51547	16734	3180	75	73	0	1158	3865	8351
45	October 30	12	44418	11548	2837	0	0	0	70	2193	5100
46	November 11	12	37620	7557	2206	190	451	0	272	1850	4969
47	November 23	12	29286	4441	1951	43	36	0	0	1337	3367
48	December 05	12	16476	1754	1336	0	0	0	0	1059	2395
49	December 17	8	10419	812	645	0	0	2220	0	1145	4010
1998											
50	December 25	9	10593	831	686	0	0	2352	0	1953	4991

West Lake

Bal	Start Date	Days	Med Area	Med Vol	Evap	Rain	Drains	Top Up	Gw IN	GW Out	Total Flux
11	September 01	12	50648	14975	1499	2517	6423	0	544	4630	15613
12	September 13	12	52824	17045	2133	2221	6080	0	411	5665	16510
13	September 25	12	52358	16600	2041	1185	3714	0	691	5707	13338
14	October 07	12	49815	14266	2153	372	1243	0	55	2617	6440
15	October 19	12	48730	13210	2572	1734	4497	0	573	3387	12763
16	October 31	12	47408	12436	2703	653	2306	0	410	3101	9173
17	November 12	12	46686	12400	2750	1976	6262	0	2744	6668	20400
18	November 24	16	42318	9770	3417	341	870	0	2923	6243	13794
19A	December 10	4	36128	6694	727	231	709	0	965	1707	4339

Notes

All area in m^2, all volumes m^3
All balance periods commence and end at 08:00 hr on date shown
Total flux is the total of all in coming and out going fluxes
West Lake data based on 12 day Cl data prorated into 4 day sub balances (refer text)

It only required a small additional input of storm water to push the lake from flow-through into recharge status.

Table 6.3 Groundwater recharge:discharge $Gw_{out}:Gw_{in}$

Balance	East '96 $Gw_{out}:Gw_{in}$	West '96 $Gw_{out}:Gw_{in}$	Balance	East '97 $Gw_{out}:Gw_{in}$
5	17.9	-	33	19.5
6	19.0	-	34	26.0
7	6.2	-	35	14.2
8	10.3	-	36	17.3
9	24.1	-	37	7.6
10	8.2	-	38	3.3
11	7.7	8.5	39	1.8
12	6.9	13.8	40	3.2
13	2.8	8.3	41	3.0
14	3.1	47.5	42	1.8
15	77.3	5.9	43	2.1
16	4.4	7.6	44	3.3
17	9.8	2.4	45	31.3
18	15.3	2.1	46	6.8
19A	-	1.8	-	-

These data provide insights illustrating how urban wetlands have been hydrologically modified. Under natural conditions such wetlands had no riparian inputs. They were maintained solely by direct rainfall and groundwater discharge. Table 6.4 summarises East Lake balance hydrology for calendar year 1997. It must be remembered that 1997 was atypical because top up was withheld for about 8-10 weeks compared to 'normal' years. Despite this, 'non natural' drain and top up inputs comprise 41.7% of the total water budget and 83.6% of total inputs. Virtually all wetlands on the Swan Coastal Plain now operate as storm water infiltration basins. Introducing storm water fundamentally modifies the way a water table lake operates. Groundwater discharge is reduced and replaced by 'non natural' surface inputs. This also affects the lake chemistry since rain and groundwater usually have substantially different cation and isotope signatures.

Table 6.4 Total balance components East Lake 1997

	Rain	Drains	Top Up	Evap	GW Discharge	GW Recharge	Total 1997
Mass (m^3)	29,468	56,398	155,017	49,299	11,957	205,289	507,428
Percent	5.81	11.11	30.55	9.72	2.36	40.46	100.0
No av lake vol	3.2	6.1	16.7	5.3	1.3	22.1	54.6

Average lake volume is at mean annual stage: 3.215m, mean volume 9300m^3, mean area 40990m^2

Covers January 3, 1997 (start sub-balance 21a) to 4 January, 1998 (end sub-bal 50b).

In permanent Swan Coastal Plain wetlands under natural conditions it appears likely that flow-through regimes were maintained all year. During heavy rain events such lakes would move towards or possibly into recharge, but these excursions from flow-through regimes would be transient. The annual trace of lake stage would approximate a smooth

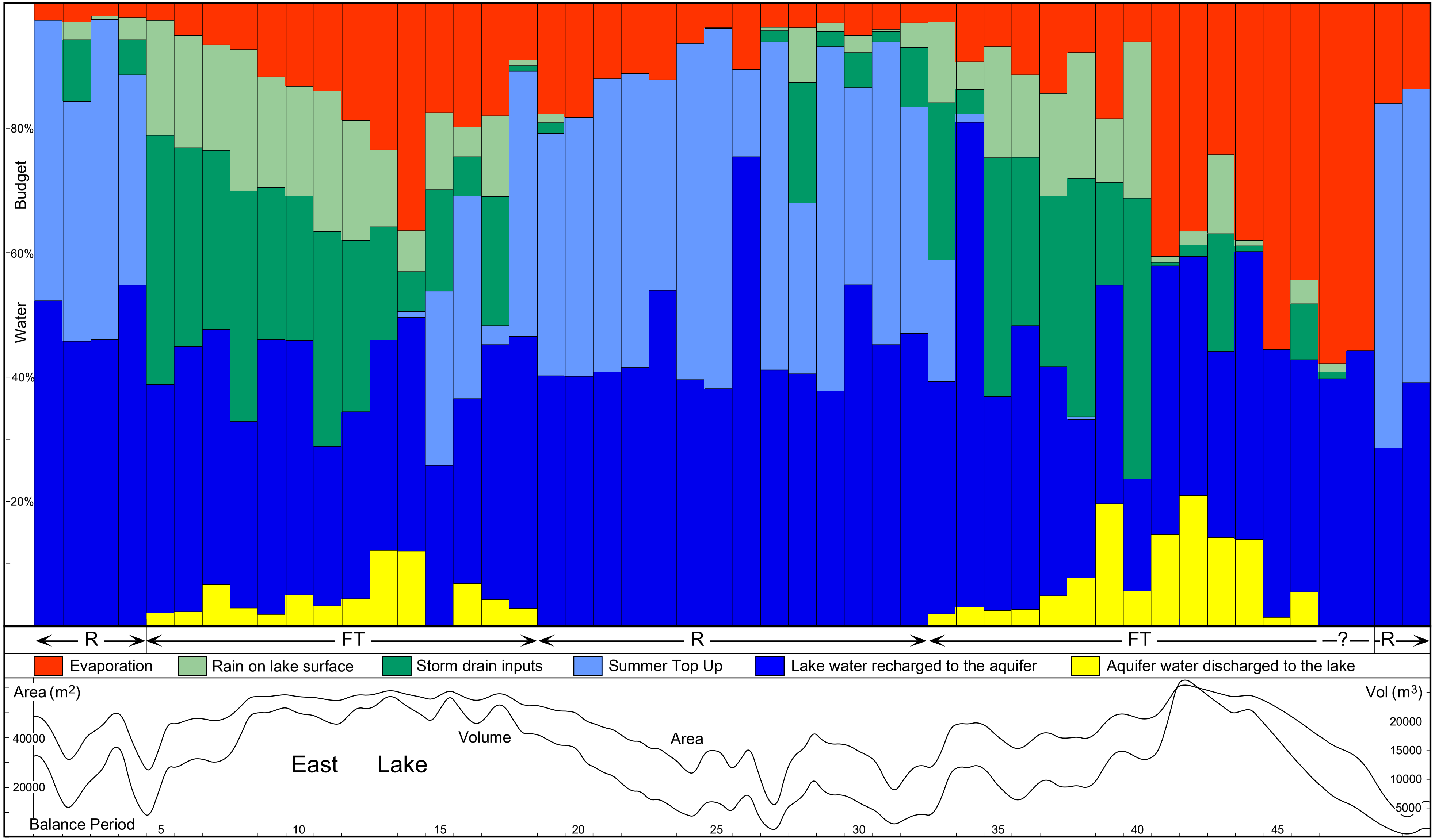
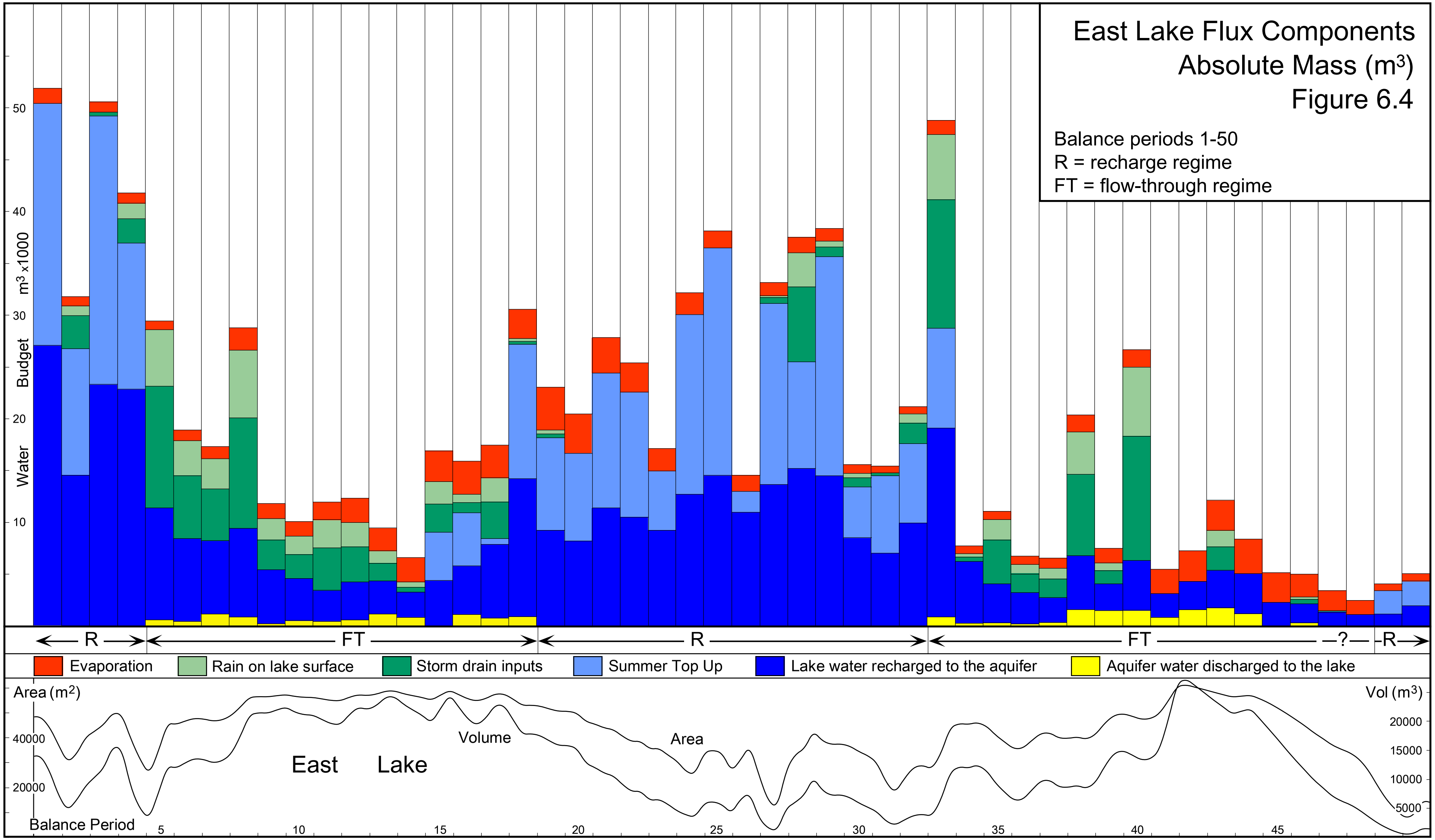

80%
60%
40%
20%
Water Budget
R
FT
R
FT
?
R
🟥 Evaporation
🟩 Rain on lake surface
🟩 Storm drain inputs
🟦 Summer Top Up
🟦 Lake water recharged to the aquifer
🟨 Aquifer water discharged to the lake
Area (m^2)
40000
20000
Vol (m^3)
20000
15000
10000
5000
Volume
Area
East Lake
Balance Period
5
10
15
20
25
30
35
40
45

Figure 6.3



East Lake Flux Components
Absolute Mass (m³)
Figure 6.4

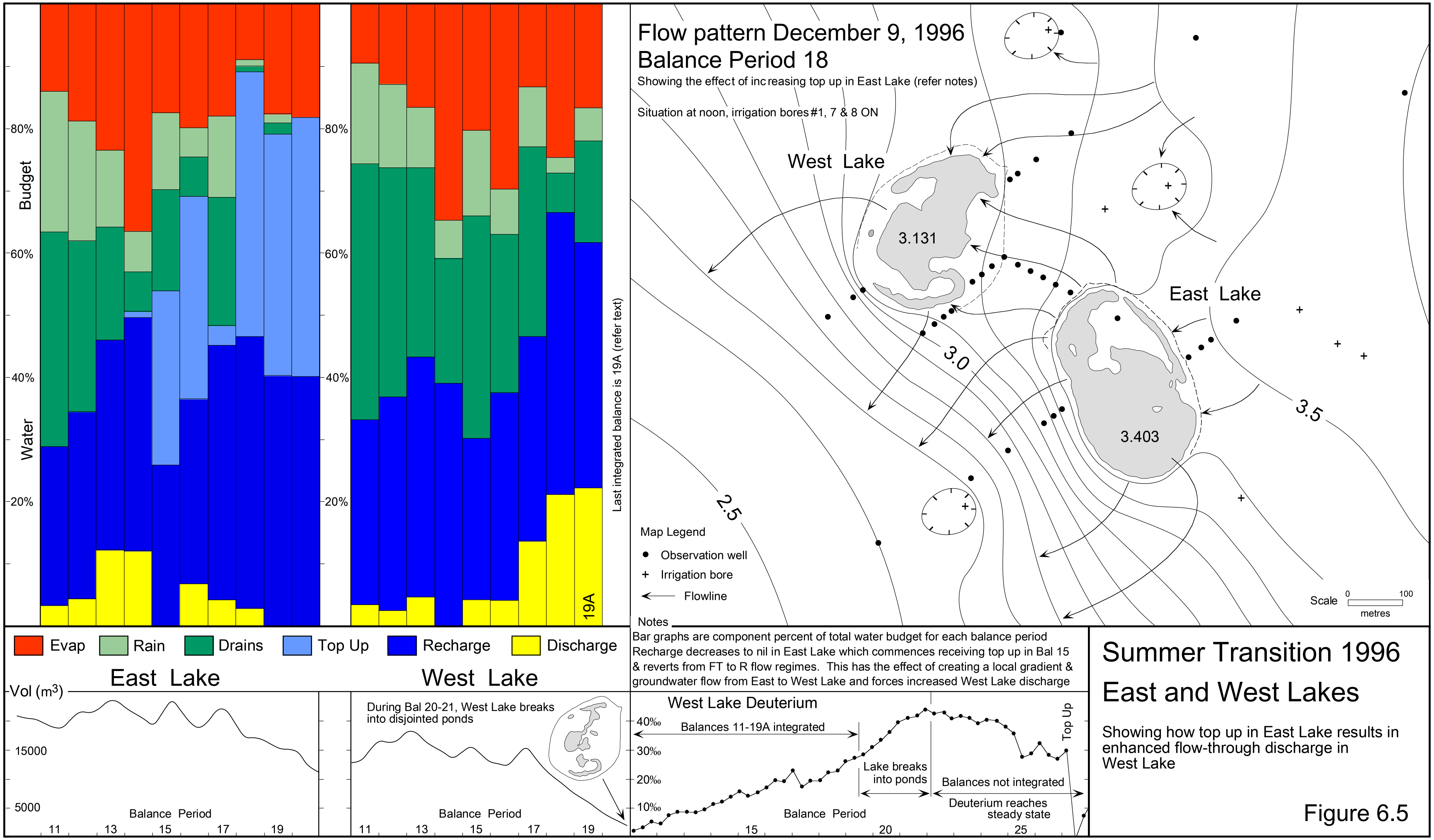
Balance periods 1-50
R = recharge regime
FT = flow-through regime

sinusoid, similar to seasonal fluctuations in the surrounding water table. Storm drains vastly increase the amount of rain water entering a wetland. These inputs are almost instantaneous and force the lake on numerous excursions towards or into recharge. The net result over winter is vastly reduced groundwater discharge compared to that which would have occurred under natural conditions.

Storm drains were introduced to Perry Lakes in the late 1950's (Chapter 2). We therefore have no lake stage records of either lake operating under natural conditions. The Camel Lake monitoring well W25 can be used to approximate natural lake stage patterns. The water table in W25 lies approximately 1m below surface and therefore responds quickly to precipitation. In Figure 6.6 (insert) continuous 5 year data logger data shows a sinusoid annual water table pattern. The water table responds to large rain events just as an adjacent lake would. A water table lake inserted into such an aquifer would function in a similar way. East Lake and W25 data logger records for calendar 1997 are superimposed. The W25 curve approximates the pre-urbanisation natural stage curve for East Lake. The most significant single feature in the East Lake data are the huge winter excursions above the 'natural' curve induced by storm drain inputs. Remember a 50mm rain event will only raise the lake surface of a natural wetland by 50mm, while a wetland acting as a retention basin is raised many times that amount. The 63.8mm event flagged in Figure 6.6 (combined with top up) raised the lake stage by over 300mm.

Figures 6.3 and 6.4 illustrate clearly the effects of early top up. In 1996 groundwater discharge into the lake is suppressed by the combined forces of early top up and lawn irrigation (commenced October 19, Balance Period 15). Extraction for lawn irrigation lowers the groundwater gradient to the east and increases it to the west, further suppressing discharge and enhancing recharge. By comparison, withholding top up in November and December 1997 significantly increased discharge, both as a percentage of the mass budget (Figure 6.3) and absolutely (Figure 6.4). If lawn irrigation extraction could also have been delayed the effect would have been even larger.

As East Lake approached dryness in December 1997, integrated balances show no discharge beyond lake stage 3.126m on November 23, sub-balance 46C (Appendix 6.2). Below this level the lake sits almost entirely within a clay lining. This, and the increasing influence of pump extraction probably combined to reduce discharge to negligible amounts. Mini piezometer surveys (Chapter 7) confirmed that positive piezometric heads were maintained on the east side of the lake until at least December 8 and negative piezometric heads persisted on the west side until top up commenced December 20. East Lake at no time became a discharge lake.

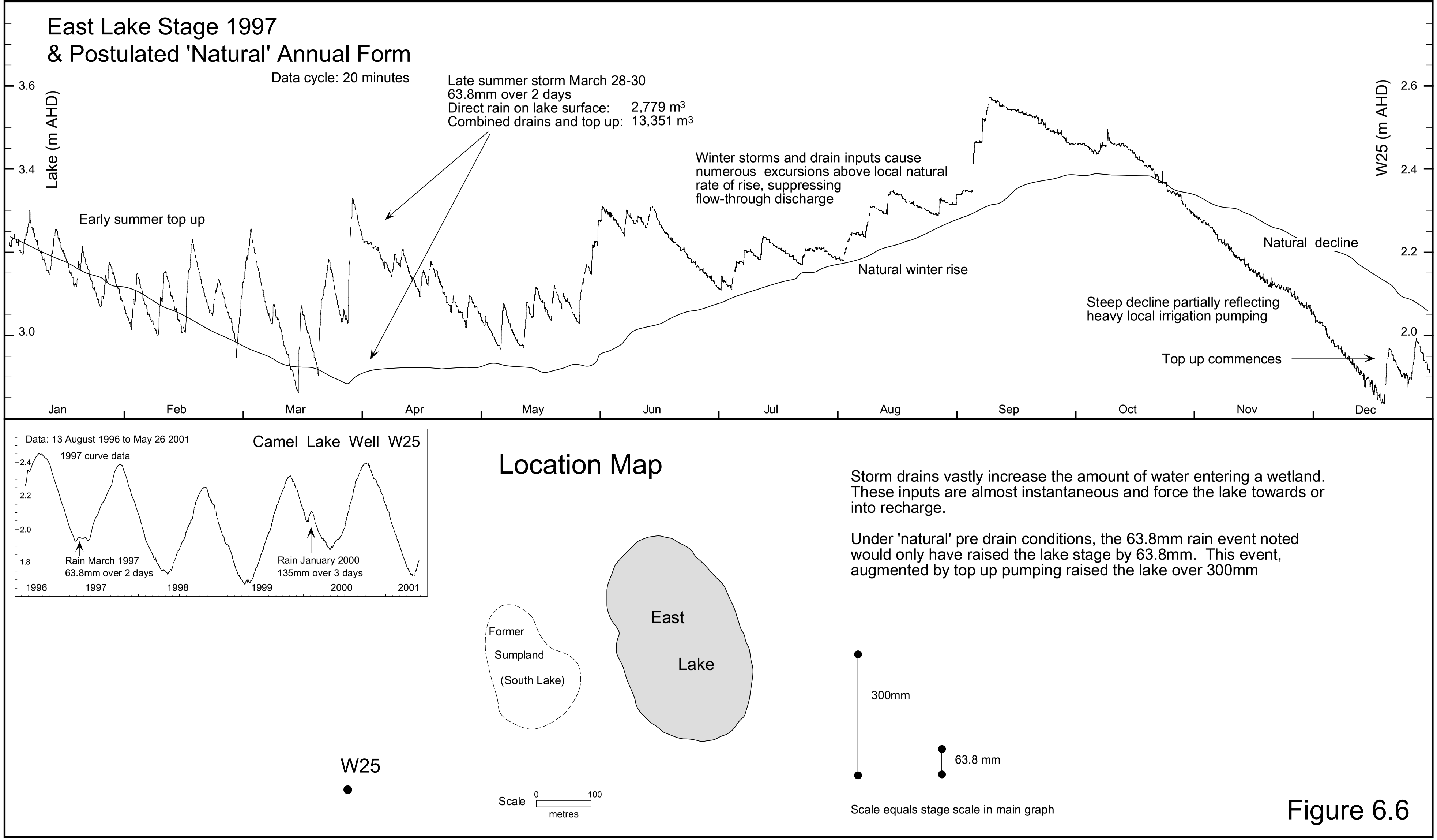


Notes
Bar graphs are component percent of total water budget for each balance period
Recharge decreases to nil in East Lake which commences receiving top up in Bal 15 & reverts from FT to R flow regimes. This has the effect of creating a local gradient & groundwater flow from East to West Lake and forces increased West Lake discharge

Summer Transition 1996
East and West Lakes

Showing how top up in East Lake results in enhanced flow-through discharge in West Lake

Figure 6.5



Storm drains vastly increase the amount of water entering a wetland. These inputs are almost instantaneous and force the lake towards or into recharge.

Under 'natural' pre drain conditions, the 63.8mm rain event noted would only have raised the lake stage by 63.8mm. This event, augmented by top up pumping raised the lake over 300mm

Figure 6.6

Figure 6.5 shows comparative water budgets for East and West Lake for September 01 to January 03 1996-97 (balance periods 11-20). As discharge diminished and then ceased in East Lake, it increased in West Lake. In East Lake, early top up suppressed and then halted discharge. East Lake became locally mounded, setting up a local inter-lake flow pattern. This local groundwater gradient was steeper than the regional gradient (already depressed by lawn irrigation pumping). The result was increased discharge into West Lake.

Chloride and deuterium data was available for West Lake to March 16, 1997 (Balance 27). Despite being a small residual 'sump', West Lake continues to function as a flow through lake over summer with discharge strongly influenced by top up events in East Lake and the constantly changing local water table gradient between the two lakes.

Figure 6.5 includes water table contours and flow patterns for December 9, 1996 within Balance 18. In East Lake excessive top up has suppressed the flow through regime and pushed the lake towards total recharge status. The East Lake stage is about 300mm above West Lake. This creates a pronounced groundwater gradient between the two lakes. Water recharged from East Lake flows towards West Lake augmenting natural discharge. In other words the effect of top up in East Lake temporarily increases the flow-through effect in West Lake. Unfortunately immediately after this (Balance 19A) West Lake broke up into a number of small disjointed ponds (refer insert map Figure 6.5). Balance computations were disrupted while the lake dried shrinking to just one residual pool in the southwest corner (Balance 21). From January 15 (Balance 22) onwards West Lake was one contiguous small pond, however isotopic balances could not be integrated with the mass and solute data because the deuterium in West Lake had reached a steady state value of about 40‰. (refer deuterium plot Figure 6.5). The lake was analogous to a constant feed evaporation pan with a small leak. Isotopic steady state is a common phenomenon in restricted water bodies such as evaporation pans and saline lakes (Gonfiantini 1986). We did not expect to see it in a freshwater lake. Extremely high deuterium enrichment has been reported in similar lakes (Fontes & Gonfiantini 1967) without steady state being achieved. These concepts are explored further in Chapter 12 where seasonal variations in isotopic steady state are used to determine isotopic exchange parameters.

6.4 MEASUREMENT OF CRITICAL BALANCE COMPONENTS

6.4.1 Groundwater Discharge (GW_{in})

Integrated balances require knowledge of the deuterium and chloride values of groundwater discharged to the lake. Two options were considered:

- periodic sampling of pore water in the lake sediments close to the up gradient shore
- periodic sampling of the aquifer up gradient of the lake

Krabbenhoft & Webster (1995) used average pore water samples. They point out however that lake bed pore water and samples from near shore piezometers may be quite different. This is probably due to flow reversal where former lake water enters the aquifer during a recharge regime and is subsequently discharged again to the lake when flow-through conditions are re-established. In Perry East pore water sampling was considered logistically impractical due to the constantly varying position of the 'shore'.

The 15 nested piezometer wells N1a-c to N5a-c were analysed for deuterium and chloride on 17 occasions (approximately monthly) between March 1996 and December 1997. An equivalent of three well volumes was bailed prior to sampling. Samples were collected from the screened sections using a position sampler. In addition irrigation bores within and in vicinity of Perry Lakes Reserve were also sampled. This was to provide data on the highly variable isotopic values noted in top up water (refer Section 6.4.2) and determine if Perry Lakes lay within the recharge plume from Herdsman Lake. Irrigation bores and piezometer samples for March 1996 were analysed for ^{2}H, ^{18}O and Cl. Remaining monthly piezometer samples (September 1996-December 1997) were analysed for ^{2}H, and Cl only. It was anticipated that wells in nests down gradient such as N4 might exhibit distinct seasonal changes in water chemistry reflecting summer solute and isotope enrichment. No obvious seasonal patterns were evident. Mean values appear in Tables 6.5 and 6.6. Note that there is a distinct isotopic enrichment in piezometers and bores down gradient from the lakes. These include N2, N4, N5 and P1.

Table 6.5 Mean deuterium and chloride, nested piezometers

Well	N1a	N1b	N1c	N2a	N2b	N2c	N3a	N3b	N3c	N4a	N4b	N4c	N5a	N5b	N5c
^{2}H	-10.7	-8.9	0.8	0.2	-2.5	-4.9	-12.5	-8.7	-13.3	-1.4	-2.2	0.3	-9.3	15.2	14.6
Cl	377	228	323	145	188	198	298	253	199	179	181	199	350	397	383

Deuterium permil (‰), Cl (mg/l)

Table 6.6 Deuterium and chloride, irrigation bores

Well	P1	P2	P4	P5	P6	P8	Ag Stn N	CSIRO
^{2}H	-2.0	-12.6	-16.9	-16.5	-13.3	-4.3	-14.9	-13.6
Cl	217	211	143	146	161	324	n/a	211

Plotting ^{2}H, ^{18}O relative to the Perth meteoric water line and considering Cl allows some conclusions to be drawn on the history of groundwater surrounding Perry Lakes. With reference to Figure 6.7 isotopically enriched water occurs down gradient from West Lake (N2) and East Lake (N4, N5 & P1). These wells lie within the lake discharge plumes.

There is a distinct chloride gradient reflecting the long term change in lake chloride chemistry discussed in Chapter 2. Waters in piezometer N5 contain chloride levels seldom encountered in East Lake today but which were common before the recent initiation of constant summer maintenance. Figure 2.14 shows that in the 1970's minimum winter chloride levels were about 200mg l^{-1} rising to 500 to 700mg l^{-1} over summer. Similar values probably persisted into the early 1990's. Now summer levels largely reflect local groundwater. Most top up water comes from P1 and P2. This is reflected in the mean summer chloride concentrations of around 180 to 200mg l^{-1}. Winter storm water dilutes this to about 30mg l^{-1}.

The isotopic data presents a similar pattern where the most isotopically enriched water occurs in N5. Up gradient of East Lake, N3 and all sampled bores (P4, P5 & P6) plot close to the Perth meteoric water line (MWL) and are considered to represent unevaporated groundwater (Figure 6.7). N1 displays increasing isotopic enrichment with depth, P8 is also enriched and both display elevated Cl. In contrast P2 displays little isotopic or solute enrichment. N1 and P8 may penetrate water evaporated from the former adjacent sumplands (now Alderbury Flats, refer Figure 6.7). Setting hydraulic conductivity at 10 to 30 m day^{-1} and assuming an effective porosity of 0.3 and gradients of 1 to 2m km^{-1} yields a seepage velocity range of approximately 12 to 72m y^{-1}. Considering that the swamps were filled in 1960-61 (refer Chapter 2), it could be argued that this evaporated groundwater must have another source such as the recharge plume from Herdsman Lake; however this, for the time being is speculation. Flow net analysis (Chapter 13) suggests that this may well be the case.

For the purpose of completing the isotopic balances it was essential that a truly representative value for groundwater discharge into both lakes be determined. Samples from N1 and N3 were considered to best represent up gradient groundwater. Average values (Table 6.7) were computed from all data from all levels in each piezometer. The raw data is included as Appendix 6.4.

Table 6.7 Average discharge water chemistry

	^2H	Cl	Derivation
East Lake	-11.5‰	250mg l^{-1}	Average of all data from nested piezometers N3a-N3c
West Lake	-6.3‰	309mg l^{-1}	Average of all data from nested piezometers N1a-N1c

This data is considered reasonable for East Lake. West Lake however shrinks over summer to a small residual pool. When East Lake is topped up, a local groundwater mound is formed with a strong local groundwater gradient towards West Lake. In hindsight a piezometer between East and West Lake would have been valuable in providing better definition of summer discharge chemistry to West Lake.

6.4.2 Summer Lake Level Maintenance

Summer lake level maintenance represented one of the most difficult problems in terms of estimating solute and isotope levels in the absence of direct sampling. The irrigation ring main system allowed water from all bores to be mixed in varying proportions and discharged through 100mm (south) and 80mm (north) flow meter equipped outlets (Figure 5.1a). Despite attempts to encourage the gardening staff to standardise the top up procedure (use the same bores and valve settings) the process remained largely *ad hoc*. Depending on whether isolation valves in the system are open or closed, water from any bore may exit through either outlet. A total of 69 samples were collected during top up events and analysed for deuterium and chloride. As a rule we attempted to sample all top up events which generally commenced either Friday evening or Saturday morning. In general water from the south outlet is dominated by P1 and to a lesser extent P6 while the north outlet is dominated by P2 and to a lesser extent P3, P4, P5 and P7. This is reflected in the average top up water chemistry (Table 6.8). Detailed top up isotopic data is included within Appendices 6.2 and 6.3.

Table 6.8 Average outlet water chemistry

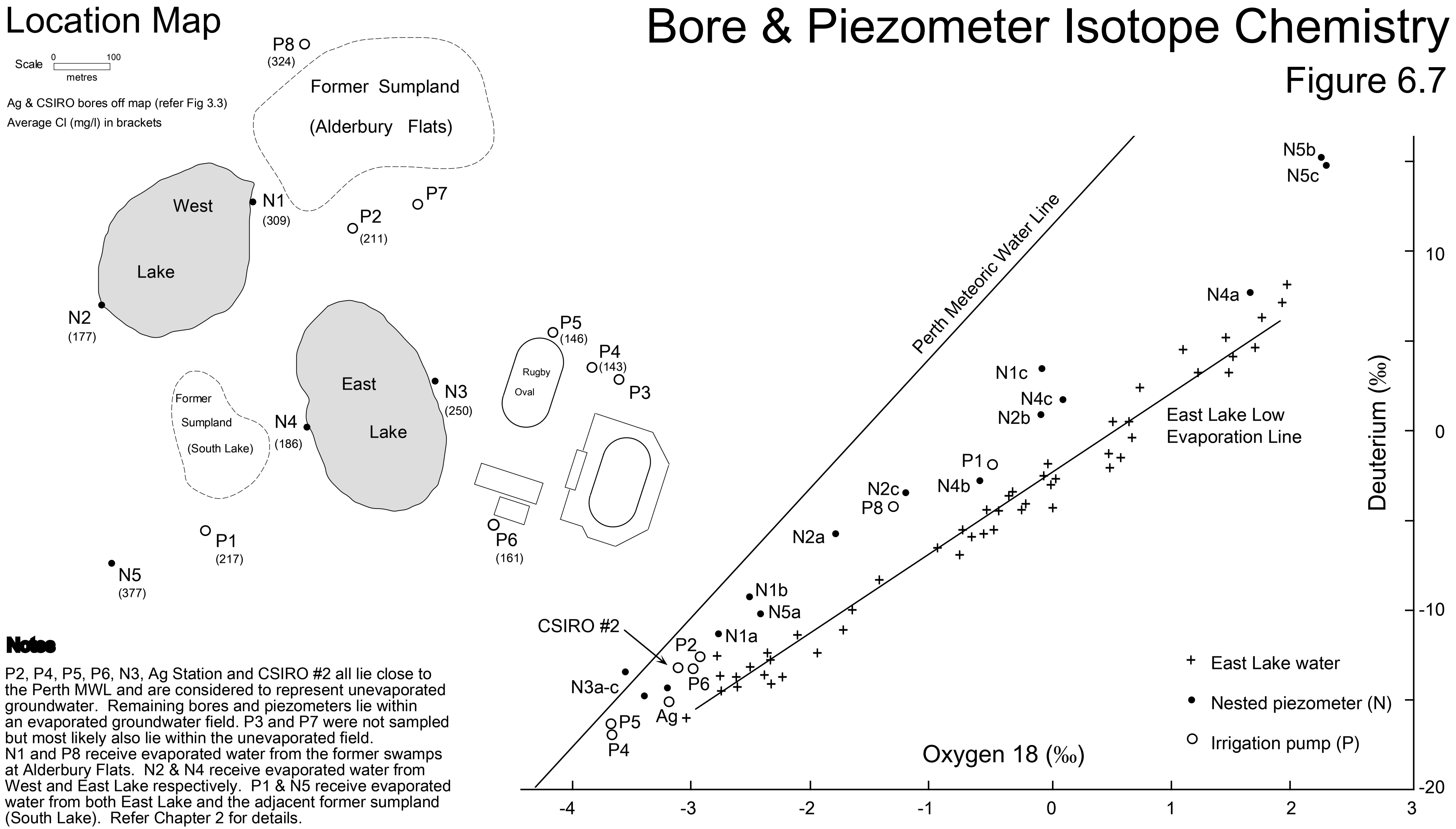
	Deuterium (‰)	Chloride (mg L^{-1})
South Outlet 'A'	-2.5	208
North Outlet 'B'	-13.5	169

Outlet 'A' is dominated by P1 which lies within the East Lake evaporated groundwater field. Bores feeding outlet 'B' all lie within the unevaporated groundwater field and have similar chloride and deuterium levels. These average values were applied to non sampled top up recorded on the flow meters.

Prior to flow metre installation (October 11, 1996), top up volume was estimated from pumping records kept by Town of Cambridge staff and rated irrigation capacity of each bore (Townley *et al* 1995). Estimated gross input chemistry utilised the outlet averages weighted against average relative outlet volume (average volume from B being 0.35 that from A). This 'average total chemistry' for water entering the lake from any top up event was -5.3‰ deuterium and 198mg l^{-1} chloride.

Bore & Piezometer Isotope Chemistry

Figure 6.7



Notes

P2, P4, P5, P6, N3, Ag Station and CSIRO #2 all lie close to the Perth MWL and are considered to represent unevaporated groundwater. Remaining bores and piezometers lie within an evaporated groundwater field. P3 and P7 were not sampled but most likely also lie within the unevaporated field.
N1 and P8 receive evaporated water from the former swamps at Alderbury Flats. N2 & N4 receive evaporated water from West and East Lake respectively. P1 & N5 receive evaporated water from both East Lake and the adjacent former sumpland (South Lake). Refer Chapter 2 for details.

6.4.3 Direct Rainfall

Rainfall was measured manually every 24 hours using 100mm diameter gauges. Rain samples for deuterium analysis were collected beneath silicon oil. This process is further described in Chapter 12 and Figure 12.4. The deuterium sampler was drained after each frontal passage or isolated rain event. Between May 5, 1996 and January 17, 1998, 112 samples were collected for individual analysis. These are included in Appendix 6.5.

Chloride in individual rain events was not measured. Chloride concentration is a function of the intensity of westerly winds (Teakle 1937) and distance from the coast (Hingston 1958). Average values for Perth rainfall are summarised in Table 6.9. A value of 12.0 mg l^{-1} was used. This is the average for samples collected adjacent to Perry Lakes at CSIRO Floreat (Hingston & Gailitis 1976).

Table 6.9 Chloride in Perth Rainfall

Location	Year	Ocean* (km)	Av Cl (mg L^{-1})	Reference
Perth Observatory	1926	8.0	16.5	Teakle (1937)
University of WA	1952-56	6.0	11.5	Hingston (1958)
Floreat (Perry Lakes)	1973-74	3.2	10.7-13.0	Hingston & Gailitis (1976)

* distance to the coast

6.4.4 Storm Water

Deuterium and chloride for any given rain event were applied directly to storm water. Early winter 'first flush' storm water however is known to carry elevated chloride. In Floreat, annual dry fallout of salt is about 12.4 kg ha^{-1} (Hingston & Gailitis 1976). Analysis of early winter 'first flush' storm water (Table 6.10) confirmed that chloride quickly diminishes to values approaching that of average rain.

Table 6.10 Deuterium and chloride in 'first flush' storm water

Drain	Date	Time	Rain (mm)	^2H in Rain	^2H in Drain	Cl in Drain
East Lake main drain	9 May 1995	2045	n/m	n/m	n/m	12.84*
East Lake CSIRO drain	"	2030	"	"	"	3.55*
West Lake main drain	"	2050	"	"	"	6.72*
East Lake main drain	22 March 1996	1630	1.4	"	"	51.6
East Lake CSIRO drain	"	"	"	"	"	46.3
East Lake basketball drain	"	"	"	"	"	47.8
West Lake main drain	"	1045	"	"	"	40.4
East Lake main drain	8 May 1996	0920	13.4	-6.2‰	-10.9‰	13.7
East Lake CSIRO drain	"	0900	13.4	"	-12.3‰	12.4
West Lake main drain	"	0940	14.0	"	-13.0‰	14.5

Deuterium in permil, Cl in mg l^{-1}

* average of three consecutive samples, n/m = not measured

The rain events on 9 May, 1995 and 8 May, 1996 were true 'break of season' events. Drains had flowed for at least an hour before sampling. The data show that already, summer salt build up had been flushed and confirm the validity of the average 12 mg l^{-1}. The small summer rain event 22 March 1996 probably approximates what happens when drains first flow. It is evident however that these elevated values do not persist. The 8 May drain deuterium values are 'point' samples whereas the rain value of -6.2‰ is the mean for the entire rain event.

6.5 COMMENTS ON WATER SAMPLING WEST LAKE

In East Lake, chloride and deuterium determinations were available every four days. Samples were collected from the centre of the south basin with all storm water and much top up water entering nearby. When East Lake was in recharge, estimates for recharge (lake water returned to the aquifer) were always similar with mass, chloride and solute balances often within 5% of each other suggesting that a single sample from the centre of this small, well mixed lake was representative. By comparison, West Lake presented a number of practical and hydrologic problems.

Sampling was at the extreme southwest corner while all storm drain inputs are in the extreme northeast corner. The lake experiences poor mixing. The sampling site is the deepest point and the only area which does not dry out in summer, however in hindsight it was probably not always adequately representative. There is almost certainly a chloride and deuterium gradient within the lake over winter. Congdon (1985) for example found significant chloride gradients within Lake Joondalup of up to 140 mg l^{-1} over distances of about 1000m. At times West Lake is really two or more lake systems comprising a southwest permanent 'sump' and remnant disjointed ponds elsewhere in the basin which receive varying amounts of storm drain water. This occurs during dry up in early summer and during early winter storm events when some storm water never reaches the southwest pond where all sampling was conducted. The extent of errors in the West Lake balances as a result of these problems remains unknown.

This study concentrated on the period September 1, 1996 to March 1997 (winter maximum to summer minimum). Financial restrictions precluded full chloride analyses.

6.6 CONCLUDING COMMENT

The integrated balances demonstrate that Perry Lakes oscillate between flow-through and recharge states and that the two lakes have a strong influence on each other's hydrology. In Chapter 7 the integrated balance information is combined with other data to examine in detail how Perry Lakes interact with the surrounding unconfined aquifer.

CHAPTER
7

LAKE-AQUIFER INTERACTION

7.0 INTRODUCTION

The historical development of lake-aquifer interaction concepts are reviewed. Field techniques used to identify flow regimes at Perry Lakes are presented and results discussed. Concepts of lake-aquifer coupling are presented. Historic and current field data is used to address possible lake 'detachment' from the aquifer over summer and explore the long term effects of water extraction near wetlands. Practical issues surrounding summer maintenance of wetlands is discussed with particular reference to Perry Lakes.

7.1 FLOW REGIMES AROUND SHALLOW LAKES

7.1.1 History

Hubbert (1940) showed the theoretical relationship between upland recharge of an isotropic homogeneous unconfined aquifer and valley discharge into streams. Tóth (1962), by developing an analytical solution to the Laplace equation, was able to mathematically define equipotentials and recharge-discharge areas for the case of an unconfined aquifer forming a ground water basin with impermeable base and sloping water table. Extending this solution to include an undulating water table Tóth (1963) demonstrated how near surface 'local' flow systems and larger, deeper intermediate and regional flow systems might coexist within the same low-order sedimentary basin[1] . The unconfined aquifer on the Swan Coastal Plain qualifies as such a 'basin'. The local flow systems include local groundwater mounds below hills which discharge into lakes or streams in the valleys. Significantly Tóth showed how some flow from these local mounds becomes part of the larger and deeper more regional flow systems, bypassing the adjacent discharge area and ultimately discharging much further down gradient. Much of the field identification of groundwater flow systems which validate Tóth's ideas was done in the post glacial 'hummocky moraine' terrain of North America. It is important to remember that glacial drift is clay rich with hydraulic conductivity typically

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[1] Later attempts to apply this model to regional sedimentary basins (Tóth 1995 & 1996) have been criticised (Mazor 1996) because of divergence from real world conditions in regional basins, particularly abundance of shale and clay, which effectively partition these systems into separate aquifers.

many orders of magnitude less than the sands encountered on the Swan Coastal Plain (Freeze & Cherry 1979, p151). In such terrains water tables frequently display high relief. Local mounds can persist close to lakes for extended periods. On the Swan Coastal Plain relatively much greater average hydraulic conductivity results in a topographically subdued water table. Hills form recharge areas and the loci of local mounds in the glacial terrain examples whereas on the Swan Coastal Plain upland areas are more likely to be reduced (or nil) recharge areas (McFarlane 1984). Perry Lakes demonstrates that mounds (in this case artificially induced) are very transient under local hydraulic conditions, persisting for days rather than months.

Flow-through lakes represent the mid point in a continuum from recharge lakes such as hydraulically mounded ombrotrophic lakes (Moore & Bellamy 1974) to groundwater discharge lakes and playas (Jacobson & Jankowski 1989). The origins of the term 'flow-through' to describe lakes with a distinct groundwater flux is unknown. The term was used as early as 1973 in regard to the Perth Coastal Plain (Balleau 1973) and later to describe some lakes in Wisconsin (Novitzki & Devaul 1978, cited Rinaldo-Lee & Anderson 1980) and as part of a primary classification scheme by Born *et al* 1979 who identified three basic configurations (Figure 7.1a) for groundwater flow around lakes:

Discharge lakes:	receive groundwater over the entire lake bed
Recharge lakes:	release lake water to the aquifer over the entire lake bed
Flow-through lakes:	receive and release water over different parts of the lake bed

Meyboom (1967) identified what he termed local and intermediate flow systems around Saskatchewan 'kettle holes' (Figure 7.1b) which received groundwater from local and regional systems. In spring local groundwater mounds flow into adjacent discharge lakes. As summer progresses, the local mounds decay and complex interlake flow is established, involving discharge and flow-through lakes. Locally, daily and seasonal seepage reversals were defined around some lakes due to local water table depression by phreatophytes. Using combined mass/phosphorous budgets Brown (1986) was able to show that the net direction of groundwater flow changed seasonally in small Minnesota lakes. Using lumped parameter modelling Crowe (1993) showed that recharge to groundwater in Wabamun Lake, Alberta was typically an order of magnitude greater than discharge to the lake, varying annually and seasonally depending on climatic variables with recharge to groundwater typically comprising 36% of water loss from the lake.

A significant feature of Tóth's flow systems is the presence of stagnation points where the sum of the magnitude and direction of the flow field vectors cancel to zero. Here groundwater paths diverge. In Meyboom (1967) for example, a stagnation point occurs (but is not shown) below the temporary spring snow melt mound and the deeper flow system (Figure 7.1b). Similarly a stagnation point is implicit below the flow-through lake of Born *et al* (1979) in Figure 7.1a. Nield *et al* (1994) note that such stagnation points are critical to understanding the flow regime. Using numerical modelling Winter (1976 & 1978) demonstrated that where an encircling water table is everywhere higher than the lake, then groundwater will discharge to the lake from all sides. Where there is also a deeper flow system which bypasses the lake, a stagnation point will exist within the aquifer below the lake. If the stagnation point occurs at the base of the lake and the piezometric head at the stagnation point exceeds lake stage, discharge will occur over the entire lake bed. Using two-dimensional transient simulations of observed seasonal changes in flow, Anderson and Munter (1981 & 1984) were able to simulate the development and migration of a stagnation point during the transition from flow-through to discharge conditions (Figure 7.1c). At their field site a temporary groundwater mound developed as a result of snow melt and spring rain on the down gradient side of a flow-through lake.

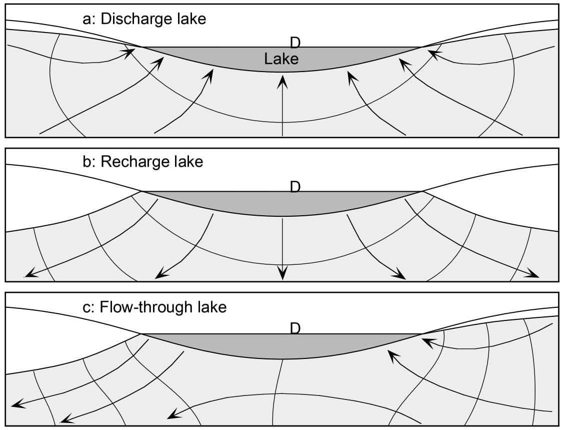
Winter's work showed that the presence of a local mound down gradient does not preclude some recharge from the lake. If the height (or other factors such as hydraulic conductivity) weakens the effect then discharge from the mound to the lake can occur as a local flow cell. Cherkauer & Zager (1989) provide a field example showing how such a system can vary seasonally (Figure 7.1d). As the local groundwater mound forms and enlarges, a reverse flow zone is established. Cherkauer & Zager show the boundary between mound discharge and lake recharge as a dashed 'hinge zone'. In fact it also defines a stagnation zone which migrates along the base of the lake. Using in lake piezometers Cherkauer & Zager were able to plot the expansion of the reverse flow zone into the lake.

7.1.2 Recent Research on the Swan Coastal Plain

Over the past decade numerical models have been developed which address specifically the hydrology of shallow lakes on the Swan Coastal Plain. In their natural state these were generally flow-through lakes with no surface flows. Groundwater therefore was the dominant water balance component. Many, like Perry Lakes, are now hydrologically modified, principally through winter storm water inputs.

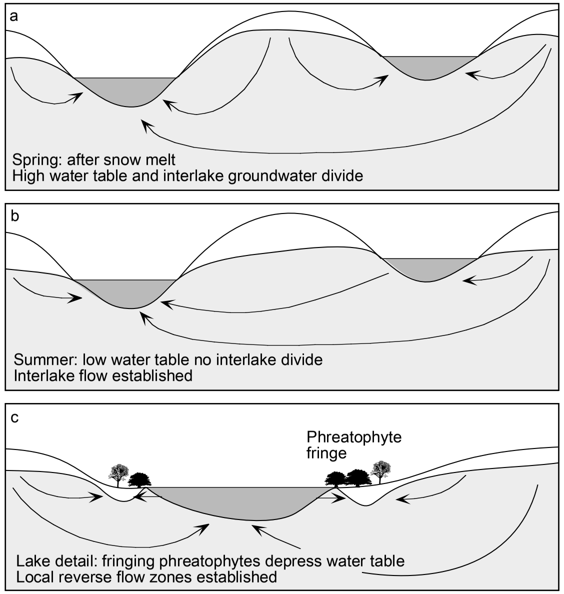
Figure 7.1

A



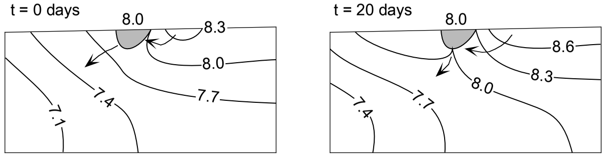
Three basic groundwater flow systems associated with water table lakes (adapted from Born et al 1979 p17), notice in (c) stagnation zone is implicit below the lake, but is not specifically noted

B



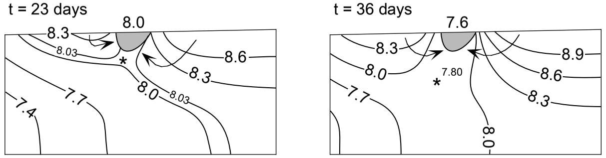
Adapted from Meyboom (1967) & Fetter (1994) p310

C



Flow-through regime, stagnation point is implicit (but not shown) at base of lake

Transition to dischargeregime, stagnation point at base of lake defines position of last vestage of recharge from lake

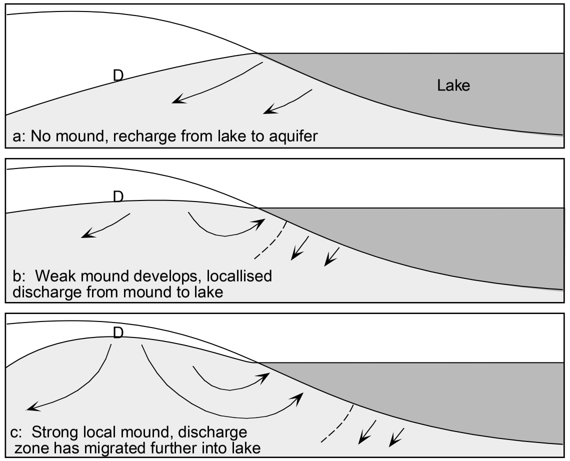


Discharge regime established, 8.03 ft contour defines head at stagnation point (defined by asterisk) which has migrated below base of lake

As lake stage decreases due to ET, the head and position of the stagnation point also change

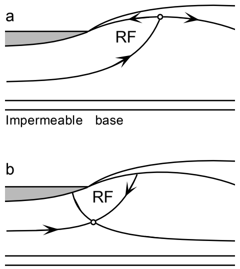
2D vertical sections used to simulate the transition from flow-through to discharge conditions and migration of the stagnation point, Snake Lake, Wisconsin (adapted Anderson & Munter 1981, Fig 6)

D



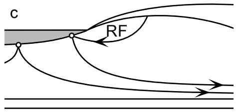
Idealised flow on downgradient side of Lower Nashotah Lake, Wisconsin showing growth of local groundwater mound and reverse flow zone (adapted Cherkauer & Zager 1989, Fig 8)

E

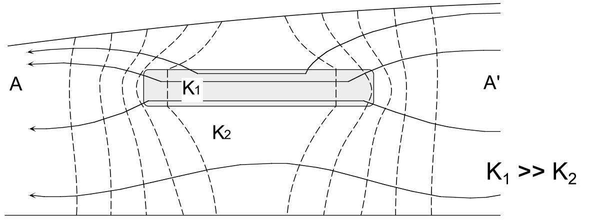


Schematic diagrams of groundwater mounds associated with lakes
RF = reverse flow zone
circles = stagnation points

(after Nield et al 1994, Fig 18)

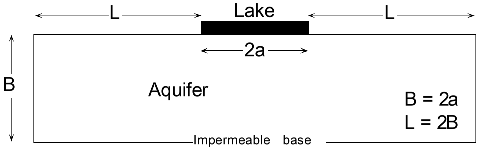


F

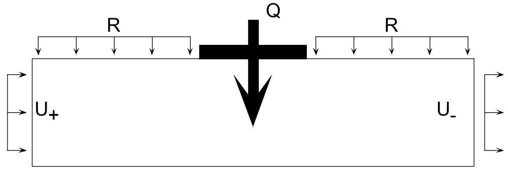


Equipotentials and flow lines around a high hydraulic conductivity sand lens within lower hydraulic conductivity sediments. The lens attracts flow. Flow lines converge on the up gradient end and diverge down gradient. If the section is bisected along A-A' and the upper section removed, A-A' becomes a water table. If the lens hydraulic conductivity is increased to that of water, we have a flow-through lake. Adapted from Fetter (1994), Fig 8.7

G



Geometry used for modelling in 2D vertical section (after Townley et al 1993b, Fig 3.1.3)



Boundary conditions for modelling in 2D vertical section through a shallow lake (after Townley et al 1993b, Fig 3.1.4)

The Geological Survey of Western Australia carried out early field studies of lacustrine hydrology at Jandabup Lake (Allen 1979), Marijiniup Lake (Hall 1985) and Bibra Lake (Davidson 1983). Allen (1979), using salinity differences demonstrated a groundwater flux and identifiable release zone through such lakes. McFarlane (1984) identified similar plumes down gradient of Mason Gardens and Shenton Park Lake, prompting further investigations by Oo (1985) and Townley & Davidson (1988). Advances in the identification and modelling of flow patterns including the chemical and isotopic identification of lake release zones are reported in Townley *et al* (1991). Nield (1990) addressed the question of lake bed seepage distributions. This work is expanded in Townley *et al* (1993a) and Nield *et al* (1994) who also provide a general framework for examining surface water-groundwater interaction. Townley *et al* (1993a) presents the results of a three year study on the interaction between lakes, wetlands and unconfined aquifers with particular emphasis on numerical modelling. It includes field validation from a number of wetlands in the Perth area and a concise review of pertinent international and Western Australian literature. Townley *et al* (1993b) is a readable summary of this work, aspects of which are further expanded in Townley & Trefry (2000) and Townley & Smith (2002).

7.1.3 Models of Surface Water-Groundwater Interaction

Simple models of recharge and discharge lakes such as Born *et al* (1979) (Figure 7.1a) are readily understood. Intuitively it is easy to see why water seeps from a recharge lake. Flow-through lakes on the other hand are not intuitively obvious. They interrupt the normal horizontal groundwater flow and, by inducing zones of upward and downward flow, divert significant quantities of groundwater through the lakes themselves. Townley *et al* (1993b) use the analogy of an electrical short circuit where it is easier for water at the base of an aquifer to rise a few metres into a lake, travel possibly many hundreds of metres in the water body and then descend back to the bottom of the aquifer rather than travel the entire distance through the more resistive pore spaces of the aquifer sediments. The lake represents a low resistance 'conductor' in parallel with high resistance sediments. Where lakes intersect an unconfined aquifer there is effectively no horizontal gradient because the lake surface is horizontal and the piezometric head at the lake bed is everywhere equal to lake stage. Therefore groundwater beneath the lake tends to stagnate while groundwater approaching on the up gradient side tends to rise over this stagnant zone, discharging into the lake close to the lake shore (Townley *et al* 1995). Another way to visualise the flow-through mechanism is to consider a sand lens of high hydraulic conductivity within lower conductivity clays (Figure 7.1f). Flow converges on the lens. If the section above A-A' is removed, the pattern is identical to the flow-through lake of Born *et al* (1979).

Figure 7.10 illustrates schematically the principal components of a flow-through lake. The 'capture zone' is that area within which any surface recharge will eventually flow through to the lake while the 'release zone' contains water which has passed through the lake. High evaporation relative to precipitation and groundwater flux means that release zone water will be enriched both in salts and stable isotopes. Nield *et al* (1994) characterised the fundamental differences between types of water bodies using simple geometric ratios. Their work extends that of Townley & Davidson (1988) who found that the ratio of horizontal hydraulic gradients up and downstream of a lake defines the position of the stagnation point separating regions of recharge and discharge through the lake boundary and determines capture zone width and depth. This approach provided a foundation for the systematic study of the shape of capture and release zones as a function of the physical properties of the lake and aquifer plus nearby aquifer flows and net groundwater recharge. Nield *et al* (1994) present a non dimensional hierarchy of models for the three basic lake-aquifer flow regimes (recharge, discharge and flow-through). These also permit quantitative predictions to be made of capture and release zone geometry.

Figure 7.1g shows the co-ordinate system used to describe their model. The lake (defined by the solid bar) has a 'length' (parallel to groundwater flow) of $2a$, aquifer thickness B and distance from the model boundary to lake edge L. Fluxes through the boundaries of the modelled domain are U_+, U_- (uniform horizontal groundwater flux), R (uniform recharge flux) and Q (flux per unit width from lake to aquifer).

Eight independent parameters a B D K_x K_z U_+ U_- and R control flow within the model domain. The first five are physical characteristics of the lake and aquifer while the remainder are components of the water balance. Flow geometry is expressed using seven non dimensional ratios (Table 7.1).

Table 7.1 Ratios defining flow geometry

Ratio	Dimensionless Flow Parameter
$2a / B$	lake length
D / B	lake lining resistance
L / B	distance to boundary
K_x / K_z	anisotropy ratio
U_+ / K_x	slope of the phreatic surface
U_- / U_+	horizontal flux ratio
RL / U_+B	recharge (net recharge/net horizontal flux)

Anisotropy

The aquifer is assumed to be anisotropic with respect to horizontal and vertical hydraulic conductivity K_x and K_z. An equivalent isotropic system is obtained by stretching the vertical coordinate z with a new coordinate z' defined as:

$$z' = \left(\frac{K_x}{K_z} \right)^{0.5} z \qquad \text{(Nield } et\ al \text{ 1994 eqn 5b)} \qquad (7.1)$$

The lake lining is similarly defined as an equivalent sediment depth D, this being the equivalent thickness of aquifer material with the same resistance to vertical flow. Therefore a lake with a continuous low conductivity lining behaves like a lake with no lining but much smaller length (expressed as $2a/B$).

Winter (1983) initially demonstrated and Nield *et al* (1994) further illustrate how small changes in anisotropy have very large effects on domain geometry (Table 7.2).

Table 7.2 Relationship between anisotropic and equivalent isotropic domains

Model Parameter	Anisotropic Domain K_x/K_z = 100	Equivalent Isotropic Domain $x' = x/10$*	Equivalent Isotropic Domain $z' = 10z$*
a	250m	25m	250m
B	50m	50m	500m
D	5m	5m	50m
L	1000m†	100m	1000m
K_x	100m d^{-1}	10m d^{-1}	10m d^{-1}
K_z	1m d^{-1}	10m d^{-1}	10m d^{-1}
U_+	0.01m d^{-1}	0.01m d^{-1}	0.001m d^{-1}
U_-	0.01m d^{-1}	0.01 d^{-1}	0.001m d^{-1}
R	0.0001m d^{-1}	0.001 d^{-1}	0.0001m d^{-1}
$2a/B$	10	1	1
D/B	0.1	0.1	0.1
L/B	20†	2	2
K_x/K_z	100	1	1
U_-/U_+	1	1	1
RL/U_+B	0.2	0.2	0.2

Data from Nield *et al* (1994), Table 1
* scaling factor $[(K_x / K_z)^{0.5}]$ = 10 is calculated using the physical values in the anisotropic domain
† L in the anisotropic domain chosen such that L/B in equivalent isotropic domain is 2

Table 7.2 illustrates the extreme effect anisotropy plays in the effective dimensions of a lake-aquifer system. A lake of physical size a = 250m behaves like a lake of only a = 25m at K_x / K_z of 100. Modelling requires such simplifications, as anisotropy renders the real world infinitely more complex. Freeze & Witherspoon (1967) for example suggest that where the hydraulic conductivity of adjacent aquifer beds differs by 10:1 or greater, the bed having the lower conductivity may be considered impermeable relative to the other.

Flow regime designations

In total Nield *et al* (1994) define 39 flow regimes in three basic categories: flow-through (FT), discharge (D) and recharge (R). These are further subdivided into partially penetrating (where water interacting with the lake flows within the aquifer), and fully penetrating (where interacting water extends to the base of the aquifer). Those theoretically most pertinent to Perry Lakes are partially penetrating. These are summarised in Figures 7.2 a-c and have been annotated to aid understanding. Water which interacts with the lake is shaded and each model (originally presented by Nield *et al* (1994) only in 2D vertical section) is also shown in plan. The shaded and non shaded areas in section are defined by dividing streamlines which separate regions of water with different source or destination. By convention Nield *et al* (1994) use a left to right groundwater flux. Figures 7.2 are mirror images (designated with an asterisk), which allow the reader to visualise lakes as they would exist on the Swan Coastal Plain, viewed looking north as per cartographic convention. Each 2D section includes information which provides clues about the relative magnitudes of the principal water balance components lake flux Q and precipitation (or irrigation) recharge R.

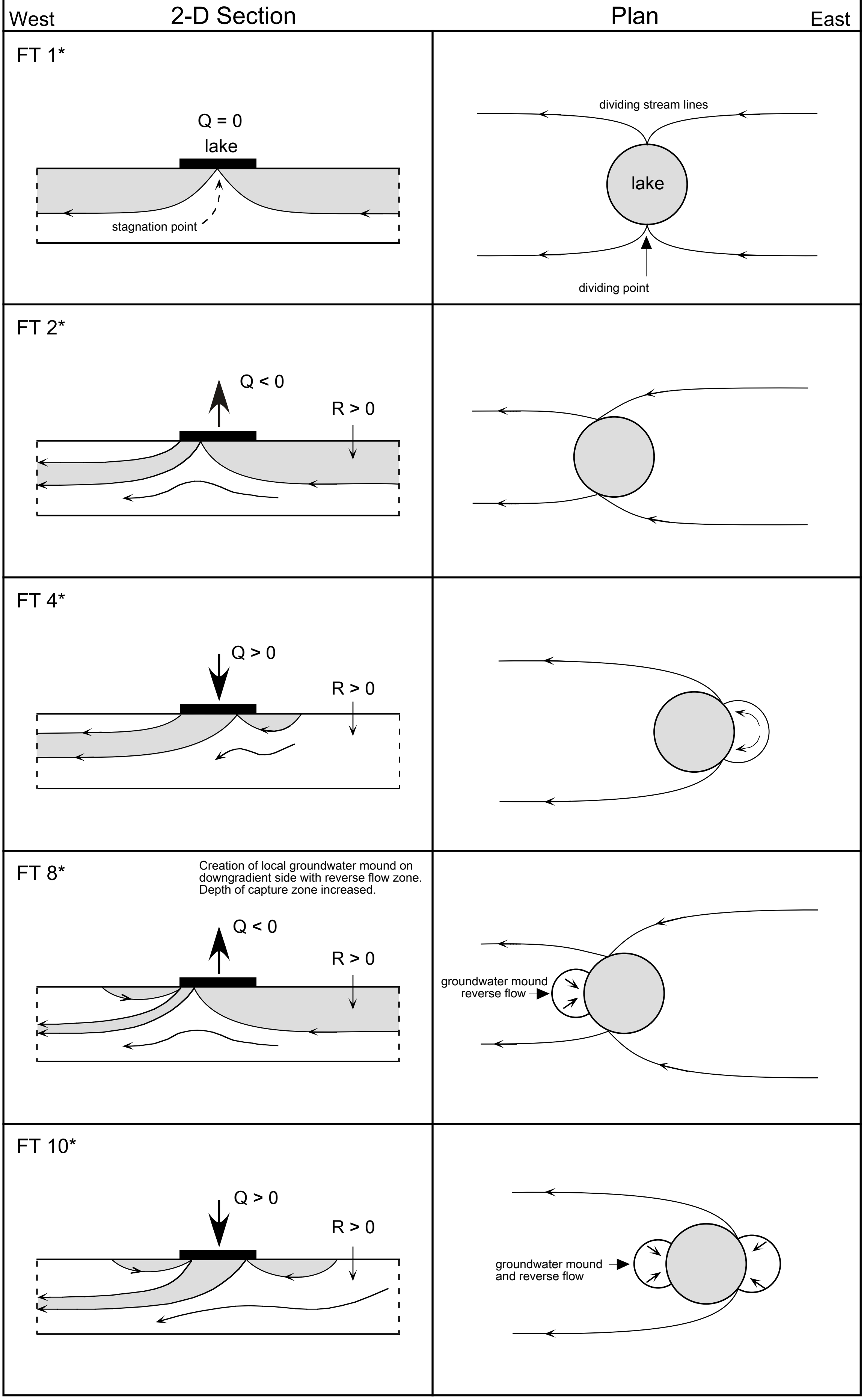
Where $Q<0$:	groundwater discharged to the lake exceeds groundwater recharged to the aquifer. Flow-through or discharge regimes occur characterised by high evaporative or surface flow losses.
Where $Q>0$:	groundwater discharged to the lake is less than groundwater recharged to the aquifer. Flow-through or recharge regimes occur characterised by high precipitation or surface flow inputs (such as storm drains).
Where $R<0$:	there is little or no precipitation (summer conditions), FT regime designations are even numbers.
where $R>0$:	recharge is occurring, (winter precipitation or summer irrigation), FT regime designations are odd numbers.

Reverse flow and stagnation Zones

Many of the flow-through regimes contain one or two reverse flow zones. Reverse flow zones identify the presence of a local groundwater mound (Nield *et al* 1994). Implicitly, these must also include stagnation points at the base of the lake (Cherkauer & Zager 1989). Figure 7.1e demonstrates three local groundwater mound configurations (all partially penetrating) and their associated reverse flow zones and stagnation points. Figure 7.1e panel a includes discharge regimes D1 and D2, where some groundwater

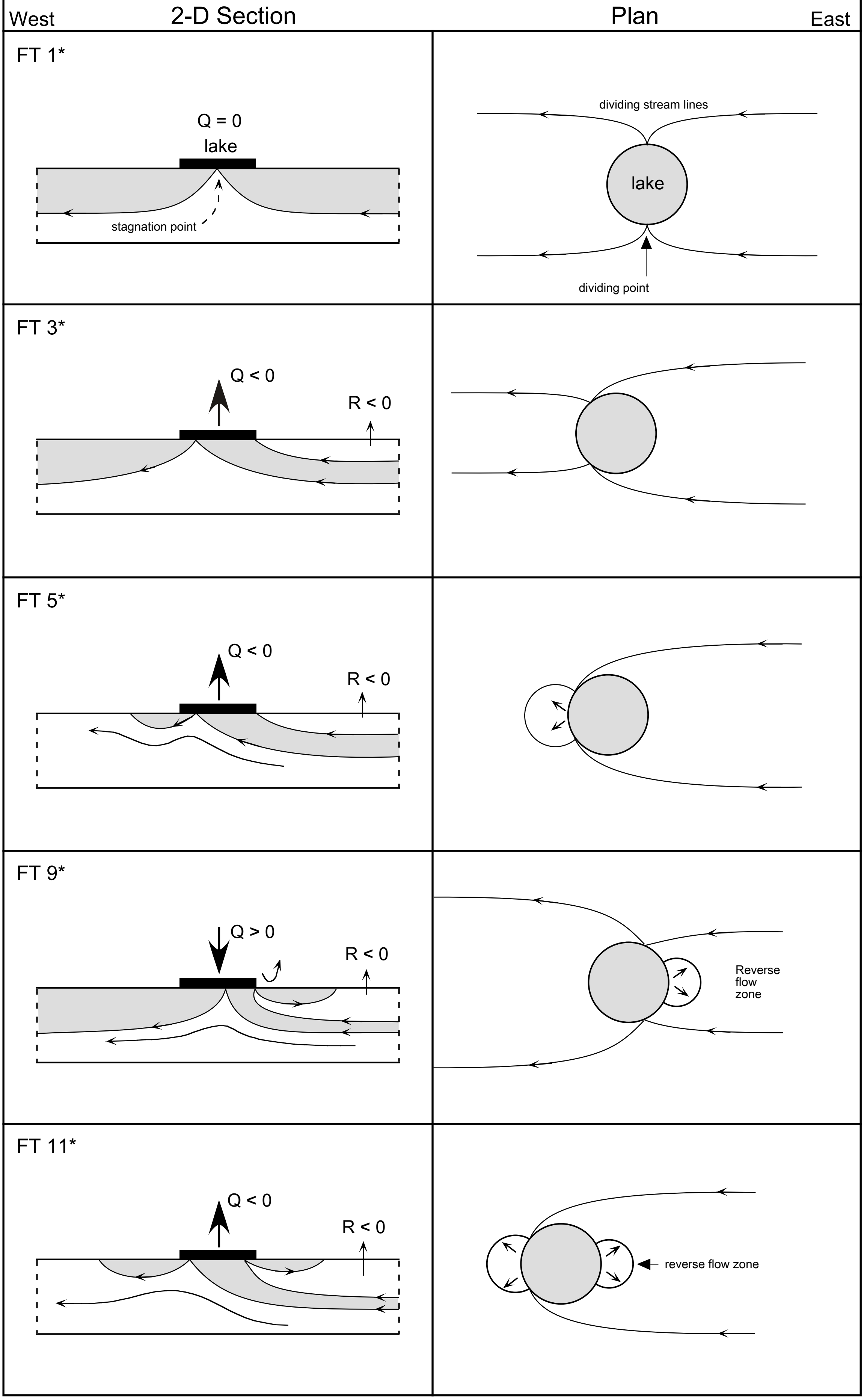
Flow-Through Regimes
Characterised by Increasing Recharge

Figure 7.2a



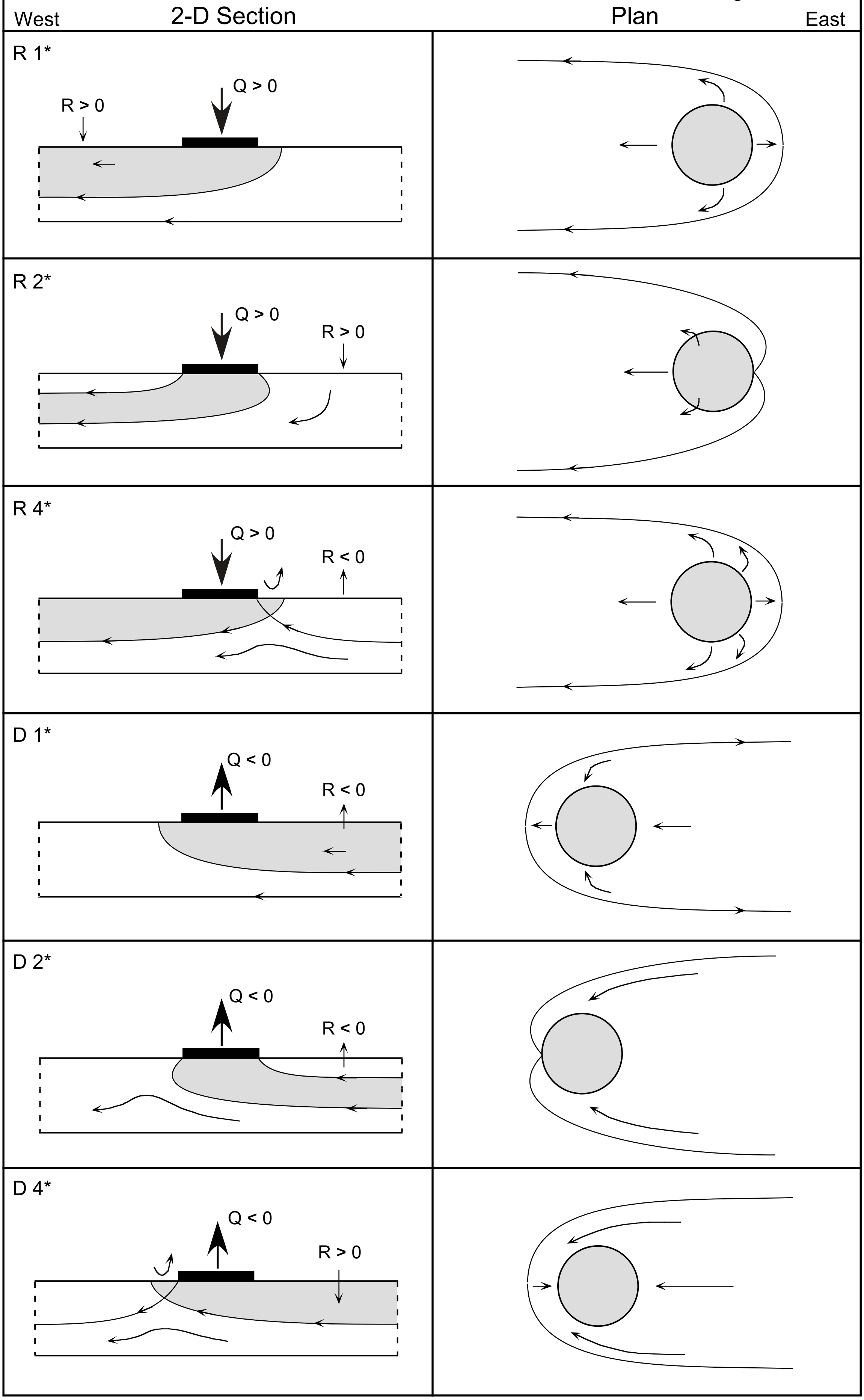
Flow-Through Regimes Characterised by Decreasing Recharge

Figure 7.2b



Recharge and Discharge Regimes

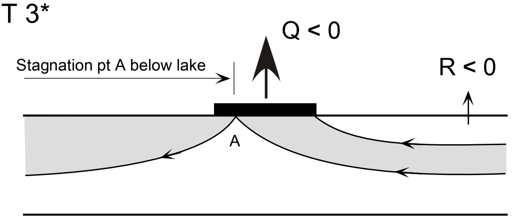
Figure 7.2c

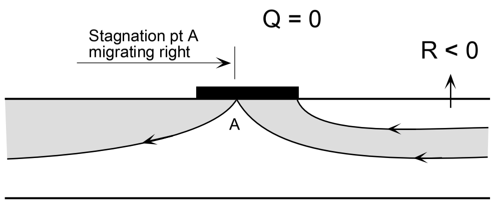


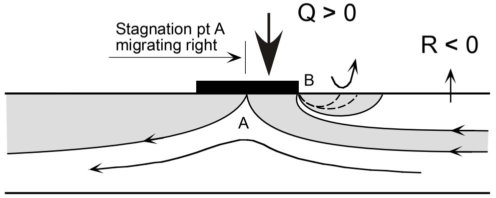
Theoretical Transition Patterns between Flow-Through and Recharge Regimes

Figure 7.3

FT 3*

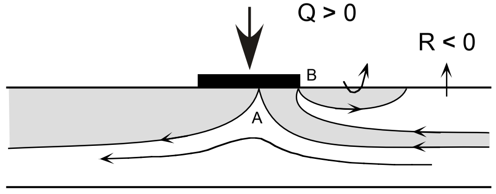




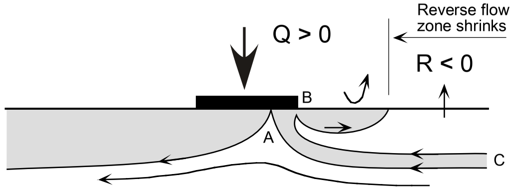


Reverse flow zone develops and grows on up gradient margin, associated with a second stagnation point B

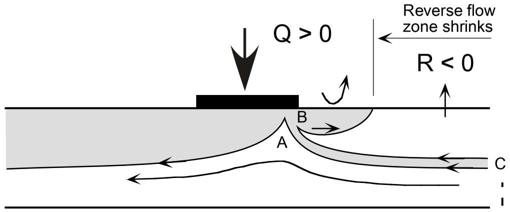
FT 9*



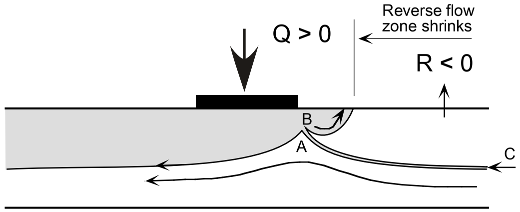
Stagnation pt A migrating right, reverse flow zone grows



Stagnation pt A continues to migrate right, B detaches from lake base
Flow-through discharge C diminishing

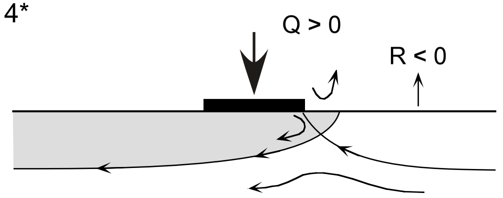


Stagnation pt A continues to migrate right, B detaches further from lake base and approaches A, Flow-through discharge C diminishing

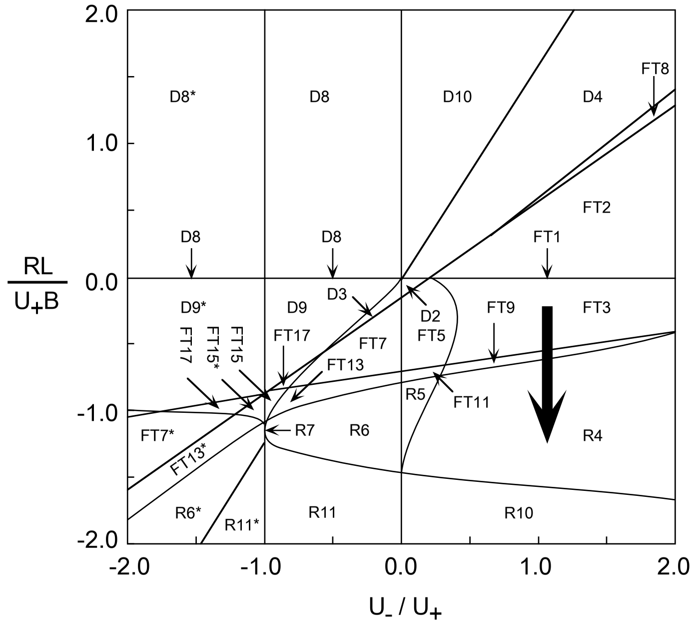


Stagnation pt A continues to migrate right, B detaches further from lake base and approaches A, Flow-through discharge C approaches zero

R 4*



Full recharge regime established, nil flow-through, stagnation points merge as single point



Transition diagram for U= > 0, 2a/B = 1 and D/B = 0 (adapted from Fig 17 of Nield et al 1994). Large arrow defines transition path from FT3-FT9-R4 shown in 2D sections. Flow regimes R1, R2, D5, FT4 & FT10 are off the diagram, occurring at U- / U+ > approximately 3

2D sections are flipped left to right to simulate conditions on the Swan Coastal Plain viewed looking north (denoted by asterisk), FT3* in section is equivalent of FT3 in transition diagram. Water which interacts with the lake is shaded.

initially bypassing the lake, discharges via a reverse flow zone on the left. Figures 7.1e panels b&c are analogous to the local down gradient recharge mounds of Meyboom (1967), Figure 7.1b panel a, Anderson & Munter (1981), Figure 7.1c (t = 23 & 36 days) and Cherkauer & Zager (1989), Figure 7.1d panels b&c.

Flow Regime Transitions

Nield *et al* (1994) provide a framework of flow regime types which effectively allow any regime to be 'pigeon holed' into a category which approximates its flow conditions. In reality there is an infinite continuum of regimes. Some are highly sensitive to changes in the water balance and/or the physical characteristics of the lake and aquifer. For example, using 'transition diagrams' plotted in $RL / U_{+}B$ versus U_{-} / U_{+} space Townley *et al* (1993a) and Nield *et al* (1994) demonstrate large changes in regime distribution when lake length (as $2a / B$) is increased from 1 to 4. Figure 7.3 illustrates the concept of a flow-regime continuum. The transition from FT3 to R4 must include the intermediate FT9 regime. The 2D vertical sections illustrate a few of the intermediate steps in the transition. A lake shrinking towards dryness is a similar case (Figure 7.10).

Capture Zone Depth and Width

Capture zone depth depends principally on lake length, expressed as $2a / B$ (Townley *et al* 1993b p27). Using the concept of 'equivalent isotropic domain' (Nield *et al* 1994 p2464), note that a lake with a continuous clay lining is the hydraulic equivalent of a lake with no lining but smaller length. Decreasing lake length and/or introducing a continuous low conductivity lining have the equivalent effect of decreasing capture zone depth (Figure 7.4a).

Capture zone width is less sensitive, depending largely on the degree of lake isolation from adjacent lakes (Townley *et al* 1993b, p28). Where a lake is isolated from adjacent lakes the capture zone width approaches double the lake diameter (Figure 7.4b). Nearby lakes have the effect of reducing capture zone width. Ignoring for a moment the possible effects of lake linings, we can estimate maximum (winter) capture zone widths at Perry Lakes, Table 7.3.

Table 7.3 Estimated capture zone widths

Parameter	East Lake	West Lake
$2W$ (distance between lake centres)	460m	460m
a (lake length/2)	120m	160m
$2a/B$ (B taken to be 37m)	~ 8	~ 8
a/W	~ 0.5	~ 0.7
Capture zone width w_{+}/a	1.6	1.3
Capture zone width	380m	420m

Lake Bottom Seepage Distribution

Field studies indicate that groundwater seepage into flow-through lakes is spatially highly variable but is generally most intense close to the up gradient shore (Lee 1977, Munter & Anderson 1981, Pfannkuch & Winter 1984). Seepage rates decrease rapidly from shore, decaying at a rate variously described as exponential (McBride & Pfannkuch 1975, Lee 1977) or rapid but non exponential (Townley *et al* 1993b p28). Seepage distribution is linked to aquifer anisotropy (Winter 1976, Lee *et al* 1980, Barwell & Lee 1981, Winter 1983) however in geologically complex multi-layered aquifer systems quite different seepage distributions can occur (Cherkauer & Nader 1989). Figure 7.4c summarises model simulations (Pfannkuch & Winter 1984, Townley *et al* 1993 a&b). The plots are symmetrical, with the distribution and intensity of discharge on the up gradient side matched by equal and opposite recharge down gradient.

In long lakes ($2a/B>4$), with no resistive lining, seepage is concentrated close to the shore, rapidly decreasing to nil just a short distance off shore. In very short lakes there is an almost linear distribution. As would be expected, the presence of a resistive lining and application of an equivalent isotropic system has the effect of reducing lake length, resulting in seepage distributions similar to those of very short lakes in isotropic domains. Figure 7.4c includes a purely diagrammatic representation of the discharge-recharge distributions in a lake of approximately similar length-width ratio as East Lake.

Non Uniform Lake Lining Distribution

Lakes on the Swan Coastal Plain typically contain resistive linings which are concentrated in the deepest part of the lake basin and thin towards the edges which may be devoid of lining. This is the general situation at Perry Lakes (Chapter 3). Townley *et al* (1993b) provide possible schematic lining configurations (Figure 7.4d). They suggest that where sediments are concentrated in the centre of lakes they will have little effect on capture zone geometry.

7.1.4 Predicted Flow Regimes at Perry Lakes

The models of Townley, Nield and others provide an easy to visualise theoretical framework. The models are steady state and rely on a large number of assumptions[2] and simplifications while the real world is highly complex and constantly changing. They rely on recharge values which represent spatial and temporal averages, and therefore simulate net surface water-groundwater interaction over some (unspecified)

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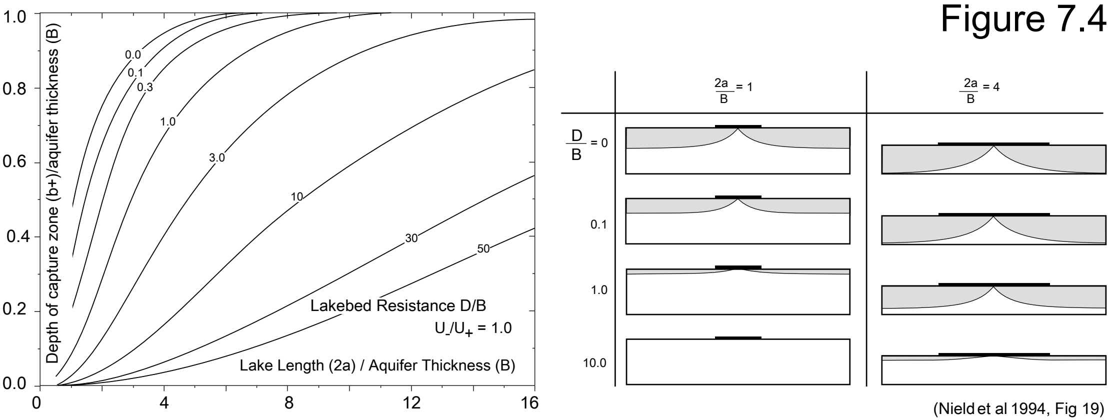
[2] Assumptions include: steady saturated groundwater flow, shallow water body relative to aquifer thickness, a 'long' water body (parallel to groundwater flow such that a 2D approach in vertical section is valid), homogeneous hydraulic conductivity, a horizontal phreatic surface within the model domain, distance L is always equal to $2B$, uniform horizontal fluxes across vertical boundaries, uniform sediment resistance, uniform recharge (a spatial and temporal average over some period of time), effect of U_+/K_x, (representing the slope of the phreatic surface) assumed to be negligible.

Figure 7.4



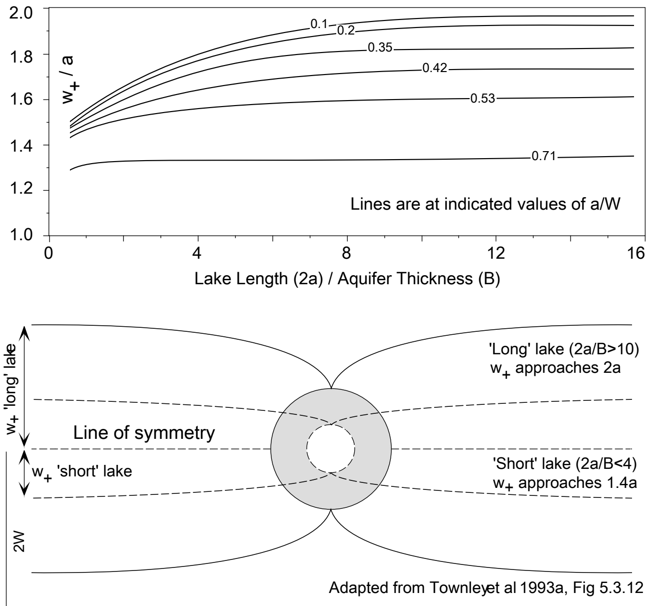
(Townley et al 1993b, Fig 3.2.6)

(Nield et al 1994, Fig 19)

A: Depth of capture zone
Effect of lake length and lake bed resistance

The depth of the capture zone is influenced by both lake 'length' and lake bed resistance. Capture zone depth is reduced by shortening the lake length and increasing the bed resistance

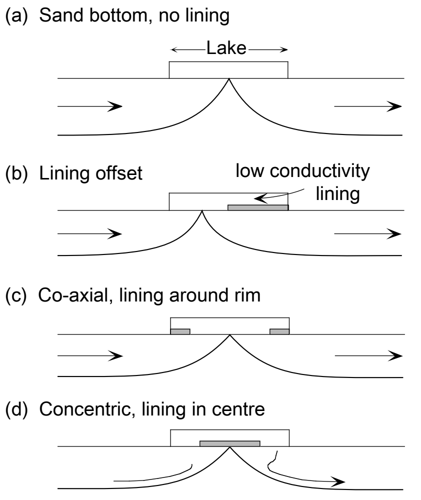
(Townley et al 1993b, Fig 3.2.14)



Adapted from Townley et al 1993a, Fig 5.3.12

2W = distance between centres of adjacent lakes
Models assume 2W is large (a/W<0.1)

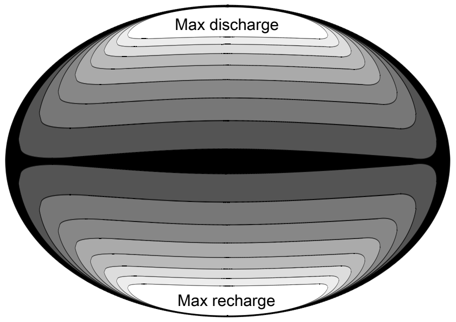
B: Width of capture zone
Effect of lake length and adjacent lakes



D: Non uniform lake linings: possible flows

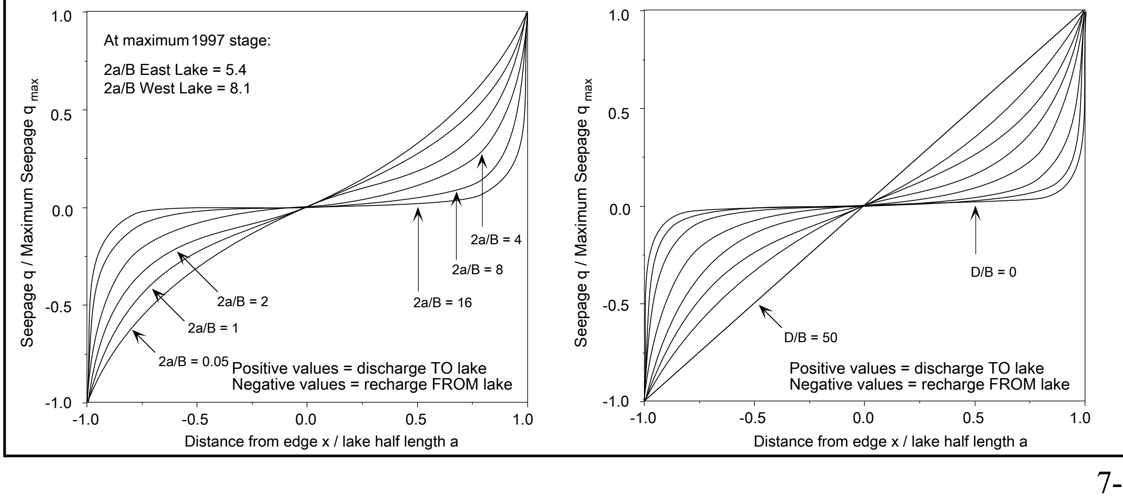
(Townley et al 1993b, Fig 3.2.8)

C: Seepage distribution
Effect of lake length and lining resistance



Spatial distribution of bottom seepage in a lake of length-width ratio similar to Perry Lakes, lighter tones = maximum flow (flow is N-S)
Modified from Townley et al 1993a, Fig 5.4.16

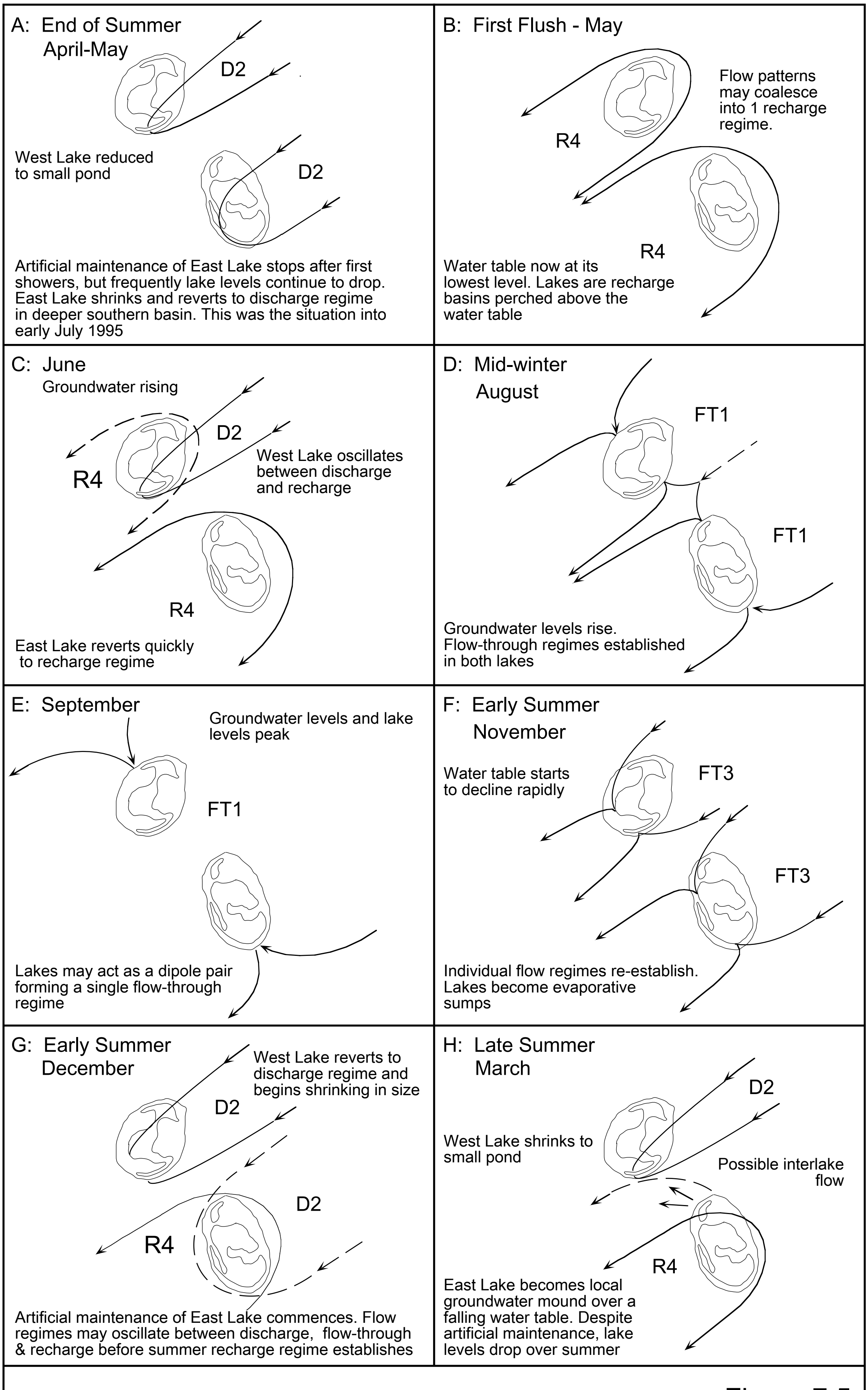
After Pfannkuch & Winter 1984 and Townley et al 1993b, Figs 3.3.1 & 3.3.2



time period (Nield *et al* 1994, p2464). But they also are based on measurable (or readily estimated) components of the lake water balance and physical characteristics of the lake and aquifer. Accurate short term water balances, such as the daily balances summarised in Chapter 6, allow realistic, detailed temporal analyses of East and West Lake as they respond to natural and artificial stimuli. The models provide not only a theoretical framework and classification scheme for describing lake-aquifer interaction but also easy to visualise 'snapshot' simplifications of a highly complex and dynamic system. Many of the regimes, while theoretically possible, have not been observed in nature. Many will probably not occur or at best occur as transient transition phases under Swan Coastal Plain hydraulic conditions.

Townley *et al* (1995) hypothesised flow regimes which might occur at Perry Lakes taking into account a regime of summer maintenance in East Lake (Figure 7.5). A seasonal oscillation between discharge and recharge regimes formed the principal theme of their predictions. In particular they suggested regular excursions to discharge in early summer (when evapotranspiration increases rapidly and the lake level falls more rapidly than the surrounding water table) and in West Lake in late summer (when the lake might become an evaporative sump). Many of their predictions have proven to be accurate as will be demonstrated later in this chapter. During early winter storm drain flow both lakes do become recharge lakes, frequently with a large single release zone encompassing both lakes. Over winter 1997 both lakes frequently exhibited separate capture and release zones while they were in flow-through status. The individual capture and release zones commonly coalesced as winter progressed (Figure 7.5 d, e & f) just as predicted by Townley *et al* (1995). What was not predicted was the persistence of flow-through regimes as lakes approached dryness and the very complex summer inter lake flows and reverse flows which result from heavy local groundwater extraction and persistent top up in East Lake. Discharge regimes proved to be extremely rare and at best transitory. These results are presented and discussed later in this chapter.

In the sections that follow we examine flow regimes observed over two years at Perry Lakes. It is worth emphasising again however that the models upon which they are based are gross simplifications of real world complexity. Aquifer anisotropy, complex lake shapes and lining distribution, surface topography, vegetation cover, land use (in particular groundwater extraction and use of wetlands as storm water depositories) all add layers of complexity which cannot be addressed in the models. The models (and flow regime designations) do however, provide a convenient framework which allows the reader to more easily visualise (in 2D steady state) what is actually happening (in 3D non steady state), under hydrologically complex conditions.



A: End of Summer
April-May

West Lake reduced to small pond

Artificial maintenance of East Lake stops after first showers, but frequently lake levels continue to drop. East Lake shrinks and reverts to discharge regime in deeper southern basin. This was the situation into early July 1995

B: First Flush - May

Flow patterns may coalesce into 1 recharge regime.

Water table now at its lowest level. Lakes are recharge basins perched above the water table

C: June
Groundwater rising

West Lake oscillates between discharge and recharge

East Lake reverts quickly to recharge regime

D: Mid-winter
August

Groundwater levels rise. Flow-through regimes established in both lakes

E: September

Groundwater levels and lake levels peak

Lakes may act as a dipole pair forming a single flow-through regime

F: Early Summer
November

Water table starts to decline rapidly

Individual flow regimes re-establish. Lakes become evaporative sumps

G: Early Summer
December

West Lake reverts to discharge regime and begins shrinking in size

Artificial maintenance of East Lake commences. Flow regimes may oscillate between discharge, flow-through & recharge before summer recharge regime establishes

H: Late Summer
March

West Lake shrinks to small pond

Possible interlake flow

East Lake becomes local groundwater mound over a falling water table. Despite artificial maintenance, lake levels drop over summer

Figure 7.5

Flow Regimes Hypothesised by Townley et al 1995

7.2 FIELD IDENTIFICATION OF FLOW REGIMES

In their natural state wetlands such as Perry Lakes had no surface inputs or outflows except direct rainfall and evaporation. In normal years they were not subject to drying out. At normal water levels the sandy rim ensured good hydraulic coupling to the aquifer. This suggests that under normal climatic conditions $Q / U_+ B$ remained close to zero and flow-through regimes persisted year round. During periods of high rainfall, the lakes would tend towards a recharge state (FT3, FT9 etc) and similarly under extreme summer evapotranspirative stress would tend towards a discharge state (FT2, FT8 etc). It appears unlikely that true recharge and discharge regimes would have been achieved for any considerable period. Section 7.2.4 shows how extensive field experiments confirm that flow-through persists even as the lakes approach dryness.

Today artificial flow regimes are induced principally through large inputs either as top up or storm water. Both induce local mounding of one or both lakes. Persistent summer groundwater extraction induces additional artificial flows.

At Perry Lakes six field techniques were used to identify flow regimes.

- nested piezometers
- in-lake piezometers close to the FT1 dividing streamline
- near lake water table levels
- identification of transient reverse water table gradients
- dividing stream line mapping using lake edge 'mini piezometers'
- lake sediment thermal profiling
- water balances

7.2.1 Nested Piezometers

Nested piezometers were planned as the principal means of identifying seasonal and transient (rain and pumping) changes in flow regime. In summary the piezometers failed to operate as planned. Mini piezometers (Section 7.2.3) close to the lake edge displayed large differences in equipotential over depth. Head differences of 10^+cm were routinely recorded between the water table and 2.5m depth. In the nested piezometers however equipotential differences over half the vertical thickness of the aquifer (about 20m) were typically <10mm. More importantly these data often displayed no seasonal change and were often in direct contradiction of the flow regime determined by other means.

Nested piezometers are a primary tool in lake-aquifer interaction studies (Townley *et al* 1993 a&b). It was anticipated that they would perform a similar function at Perry Lakes providing a simple physical indication of lake-aquifer interaction. Simply put, a piezometer is a small diameter well, sealed along its length and either open at the bottom or screened over a short distance. When inserted into an aquifer to depth *d* water will rise within it in proportion to the hydraulic head at *d*. In lake-aquifer interaction studies it is the vertical hydraulic gradient which is of primary interest. Around a flow-through lake this gradient will be positive or upwards close to the shore on the up gradient side and negative or downwards on the down gradient side. It is these upward and downward flows which drive the groundwater discharge and recharge in flow-through lakes (Figure 7.4c). The water in a piezometer on the up gradient side of such a lake will rise above the level of the water table. This is because there is a greater hydraulic head at depth than at the water table. This vertical gradient drives the upward flow. Similarly on the down gradient side the vertical gradient and flow direction will be reversed and water in the piezometer will be below the level of the water table.

In Section 7.1.3 we examined partially and fully penetrating flow regimes. The 2D sections in Figures 2, 3 & 4 clearly demonstrate that capture and release zones do not always penetrate to the base of the aquifer. Constructing a nest of piezometers terminating at different depths allows the vertical distribution of hydraulic heads to be defined. It was our initial intention that extensive 2D modelling would be performed to augment the field studies completed by Townley *et al* (1993 a&b) and validate the models of Nield *et al* (1994). In particular it was proposed that calibrated 2D models might be capable of defining the groundwater flux by combining solute and isotopic data with the dimensionless ratios defined in Table 7.1. This method (Townley *et al* 1993a p287-294) relies on knowing (among other things) the release zone depth (b_-). The ratio of release zone depth to aquifer thickness (b_- /B) and (b_-) must be measured at a distance $L = 2B$ down gradient in an equivalent isotropic domain (*ibid* p298). In an anisotropic real world this distance is increased by the square root of the anisotropy ratio (*ibid* p171 & 298). This ratio was (and remains) unknown, but using the assumption $K_x / K_z = 50$, and where *B* is 35m then

$$L = 50^{0.5} 2(35) \tag{7.1}$$

This suggested that N5 should be a minimum 400-500m down gradient of East Lake - where it was ultimately constructed[3]. Piezometers N1-N4 were installed at the up and

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[3] the only available data (Chapter 3, Table 3.4) suggests anisotrophy ratios of 100 to over 1000 for Swan Coastal Plain sediments. This resulted in N5 placements 700 to 2200m down gradient, an impractical distance.

down gradient basin margins along the regional groundwater flow lines where they bisected each lake (Figure 3.3 and insert Figure 7.6). Nest N5 was located 420m down gradient of East Lake. All five were of identical construction, comprising three wells designated a to c as summarised in Table 7.4. It was important that the deepest ('c') piezometers were screened at or below the maximum capture and release zone depths (b_-). Possible values were estimated from FlowThru (Townley *et al* 1992). Using known values of *2a* and *B*, setting K_x / K_z equal to 10 to 100 and *D* equivalent to up to 2m of mud with hydraulic conductivity 1.0 to 0.1m d^{-1} suggested that b_- lay in the range 10 to 18m below the water table. Using an auger rig, all deeper holes were terminated in limestone with the target depth reached only with difficulty. All 15 piezometers were fitted with capacitive water level loggers calibrated with weekly manual readings.

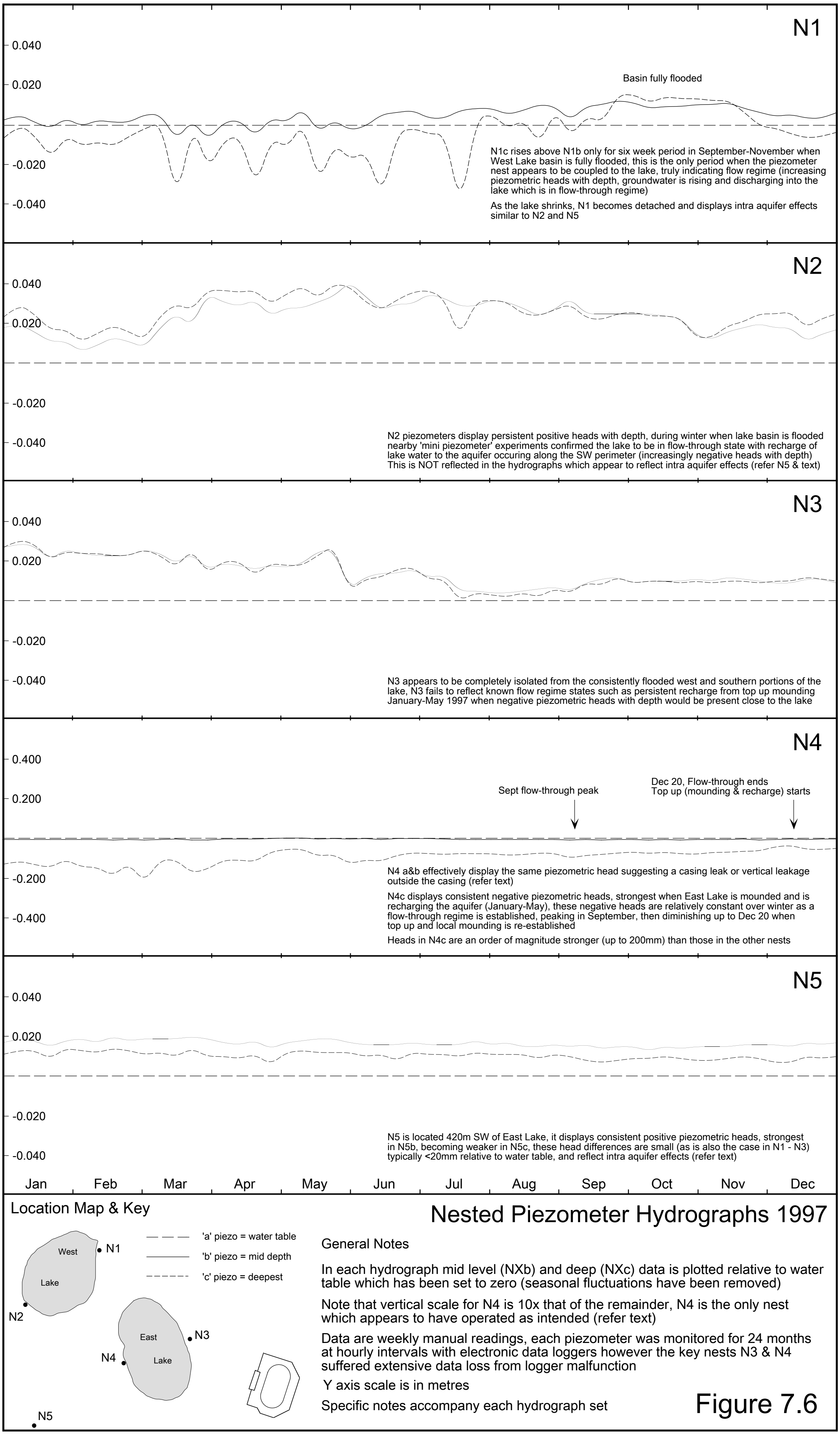
Table 7.4 Nested piezometer details N1-N5

Target	Well	Depth[1]	Screen
Water table	'a'	2.0	1.5-2.0
Mid level	'b'	10.0	9.5-10.0
Max b_-	'c'	18.0	17.5-18.0

[1] depth below minimum winter water table
All piezometers constructed from 50mm PVC

The nested piezometers were to be the primary physical tool by which lake flow regimes would be identified and monitored. It was anticipated that their data would provide an unequivocal framework for guiding the integrated balances which would quantify water masses and in particular the groundwater flux. Considerable thought and discussion preceded the piezometer installation and it is therefore important to digress slightly and investigate why they failed to function as planned.

The study period 1996-97 coincided with the transition from permanent to seasonal lakes. When the piezometer nests were planned during 1994 West Lake had not (in recent years) completely dried out over summer and weekend top up was sufficient to maintain East Lake as a contiguous water body from the NW Arm to the South Basin. West Lake first dried out completely (apart from the basin around the staff gauge) in February 1995 and remained so as late as the first week of July 1995. East Lake on July 4, 1995 was at a stage of only 2.9m and confined to the South Basin. These extreme low water conditions were ascribed to several seasons of below average rainfall. In hindsight these levels were merely a continuation of a long term decline in regional groundwater levels (Chapter 2). Unfortunately the piezometer installation coincided with the critical point where the lakes became dry for portions of each annual groundwater cycle.



N1c rises above N1b only for six week period in September-November when West Lake basin is fully flooded, this is the only period when the piezometer nest appears to be coupled to the lake, truly indicating flow regime (increasing piezometric heads with depth, groundwater is rising and discharging into the lake which is in flow-through regime)

As the lake shrinks, N1 becomes detached and displays intra aquifer effects similar to N2 and N5

N2 piezometers display persistent positive heads with depth, during winter when lake basin is flooded nearby 'mini piezometer' experiments confirmed the lake to be in flow-through state with recharge of lake water to the aquifer occuring along the SW perimeter (increasingly negative heads with depth) This is NOT reflected in the hydrographs which appear to reflect intra aquifer effects (refer N5 & text)

N3 appears to be completely isolated from the consistently flooded west and southern portions of the lake, N3 fails to reflect known flow regime states such as persistent recharge from top up mounding January-May 1997 when negative piezometric heads with depth would be present close to the lake

N4 a&b effectively display the same piezometric head suggesting a casing leak or vertical leakage outside the casing (refer text)

N4c displays consistent negative piezometric heads, strongest when East Lake is mounded and is recharging the aquifer (January-May), these negative heads are relatively constant over winter as a flow-through regime is established, peaking in September, then diminishing up to Dec 20 when top up and local mounding is re-established

Heads in N4c are an order of magnitude stronger (up to 200mm) than those in the other nests

N5 is located 420m SW of East Lake, it displays consistent positive piezometric heads, strongest in N5b, becoming weaker in N5c, these head differences are small (as is also the case in N1 - N3) typically <20mm relative to water table, and reflect intra aquifer effects (refer text)

Nested Piezometer Hydrographs 1997

General Notes

In each hydrograph mid level (NXb) and deep (NXc) data is plotted relative to water table which has been set to zero (seasonal fluctuations have been removed)

Note that vertical scale for N4 is 10x that of the remainder, N4 is the only nest which appears to have operated as intended (refer text)

Data are weekly manual readings, each piezometer was monitored for 24 months at hourly intervals with electronic data loggers however the key nests N3 & N4 suffered extensive data loss from logger malfunction

Y axis scale is in metres

Specific notes accompany each hydrograph set

Figure 7.6

Piezometers were installed in December 1995 in positions which assumed that the bulk of the lake basins would be covered by water for most of the year. Instead West Lake became dry for 6-7 months of every year and the wetland managers had increasing trouble maintaining water in East Lake for 6 months of every year (refer Chapter 7.6). Commencing in late summer 1995 only the South Basin had permanent water despite regular top up. Over the period of intense monitoring (1996-98), the permanently wetted area of East Lake continued to decline and became restricted to the South Basin, well offset from N3 and N4. Similarly, West Lake was dry for at least half of both 1996 and 1997.

Despite this, it was expected that the piezometer nests would function as planned during winter high water conditions when both lake basins were flooded. They didn't. What we found instead were seasonally persistent patterns of very weak positive or negative heads (relative to the water table) which often contradicted the lake-aquifer hydrology indicated using other methods (Figure 7.6). These are interpreted as piezometric effects within the aquifer resulting from its strongly layered stratigraphy, particularly the presence of limestone. For example the magnitude of these head differences in N5 (420m distant from East Lake) is similar to those observed in N1 and N2 when West Lake is dry. Importantly local pump tests (Table 3.4) confirm that the surficial aquifer is not unconfined. This is in agreement with pump tests elsewhere on the Swan Coastal Plain which indicate persistent semi-unconfined and locally semi-confined conditions consistent with strong vertical heterogeneity. Local vertical differences in piezometric head are probably widespread, but seldom documented. They have been reported west of the East Beeliar chain of wetlands, around Jackadder Lake and elsewhere (refer Chapter 7.7).

N4 was the only nest which appeared to consistently indicate lake-aquifer interaction. We can really only compare N4a and N4c as heads in a and b displayed negligible difference. There are two possible explanations:

1: the piezometer casing in N4b leaks close to the water table

2: vertical mixing is occurring outside the casing neutralising any head differences

Vertical mixing results from incorrect piezometer construction. The recommended way to construct piezometers in sand/rock layered aquifers is to insert the piezometer tube into a cased hole and then back grout to prevent vertical communication outside the casing (Wallis Drilling pers com). The grout is injected under pressure via the annulus between the casing and the piezometer tube, as the casing is withdrawn, completely sealing the drill hole void above the piezometer screen. This was not possible with the equipment used to construct these piezometers which were drilled open hole and backfilled by hand filling drill spoil from the top of the hole.

As we will see in subsequent sections of this chapter strong piezometric heads persisted in and close to the wetted sections of the lake basins. Apart from N4 (which was within 10m of water most of the time) the piezometers were simply outside the zone of lake-aquifer interaction. The data represent a graphic field demonstration of the extreme influence of anisotropy on lake-aquifer domain geometry.

7.2.2 In Lake Piezometer Close to the Dividing Stream Line, East Lake

Piezometric heads in nest N3 failed to provide any resolution of lake-aquifer flow regimes. Lack of funding precluded construction of a second piezometer nest closer to the South Basin. During July and August 1996, access tubes for thermistor strings were installed at ten locations within East Lake. These are shown in Figure 5.1a and described in detail in Chapter 9. These tubes were sludged[4] through the lake lining to a constant depth of 7m below the sediment-water interface. The tubes were open at the bottom and sealed to above the water surface, and therefore (unintentionally) functioned as in-lake piezometers. Observations prior to thermistor string installation showed consistent positive heads in tubes close to the east shore (TS 2, 6 and 9) and negative heads close to the west shore (TS 5, 8 and 10). TS 3 displayed weaker positive heads while TS 4 and 7 had levels close to that of the lake (but generally weakly positive). The access tube data showed quite clearly that the lake was in flow-through mode and that the position of the dividing streamline must lay close to and slightly west of TS 4 and TS 7. Head differences in TS 2, for example, were typically in the order of 300mm relative to the lake surface. This effect became progressively less intense in TS 3 and TS 4. These observations are entirely consistent with model simulations of bottom seepage (Townley *et al* 1993b p28). Moore & Turner (1989) used similar techniques to confirm and sample discharge across the bed of Lake Clifton. In Wisconsin, Cherkauer & Zager (1989) used in-lake piezometers to identify reverse flow from adjacent transient mounds.

These quite accidental observations suggested that a shallow piezometer located close to the winter position of the dividing streamline could show subtle changes in flow regime. During rain, storm drain inputs would raise the lake surface, the lake would immediately tend towards recharge (say from FT1 to FT3 or R). Regardless, the dividing stream line would also migrate up gradient and the level within the piezometer would fall as the piezometer would now be on the down gradient side of the dividing streamline. At Shenton Park Lake Sim (1995) showed that small lakes with large storm water inputs can oscillate rapidly between flow-through and recharge status.

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[4] using a sludge pump (a miniature version of the familiar cable tool drill rig bailer) consisting of a section of steel pipe with a ball valve at the base.

A single in-lake permanent mini-piezometer W28 (Figures 5.1a & 7.7b) was sludged through the lake lining clays close to the anticipated winter position of the dividing stream line. Subsequent mini-piezometer experiments November-December 1997 showed that the dividing stream line orientation becomes more east-west as the lake shrinks however this was not known when W28 was installed. The W28 location was therefore a compromise. As the lake shrinks and approaches dryness, the dividing stream line migrates southwest, however for lake stage >3m W28 lies on or very close to the dividing stream line. The piezometer was fitted with a standard Dataflow logger and 2m capacitive water level sensor. Data (Figure 7.7a) was collected from April 15 to October 18, 1997 (at which time the logger failed).

Interpretation of the W28 data assumes that:

- the piezometer always lies on or close to the dividing stream line, therefore under stable flow-through conditions, piezometric head will be very close to lake surface level
- during storm events drain inputs will push the lake towards recharge status, the lake surface will then exceed the piezometric head

Interpreted flow status is summarised in Figure 7.7a. During April and May East Lake was being periodically maintained through top up and was clearly mounded (recharge status). This situation continued into July, becoming more extreme during rain events in late June. Between early July and lake stage peak (3.575m September 10) the lake oscillated between recharge and flow-through status. This oscillation between flow states is a direct consequence of storm drain inputs which can double the lake volume and substantially increase lake stage within a few minutes. The patterns are similar to those observed at Shenton Park Lake (Sim 1995). Following September peak stage, flow through status persisted as the lake shrank until artificial maintenance commenced December 20.

As a single fixed piezometer W28 was of limited usefulness because its position relative to the dividing stream line was never certain. Along with the thermistor tubes however it provided valuable 'proof of concept' data. This lead directly to experiments with numerous 'mini piezometers' to track dividing streamline migration, described later in this chapter.

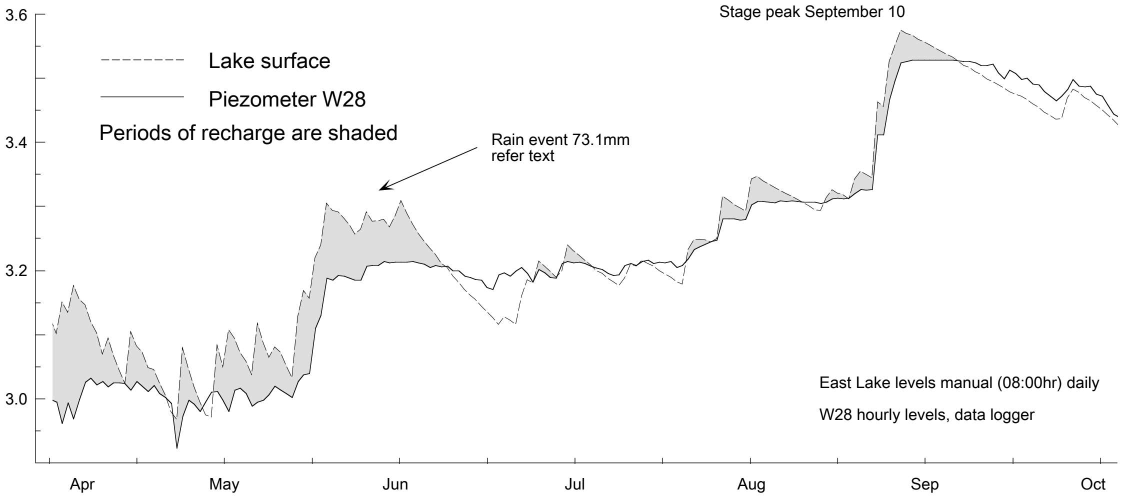
7.2.3 Near Lake Water Table Levels

Comparison of lake and monitoring well levels

Where lakes intersect the unconfined aquifer there is nil horizontal gradient. The lake surface is horizontal and piezometric head at the sediment-water interface is everywhere

In Lake Piezometer W28 Hydrograph, Winter 1997

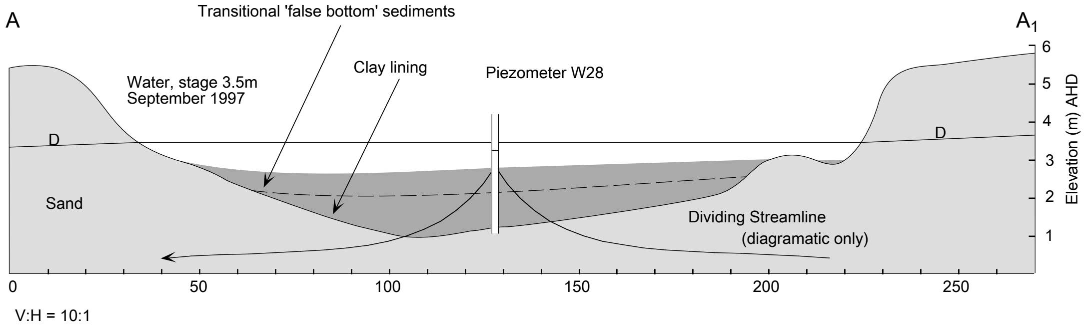
Figure 7.7a

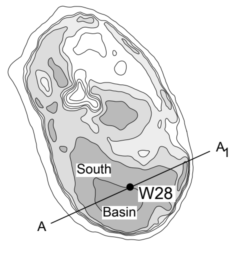


East Lake flow regimes winter 1997 as indicated by piezometer located on the approximate position of the dividing streamline, data spans April 15 - October 18, a well defined constant recharge regime in late summer oscillates between recharge and flow-through as lake and local water table levels rise over winter with constant flow-through established by late winter peak levels

In Lake Piezometer on the Dividing Stream Line

Figure 7.7b





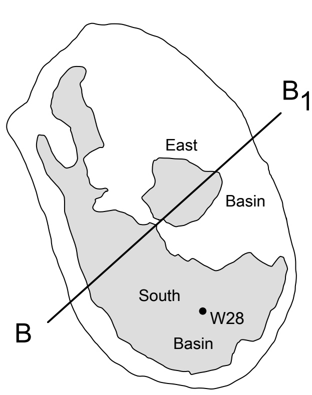
Shaded areas are water surface at 3.5m stage

Piezometer W28 is shown located directly on the position of the dividing streamline. Initial experiments over winter 1996 during thermistor access tube construction suggested that once a winter flow-through regime was established in East Lake the position of the dividing streamline did not vary much. This lead directly to the W28 experiment (installed April 1997) and later mini piezometer experiments as East Lake approached dryness Nov & Dec 1997

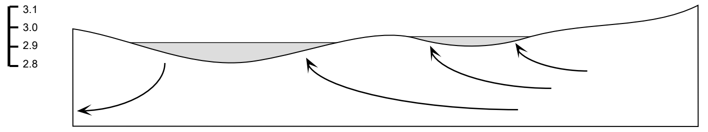
W28 was fitted with a standard Dataflow logger and capacitive water level probe, readings hourly

Flow Regime Detail, East Basin

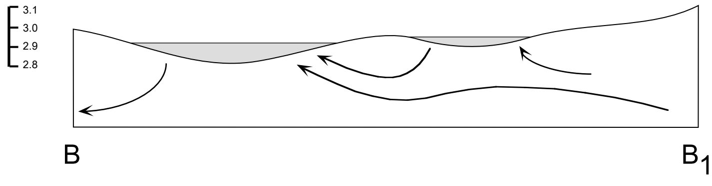
Figure 7.7c



November 25-December 02
Discharge Regime



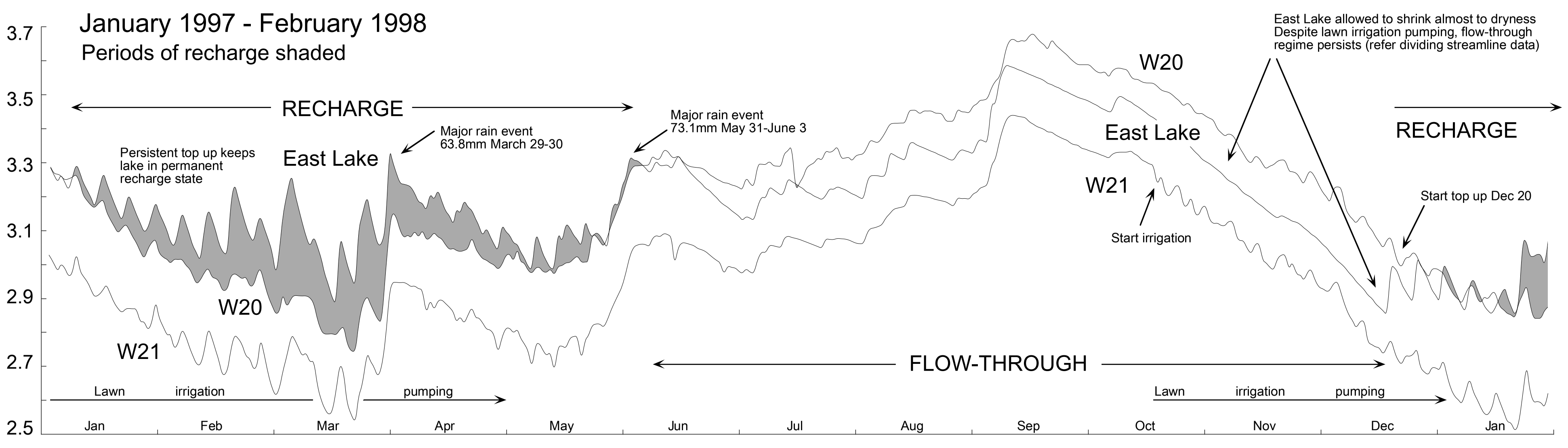
December 02-December 14
Flow-through regime

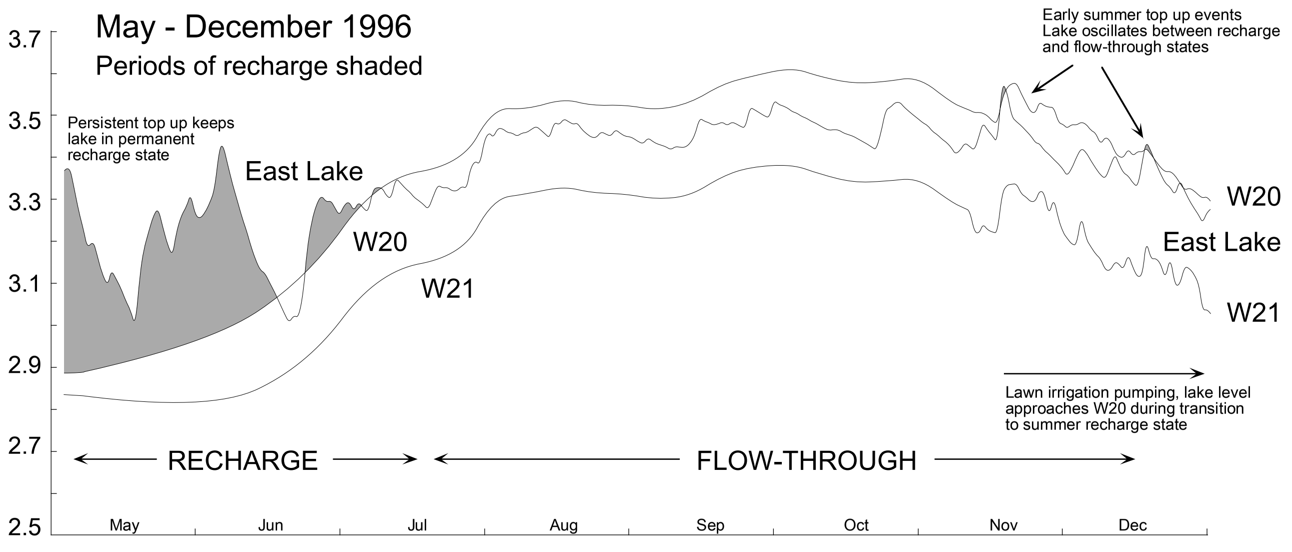


equal to the elevation of the water surface (Townley *et al* 1995 p28). Therefore subtle differences in water table close to a flow-through lake can assist in providing clues about its flow state. Consider a roughly circular lake within which a flow-through regime is established. Along a line bisecting the lake and parallel to the regional gradient groundwater levels will increase up gradient and decrease down gradient. A line bisecting the lake normal to the regional gradient will exhibit no change in slope as the lake is approached. Such a line is parallel to the regional water table contours at a water table elevation equal to the lake surface. Keeping this in mind, changes in the relationship between lake level and nearby groundwater level can provide additional clues regarding lake-aquifer flow status.

Detailed analysis of electronic logger data from wells W20 and W21 immediately up and down gradient provide gross patterns of annual flow status in East Lake. With reference to Figure 7.8 summer (1996 and 1997) top up maintained a local groundwater mound with the lake level always above W20 (defined by shading in Figure 7.8). This pattern was maintained up to the major early winter frontal passage May 31-June 3 when 73.1mm rain fell over four days. Shortly thereafter a winter flow-through regime was established with W20 SWL>East Lake>W21 SWL. Comparing Figure 7.7a (the in-lake piezometer W28) with Figure 7.8 it is evident that in such highly permeable sands such mounds decay quickly. The mound was present at W20 only for several days whereas in and immediately adjacent to East Lake recharge status persisted for about three weeks. This large storm induced mound will be further discussed in Section 7.3.

The relationship between a flow-through lake and wells equidistant up and down gradient is clearly illustrated in the hydrographs October-December 1997 where the East Lake level lies between but is synchronous with W20 and W21. Approximately two weeks after top up commenced lake level was higher than W20 (shaded) for each top up session (defined by peaks in the hydrographs). Remember that W20 was 50 to 100m up gradient of the closest flooded section of the lake. The shaded portions of the hydrograph records represent mounding peaks. East Lake was often locally mounded but with a stage less than the SWL in W20. As an experiment plots showing the level of W20 were adjusted down by an amount equal to the average watertable difference between W20 and East Lake during stable winter flow-through conditions (about 120mm). Experimentally setting W20 120mm lower essentially duplicated the patterns observed using the in-lake piezometer W28.





Identification of Flow Regimes Natural & Artificially Induced East Lake

East Lake data daily manual reading at staff gauge

Well hydrographs May - November 6, 1996 generated from weekly manual reading

Well hydrographs November 7, 1996 - February 1, 1998 generated from dataloggers operating hourly & corrected weekly against manual readings, plotted data is daily 1400 hr level

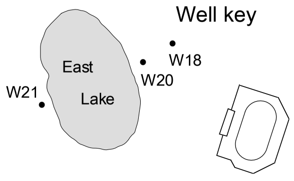


Figure 7.8

Identification of Reverse Groundwater Gradients

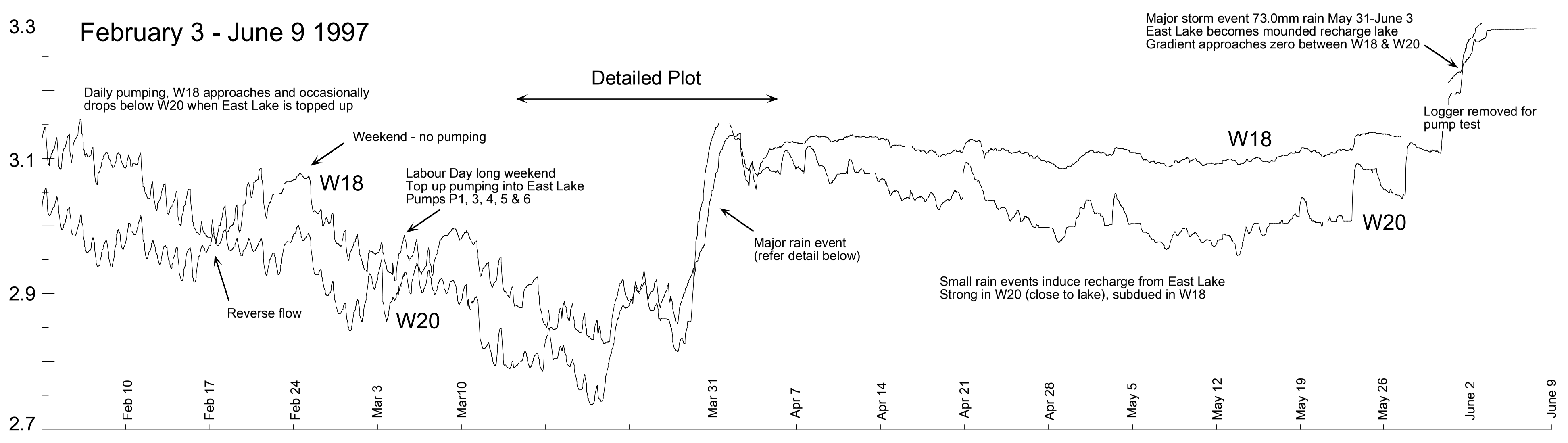
Mounding, whether from lake top up or storm water, induces negative groundwater gradients northeast of East and West Lake. Such gradients can also be enhanced by, or result directly from irrigation pumping. Wharton (1981a) identified reverse gradients east of Lake Jandabup from heavy pumping for the production of potable water. At Perry Lakes the effects are frequently transient, occurring daily during irrigation. The gradient then reverses during overnight or weekend recovery. Reverse gradients were observed in hydrograph data from W18, W19, W20 and N3a at East Lake and W1, W2, W3 and N1a at West Lake. The combination of artificial lake level maintenance and persistent pumping combine to create a very dynamic groundwater system over summer. This is illustrated in data logger hydrographs from W1, W3, W18 and W20 (Figures 7.9 a&b). Well and irrigation pump locations are included in the insert maps with each figure.

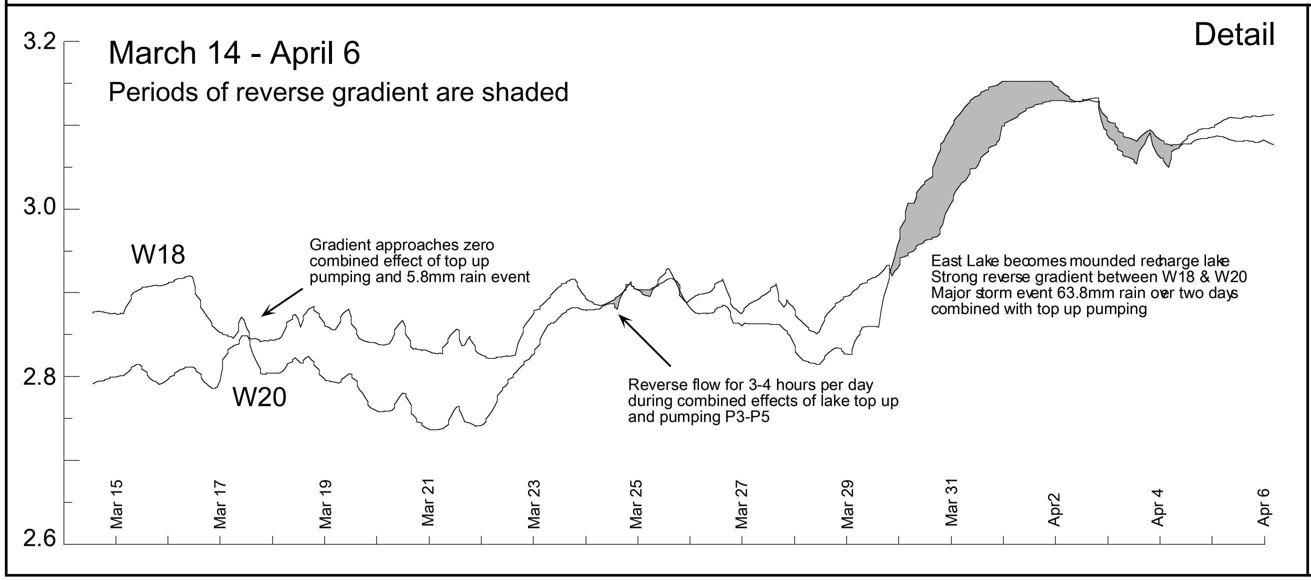
East Lake Figure 7.9a

- bores P3-P5 were used daily over summer for lawn irrigation and frequently for weekend top up to East Lake
- during daily pumping, W18 frequently approaches and occasionally drops below W20 indicating a local pump induced reverse gradient
- this usually occurs immediately following lake top up when the local mound around the lake combines with the local depression of the water table around P3-P5 (detail Figure 7.9a)
- the effect intensifies in late summer because W18 continues to decline in step with the regional water table while East Lake is maintained at the equivalent of early summer levels
- these pump induced effects are small compared to lake top up and mounding from large late summer storm events such as that of late March 1997 which mounded East Lake creating reverse gradients which persisted for a week (detail Figure 7.9a)

West Lake Figure 7.9b

- over summer 1997 the West Lake basin remained dry, reverse gradients in W1 and W3 resulted directly from irrigation pumping from P2, P7 and P8
- difference in level between W1 and W3 diminishes in late summer, but unlike East Lake this is a direct consequence of pumping which maintains a very shallow groundwater gradient below the Alderbury Flats over summer
- the gradient recovers when pumps are off for several days such as March 22-24 (detail Figure 7.9b)
- as in East Lake, the pump induced effects are small in comparison with the storm induced lake mounding in late March (detail Figure 7.9b)





Natural & Artificially Induced Reverse Groundwater Gradients East Lake

Hydrographs generated from dataloggers operating hourly and corrected weekly against manual readings
Distance between W18 & W20 80m
Typical difference in SWL in winter (no pumping)
0.04-0.05m, winter gradient approximately 0.0007

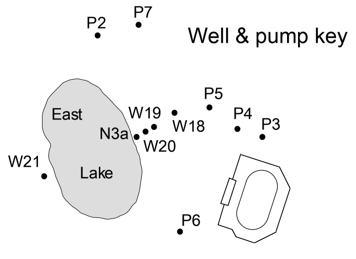
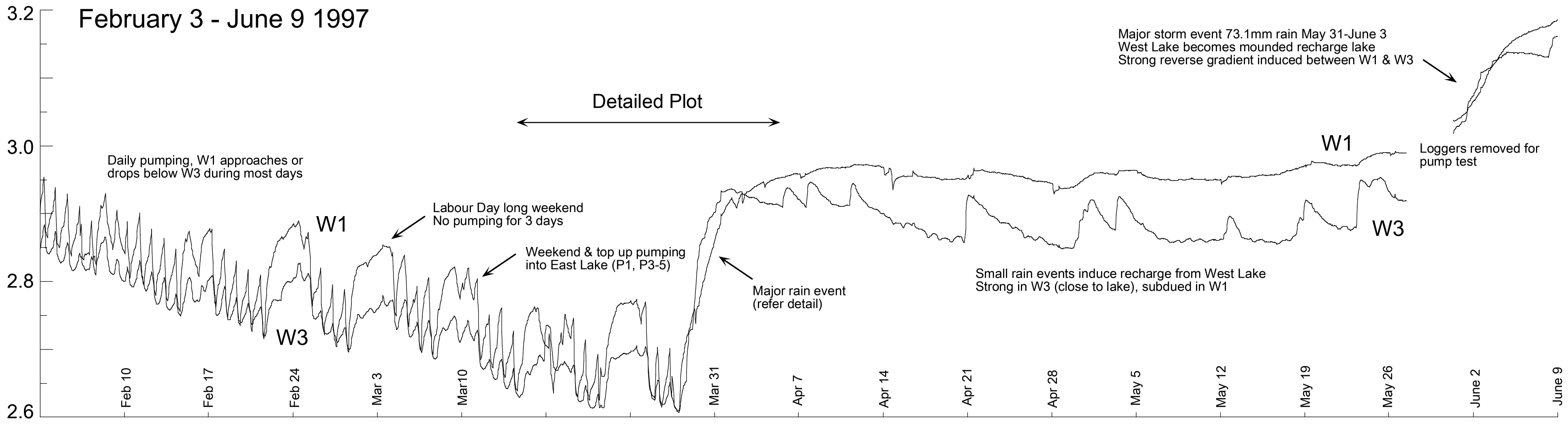
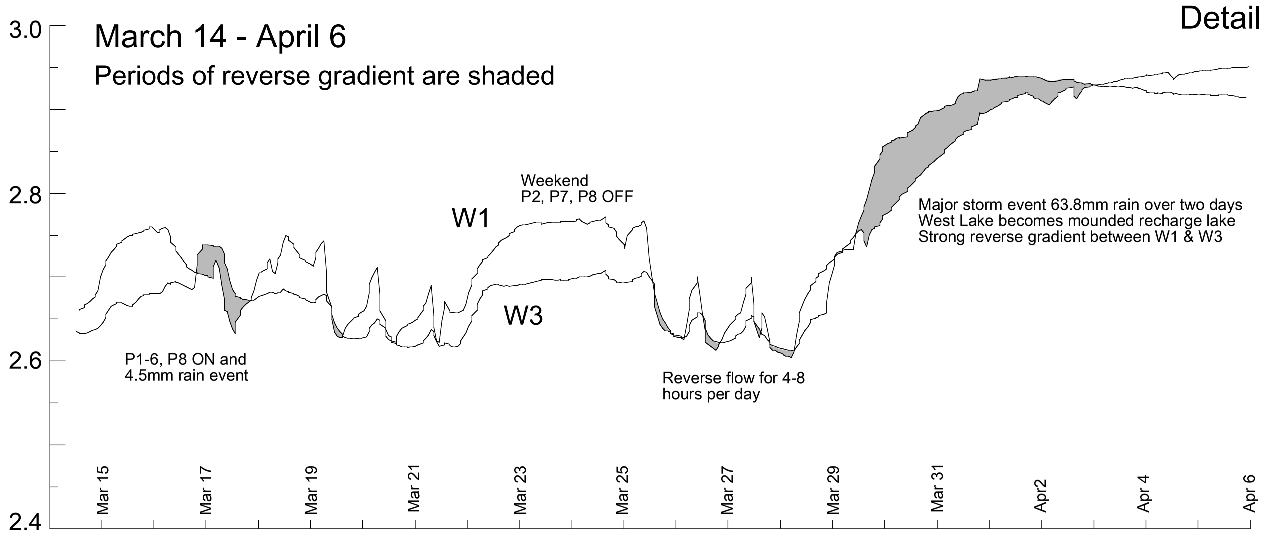


Figure 7.9a





Natural & Artificially Induced Reverse Groundwater Gradients West Lake

Hydrographs generated from dataloggers operating hourly and corrected weekly against manual readings

Distance between W1 & W3 130m

Typical difference in SWL in winter (no pumping) 0.12-0.13m, winter gradient approximately 0.001

Well & pump key

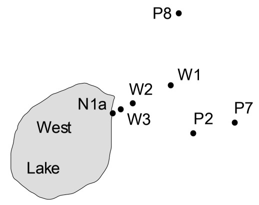


Figure 7.9b

7.2.4 Dividing Stream Line Mapping using Lake Edge 'Mini Piezometers'

The method was adapted from earlier field experiments used to define the distribution of seepage into lakes (Lee & Cherry 1978, Woessner & Sullivan 1984) and pore water sampling (Krabbenhoft & Webster 1995) who used small tubes around groundwater discharge/recharge points to determine the vertical direction of the hydraulic gradient at the sediment-water interface. Previous experiments with the in-lake piezometer W28 and thermistor access tubes clearly indicated that piezometric head differences could be readily measured close to the edge of the lake. Cherkauer & Zager (1989) used similar in-lake piezometers to plot stagnation zone migration.

Initial experiments using 'short' (relative to aquifer thickness) piezometer tubes confirmed that head differences could easily be resolved using tubes as short as 1m when installed close to the lake margin, using the level of the lake as a datum. A tube 2.5m long (Figure 7.11c) was chosen as a 'standard' (it is the longest practical length which can be installed with a manual sludge pump without having to glue sections). Mini piezometers are easiest to use when the piezometer lip is about 10cm proud of the lake surface. Head differences can be rapidly observed and measured. Once the approximate position of the dividing stream line has been established, additional piezometers can be installed to provide greater resolution. Figure 7.10 demonstrates how mini piezometers installed around a flow-through lake can be used to resolve the position of the dividing streamline. Piezometers located on the dividing streamline will show piezometric heads equal to the lake surface. Maximum and minimum piezometric heads occur at the centre-line of the capture and release zones respectively. Mini piezometer studies permit rapid identification of gross flow state (D-FT-R) and allow the position of the dividing streamline to be mapped as the lake responds to differing hydrological conditions.

During the period November 11-December 20 1997, East Lake was allowed to recede almost to dryness without artificial top up. Migration of the dividing stream line was observed by daily (early morning) observation of the mini piezometers. As levels declined additional piezometers were installed and existing ones removed and re-installed. The process was labour intensive, but provided a detailed picture of the dividing stream line migration over a two month period.

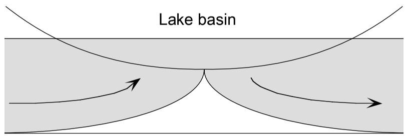
The results are displayed graphically in Figures 7.11a-c, and summarised below.

- During the period November 17-20 the dividing streamline position was observed to oscillate between mini piezometers MP 9 & 10. The reason for these small shifts is not known but is probably related to nearby pumping.
- Between November 20 & 29 the southwest section of West Lake detaches from the main lake. The dividing streamline immediately shifts position.

Dividing Streamlines Defined using Mini Piezometers Figure 7.10

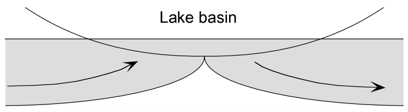
Transition in Flow Patterns as Flow-Through Lake Dries Out

A



Lake basin completely flooded, influence of positive and negative piezometric pressure extends well beyond the lake basin

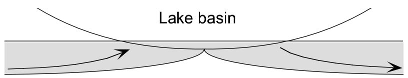
B



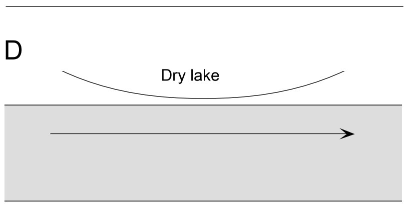
As the lake shrinks, areal influence of the locally induced positive and negative heads becomes smaller and smaller.

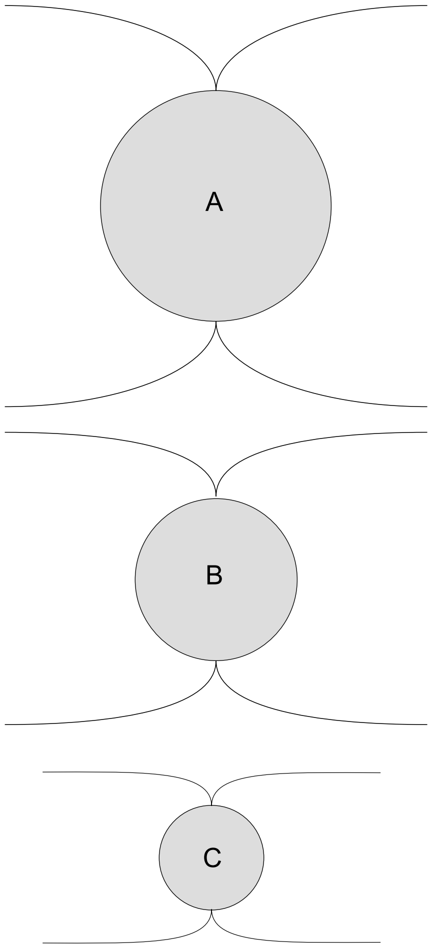
As dryness is achieved, horizontal flow is re-established in aquifer

C



D





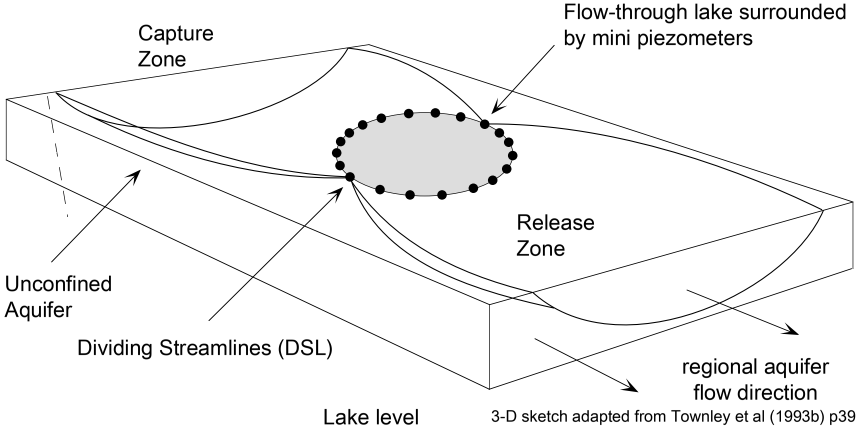
These patterns help explain why piezometer nests adjacent to the lake basins did not respond to flow regimes in the lakes whereas much shallower mini piezometers within or at the lake shore displayed large differences in piezometric head

Sketches adapted from Townley et al (1993b) p71

Notes:

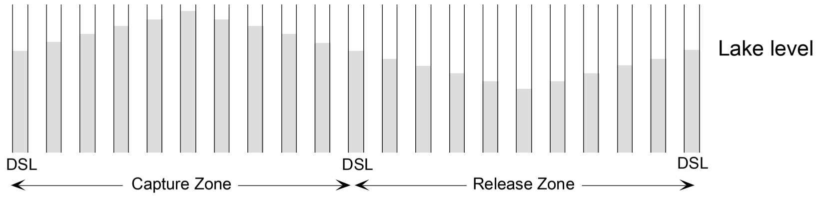
Model assumes a homogeneous aquifer and distribution of lake lining with all piezometers installed to same depth and position relative to shore

In a flow-through lake, the dividing streamlines occur where the piezometric head is equal to the lake surface



3-D sketch adapted from Townley et al (1993b) p39

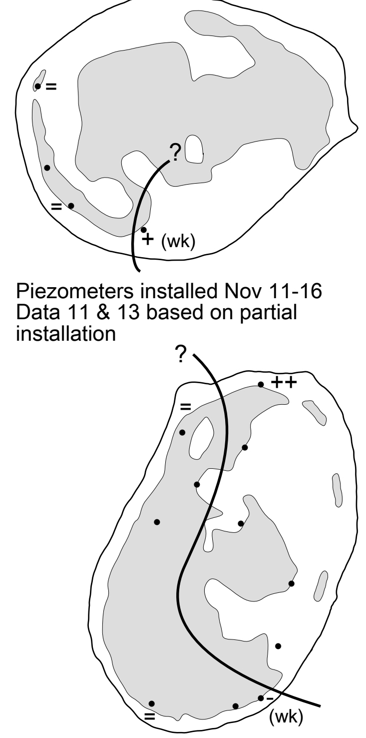
Piezometer Response



Dividing Stream Line Migration

Figure 7.11a

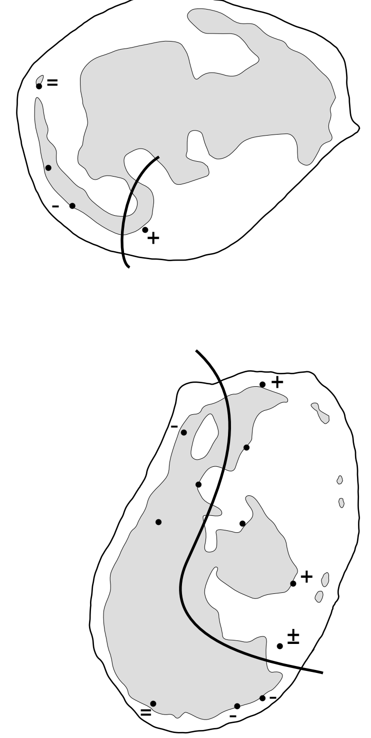
November 11
Thursday



Piezometers installed Nov 11-16
Data 11 & 13 based on partial installation

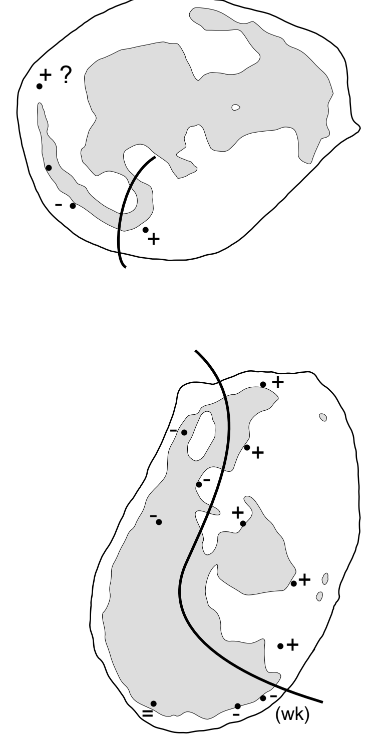
East Lake stage: 3.209
West Lake stage: 3.095

November 13
Saturday



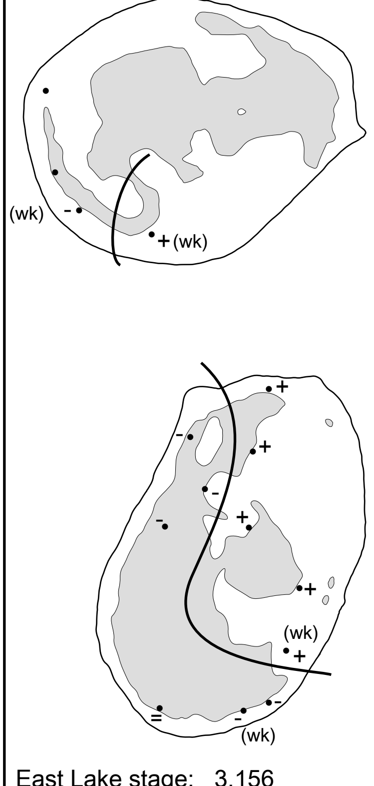
East Lake stage: 3.190
West Lake stage: 3.080

November 16
Tuesday



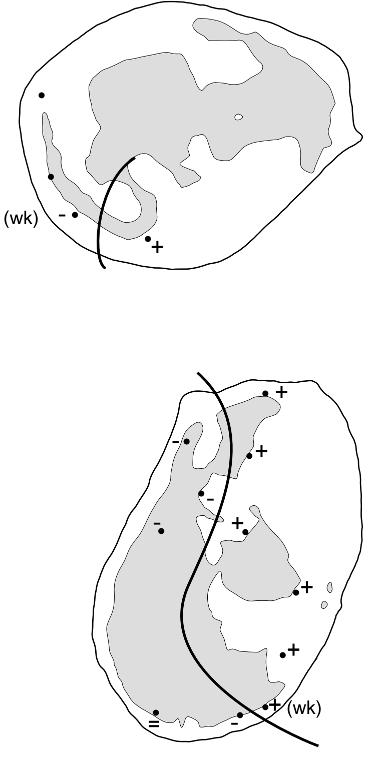
East Lake stage: 3.164
West Lake stage: 3.059

November 17
Wednesday



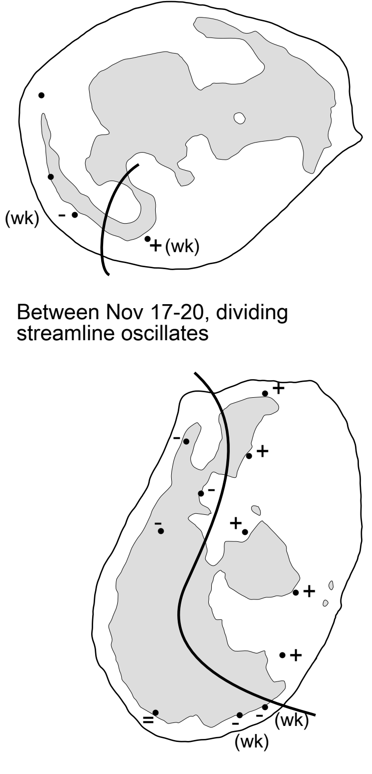
East Lake stage: 3.156
West Lake stage: 3.052

November 18
Thursday



East Lake stage: 3.148
West Lake stage: 3.045

November 20
Saturday

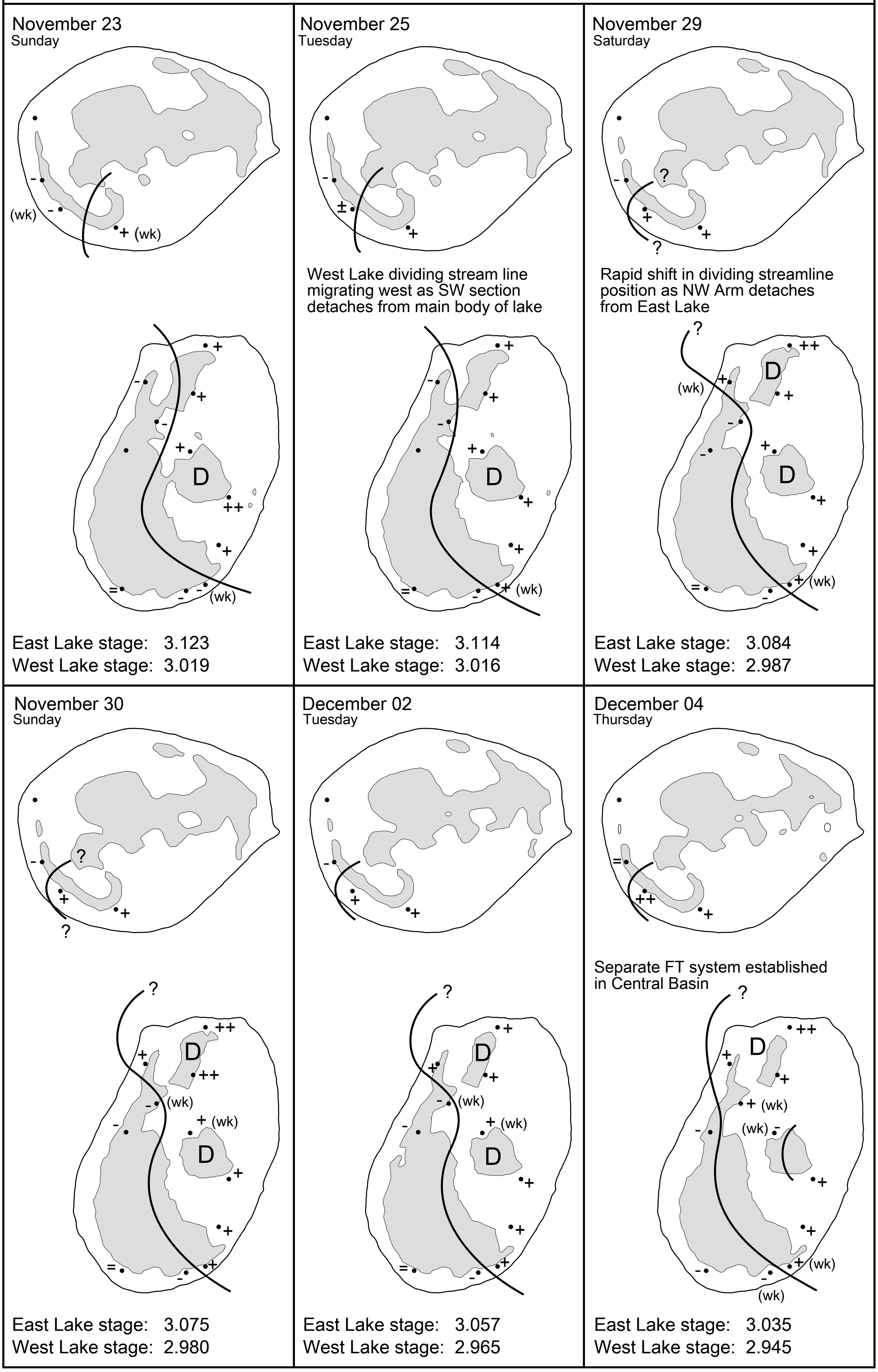


Between Nov 17-20, dividing streamline oscillates

East Lake stage: 3.130
West Lake stage: 3.027

Dividing Stream Line Migration

Figure 7.11b



November 23
Sunday

East Lake stage: 3.123
West Lake stage: 3.019

November 25
Tuesday

West Lake dividing stream line migrating west as SW section detaches from main body of lake

East Lake stage: 3.114
West Lake stage: 3.016

November 29
Saturday

Rapid shift in dividing streamline position as NW Arm detaches from East Lake

East Lake stage: 3.084
West Lake stage: 2.987

November 30
Sunday

East Lake stage: 3.075
West Lake stage: 2.980

December 02
Tuesday

East Lake stage: 3.057
West Lake stage: 2.965

December 04
Thursday

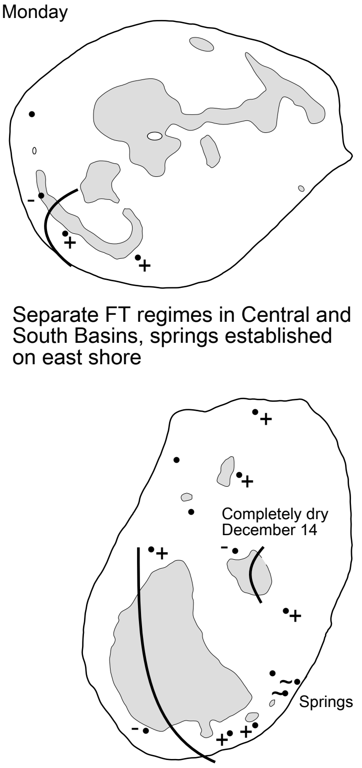
Separate FT system established in Central Basin

East Lake stage: 3.035
West Lake stage: 2.945

Dividing Stream Line Migration

Figure 7.11c

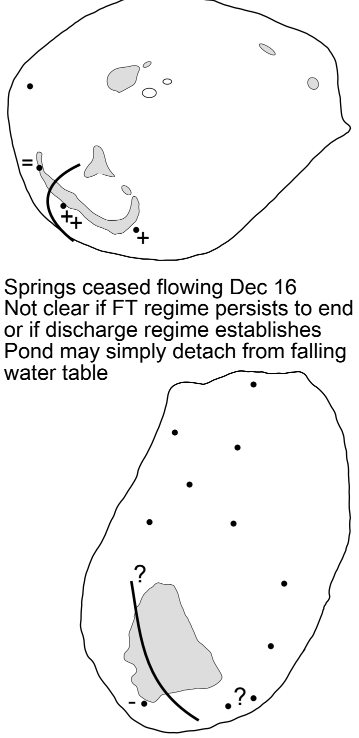
December 08
Monday



Separate FT regimes in Central and South Basins, springs established on east shore

East Lake stage: 2.988
West Lake stage: 2.908

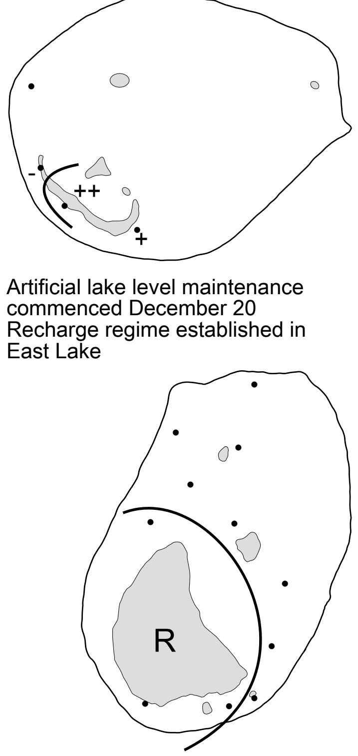
December 18
Thursday



Springs ceased flowing Dec 16
Not clear if FT regime persists to end or if discharge regime establishes
Pond may simply detach from falling water table

East Lake stage: 2.861
West Lake stage: 2.798

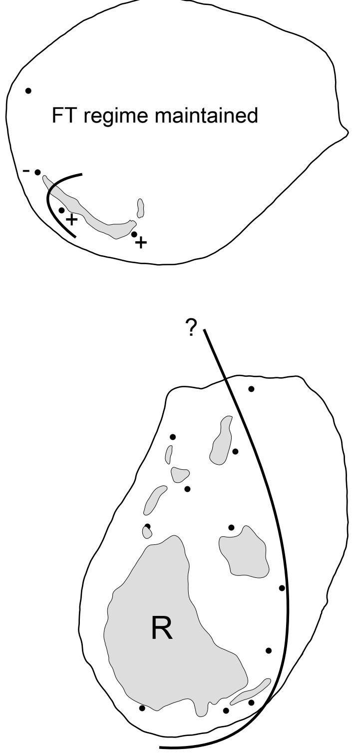
December 21
Sunday



Artificial lake level maintenance commenced December 20
Recharge regime established in East Lake

East Lake stage: 2.960
West Lake stage: 2.774

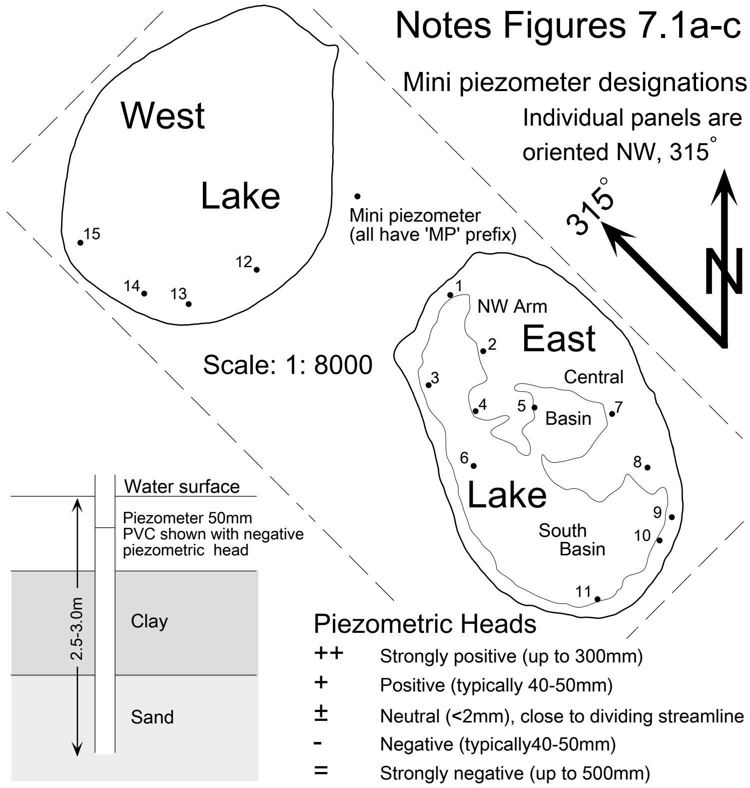
January 4
Sunday



East Lake stage: 2.990
West Lake stage: 2.681

Notes Figures 7.1a-c

Mini piezometer designations
Individual panels are oriented NW, 315°



Scale: 1: 8000

Typical mini piezometer installation detail

Piezometric Heads

++	Strongly positive (up to 300mm)
+	Positive (typically 40-50mm)
±	Neutral (<2mm), close to dividing streamline
-	Negative (typically40-50mm)
=	Strongly negative (up to 500mm)
(wk)	Weak difference (<10mm)
▬	Dividing streamline in flow-through regime
R, D	Discharge & Recharge flow regimes

- Between November 23 & 29 the Central Basin separates from East Lake. This separate pond then functions as a discharge ('D') lake for about 10 days until a separate flow-through ('FT') regime establishes. This separate FT regime does not appear to form until the principal dividing streamline has shifted west in response to detachment of the northwest arm about November 29. The detached section of the northwest arm also becomes a discharge lake.
- Between December 2 and December 8, the principal dividing streamline in East Lake continues to shift west as the lake shrinks and mini piezometers 4 & 6 develop positive heads. By December 8 the position of the dividing streamline suggests the lake may approach the FT 3 or FT 5 flow regimes of Nield *et al* (1994). A similar FT regime persists in West Lake.
- Once artificial level maintenance commenced December 20, a permanent recharge regime was established in East Lake. In West Lake a flow-through regime (possibly FT 3 or FT 5) was maintained into January 1998 when observations ceased.

As the East Basin detached separate water samples were collected daily and analysed for deuterium. This data plotted along with the routine South Basin sampling is plotted in Figure 7.12. The initial three samples were enriched relative to the South Basin. Rainfall November 22 disrupted the experiment. It was expected that under discharge conditions an influx of isotopically depleted groundwater might be observed. This would have an isotopic signature similar to that observed in the upper portions of the aquifer in N3 (Table 6.7), typically about -11‰. Isotopic enrichment of the water through evaporation however appears to predominate over any discharge which is probably minimal given that the lake lining here is 1.0 to 1.4m thick.

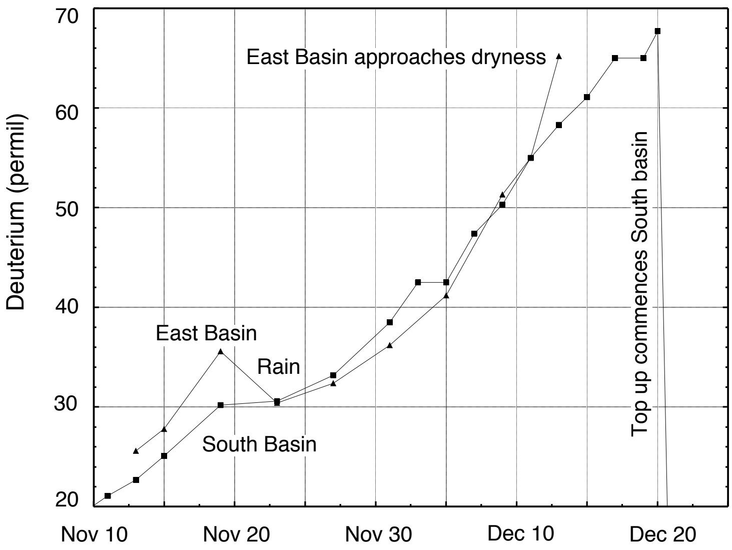


Figure 7.12 Deuterium enrichment East and South Basin. Transition from discharge to flow-through (December 4) is not evident in the data. When last sampled on December 13 the East Basin was a small pool 5x5m and 20 to 30mm deep. By December 14 it was dry

The vertical piezometric head differences observed in the mini piezometers are much greater than those observed in the large piezometer nests. Around the southern end of East Lake groundwater head differences of up to 0.7m were observed in mini piezometers only 100m apart, separated by the dividing stream line. The results indicate that when a small lake approaches dryness, the piezometric effects of lake-aquifer interaction become extremely localised. These observations agree with theoretical modelling (Townley *et al* 1993b, p28) which showed that maximum seepage in flow-through lakes occurs at the lake edge, and that this effect is enhanced by a resistive lake lining.

Townley *et al* (1995) hypothesised that as levels dropped in spring, East Lake might under go a transition from flow-through to discharge regime (Figure 7.5) prior to the commencement of summer artificial recharge. No such transition was observed. Rather flow-through regimes were maintained virtually to lake extinction. The only exceptions were the detached sections of the lake isolated up gradient which did become small discharge ponds. In the East Basin this persisted for about 12 days before a small local flow-through regime was established (Figure 7.11b). Once such a separate flow-through regime is established the two pools represent a miniature example of cascading flow through lakes where enriched waters in the release zone of one lake are captured by the adjacent down gradient lake and further enriched. Townley *et al* (1993b) illustrate a larger scale example from Lakes Pinjar and Nowergup. Figure 7.7c illustrates schematically the probable flow regime detail over the period November 25 to December 14 1997. Lakes on the Swan Coastal Plain which continue to hold water during January and February when evapotranspiration is greatest may undergo transition to discharge regimes, but such changes were not observed in the main body of East Lake as it approached dryness.

Springs and Seeps

Springs and seeps are commonly observed close to the up gradient shores of flow-through lakes on the Swan Coastal Plain (Allen 1979, Hall 1985). As levels declined in East Lake, two small springs developed along the east shore and persisted for about 10 days (December 08 panel, Figure 7.11c). The spring water is isotopically enriched (Table 7.5) suggesting that it is derived from the top of the aquifer where lawn irrigation and high evaporation off the adjacent playing fields probably produce strongly fractionated recharge.

Table 7.5 Deuterium analyses, East Lake Seeps

Date	Sample	Deuterium ‰
Dec 9	SP 1	48.7
Dec 11	SP 2	54.1
Dec 15	SP 3	56.5

7.2.5 Lake Sediment Thermal Profiling

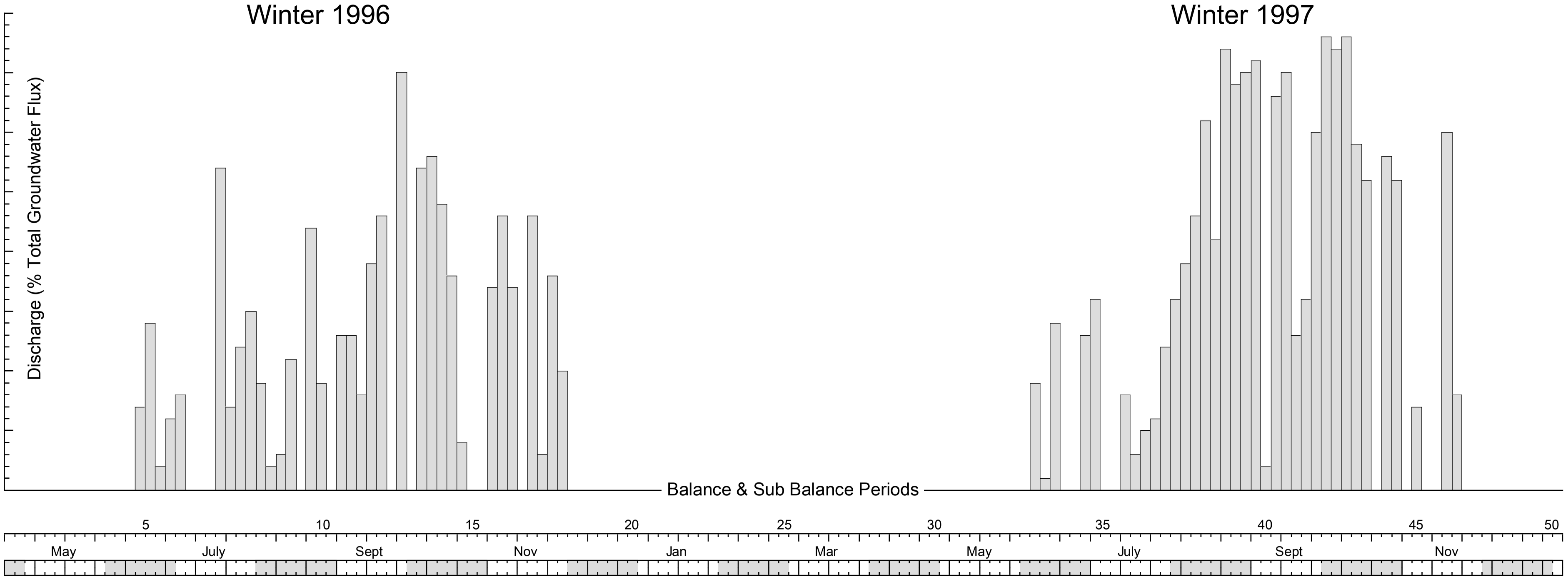
Groundwater maintains an almost constant temperature throughout the year. Lake water on the other hand displays large temperature variations over a year. Changes in flow regime therefore induce distinctive patterns in the thermal gradients below lakes. These are the subject of Chapter 9.

7.2.6 Water Balances

It is clear from the hydrograph and in-lake piezometer data that storm water, top up and intense groundwater extraction combine to make Perry Lakes a very dynamic lake-aquifer system. Reverse flow zones induced from heavy pumping may last just a few hours. In the lakes, oscillation between flow-through and recharge regimes, as a result of storm water inputs, may similarly last a few hours or several days. The integrated water balances, however, provide the best overview of lake-aquifer flow status. Balance results for December 1997 show that while piezometric data may indicate flow-through status (or at least piezometric heads conducive to flow-through) once the water is retained in the deeper clay lined portions of the lake basin the amount of water discharged becomes so small as to be non quantifiable using the integrated balances. Despite the presence of positive and negative piezometric heads, a lake is really only in a flow-through state if water is actually being discharged and recharged, in other words if there is a measurable groundwater flux through the lake.

In Chapter 6 balance results were presented (along with all other components of the balance) as 12 to 20 day 'balance period' data. If we consider only the groundwater flux components and use the more detailed four day sub balances we can obtain considerably greater detail about gross lake-aquifer status. In Figure 7.13 four day balance discharge and recharge data is presented. This is basically an integrated overview of lake-aquifer interaction over two winters and one summer. The histograms plot East Lake discharge as a percentage of groundwater flux (discharge from the aquifer and recharge to the aquifer) for all 155 four day sub balances. Where a histogram is absent, the lake was in recharge flow status (discharge equal to zero). The presence of a histogram indicates a four day sub balance in which there was measurable groundwater discharge using integrated mass-solute-isotope balances.

It is important to remember that in summer the regional water table declines naturally. As the water table declines so too do the levels in any associated water table lakes. Any mass balance must take into account all water lost and that includes water which leaves the lake due to surrounding water table decline. Therefore in summer a lake may be in



Notes

Histograms plot discharge as a percentage of total groundwater flux. Percentage flux (rather than absolute discharge water mass) is plotted because of the huge seasonal changes in lake volume (and hence discharge volume). Discharge is plotted for all 155 four day sub balances. Where vertical bars are absent East Lake was in recharge flow status (discharge equals zero). The presence of a bar indicates a four day sub balance in which there was a measurable groundwater discharge using integrated mass-solute-isotope balances. In other words periods in which East Lake was in flow-through status with measurable discharge.

The mini piezometers indicated flow-through status for some periods not indicated with vertical bars. This is because a lake is really only in flow-through status if water is actually being discharged and recharged, ie there is a measurable groundwater flux through the lake.

Refer Appendix 6.2 for sub balance details.

Flow Regime Summary
East Lake 1996 - 1998

Figure 7.13

flow-through status but with constantly falling lake levels. In this case the recharge component of the groundwater flux will generally be far greater than the discharge component because it must include all water lost as the surrounding water table declines.

7.3 FLOW REGIMES AT PERRY LAKES

7.3.1 Development of Flow Regime Contour Plots

In addition to the nested piezometers only a few of the monitoring wells in Perry Lakes Reserve were equipped with data loggers. With reference to Figure 7.15a and Appendix 2.1 these were PL1, W1, W3, W5, PL2, W15, W17, W18, W20, W21 and W25 (Camel Lake). Hydrograph data from these wells was augmented with manual readings from an additional 19 wells within Perry Lakes Reserve and 11 regional wells within a 2km radius of East Lake. These included a monitoring well within the grounds of the CSIRO complex, two wells within the UWA Field Station, GE1 in Bold Park, an abandoned production well at City Beach High School, a disused government monitoring well on Lemnos Street, two wells in McLean Park, a well adjacent to the Floreat tennis courts, one well in McGillivray playing fields and one well in Henderson Park. SWL in all wells was read manually weekly. These data comprise Appendix 7.1. The data from the regional wells were important as they imposed accurate boundary conditions for detailed water table contouring within the area of interest. Contours were generated in SURFER using a kriging routine on 10x10m grids. East and West Lake were set as constant head boundaries at the 0800hr stage. The local effect of irrigation wells was known to be large as evidenced by the persistent pumping induced reverse flow zones identified in the hydrograph data (Figure 7.9 a&b). The effects of pumping wells were imposed on the contours by estimating the form and boundary heads of the depression cones.

On a sloping water table the cone of depression of a pumping well will approximate an eccentric ellipse (Bear 1972, p323) with water table contours distorted around the well (Figure 7.14). Using pump test drawdown data for P1 and similar data logger hydrograph records for P5 from wells W18 and W20, drawdown curves (drawdown vs distance from pumped well) were developed for pumping times up to 10 hours. These two wells are representative of the two principal well types at Perry Lakes , which have different irrigation and open pipe outputs as summarised in Table 7.6.

Table 7.6 Irrigation well characteristics, Perry Lakes

Bore	Wells	Irrigation Rate	Top Up (measured)
Submersible	P1	55m^3/hr	110.5m^3/hr - 120.7m^3/hr
Turbine	P2-P8	38m^3/hr	74m^3/hr-79.5m^3/hr

Irrigation rate is manufacturer's rated output into typical pressurised distribution system
Top up rate is output measured with flow metres into non pressurised pipe during lake top-up, bores P1 & P6

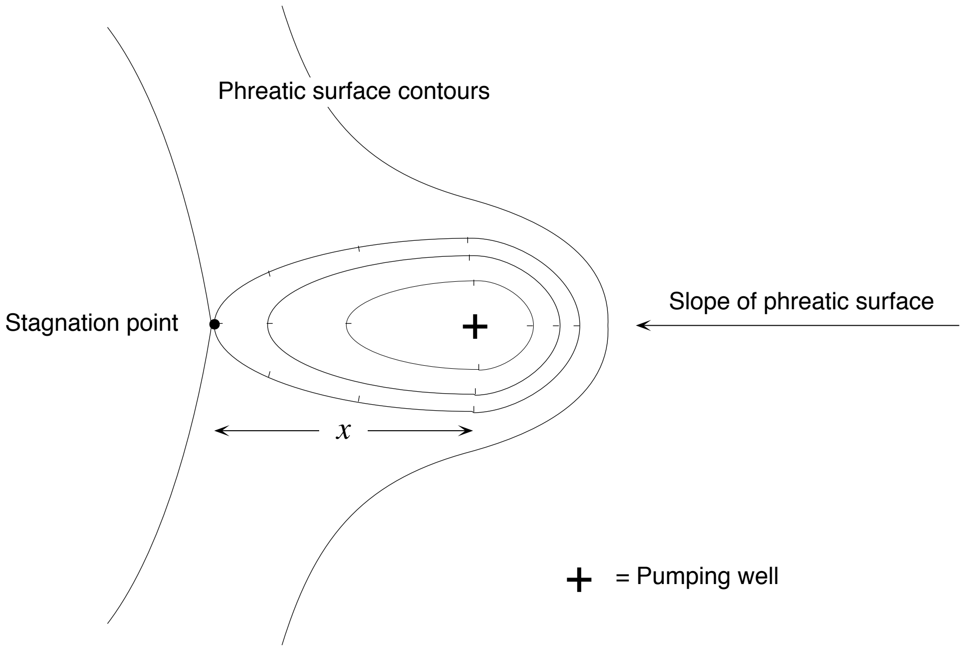


Figure 7.14 General form of the cone of depression from a pumping well superimposed on a sloping phreatic surface (after Bear 1972 Figure 7.8.10).

Theoretical distance x to the stagnation point is given by Todd (1959) as

$$x = -\frac{Q}{2\pi Kbi} \tag{7.2}$$

where Q is discharge rate (m^3 d^{-1}), K is hydraulic conductivity (m d^{-1}), b is average saturated aquifer thickness (m) and i is natural water table slope. Table 7.7 shows theoretical equilibrium values for x at typical lawn irrigation and top up rates.

Table 7.7 Distance to stagnation point x

Hydraulic Cond K (m d^{-1})		15	20	25	30
Discharge (hour)	Discharge (day)	x (m)	x (m)	x (m)	x (m)
$38m^3$ h^{-1}	912	262	196	157	131
$55m^3$ h^{-1}	1320	379	284	227	189
$75m^3$ h^{-1}	1800	516	387	310	258
$120m^3$ h^{-1}	2880	826	619	496	413

Slope set to 0.001 which is average phreatic surface slope around Perry Lakes, b set to 37m

For each contour period a stagnation point elevation was estimated and an ellipse of x = 100m (P2-P8) and 200m (P1) set as a constant head boundary in SURFER. Where P3-P4-P5 were pumping simultaneously, the outline of superimposed ellipses was used. In many cases the position of the stagnation point can be closely estimated from monitoring wells. This, when compared to Table 7.7 suggests that the effective hydraulic conductivity for wells pumped in the basal sands and monitored at the phreatic surface approaches 30m d^{-1}. This is very close to the 27m d^{-1} estimated in Chapter 3 from steady state pump test data.

Data for 17 February to 5 May 1997 were collected on Mondays while irrigation bores were operating to maximise the combined 'artificial' effects of weekend top up and weekday lawn irrigation. There was no lawn irrigation over the period 2 June to 12 October during which data was generally collected on Sundays. 'Unnatural' flows during this period were induced solely by storm drain input.

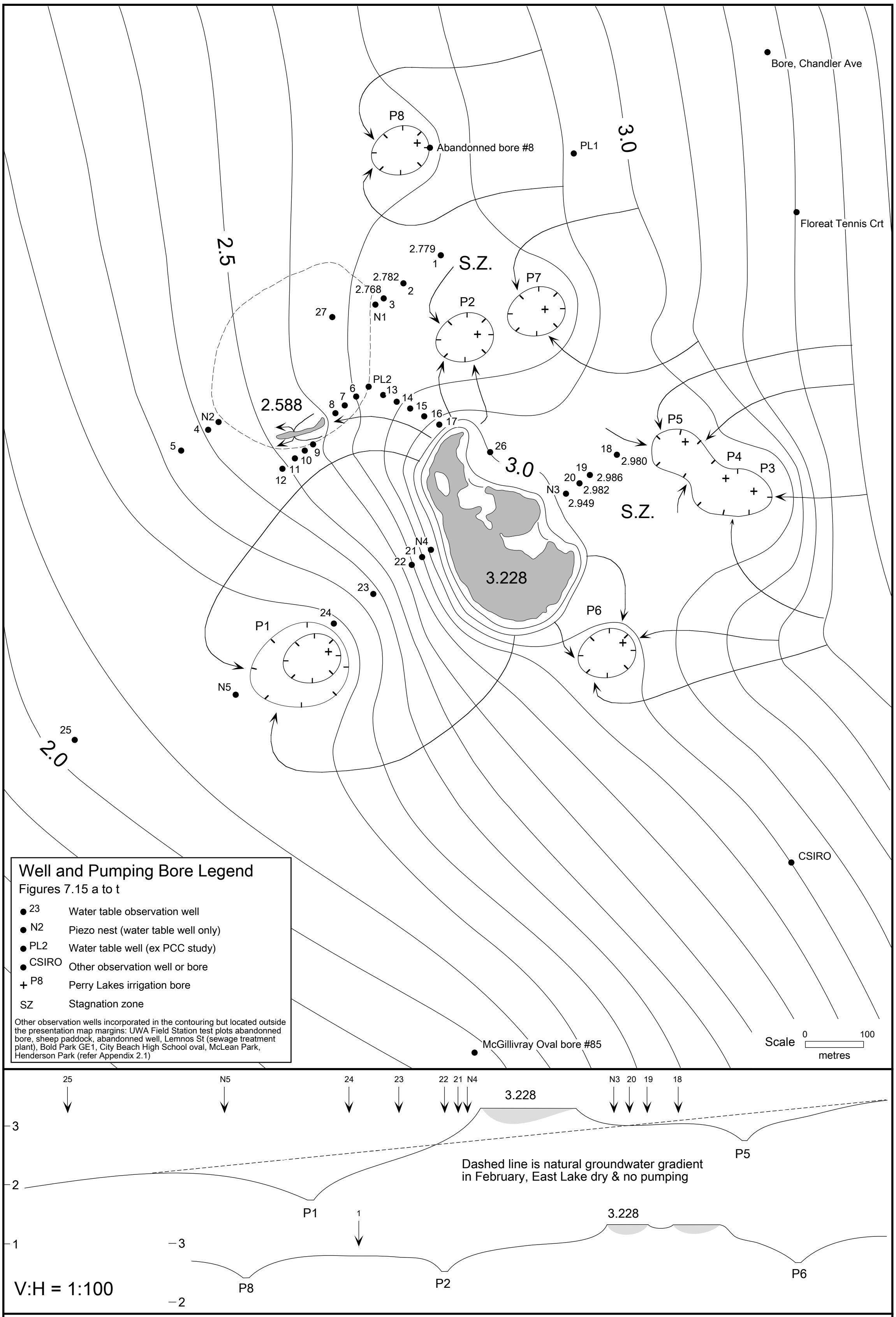
Weekly water table contour plots with flow nets were generated of which 20 are presented here. These are 'snapshots' of a continuum of both natural and artificially induced flow patterns reflecting wetland response to natural and artificial stimuli over a period of one year. Each plot represents average conditions over about 6 hours (the average time taken for one person to measure all monitoring wells). They are therefore not truly steady state and contain unavoidable time effects. These effects were minimised by always reading bores in the same order and starting about six hours after irrigation pumping commenced.

7.3.2 Results

Late summer top up and irrigation pumping

Figure 7.15a illustrates a typical mid summer Monday morning pattern. Wells P1-P7 have all been operating since the previous Friday evening topping up East Lake and now (in addition to P8) are being used for lawn irrigation. East Lake is a local water table mound. It is elevated 0.3 to 0.5m above the natural position of the groundwater surface (section through P1 & P5). The local mounding is enhanced by cones of depression around the pumping bores. These cones of depression surround East Lake on all four sides (refer sections). The plan and cross sections illustrate the long standing difficulty which has plagued managers attempting to maintain Perry Lakes as viable wetlands by topping up from local bores. The harder the pumping the greater the head difference between the lake and the natural water table. When these same bores are used for lawn irrigation during the week, the cones of depression create an even greater head difference relative to East Lake which drains away even faster.

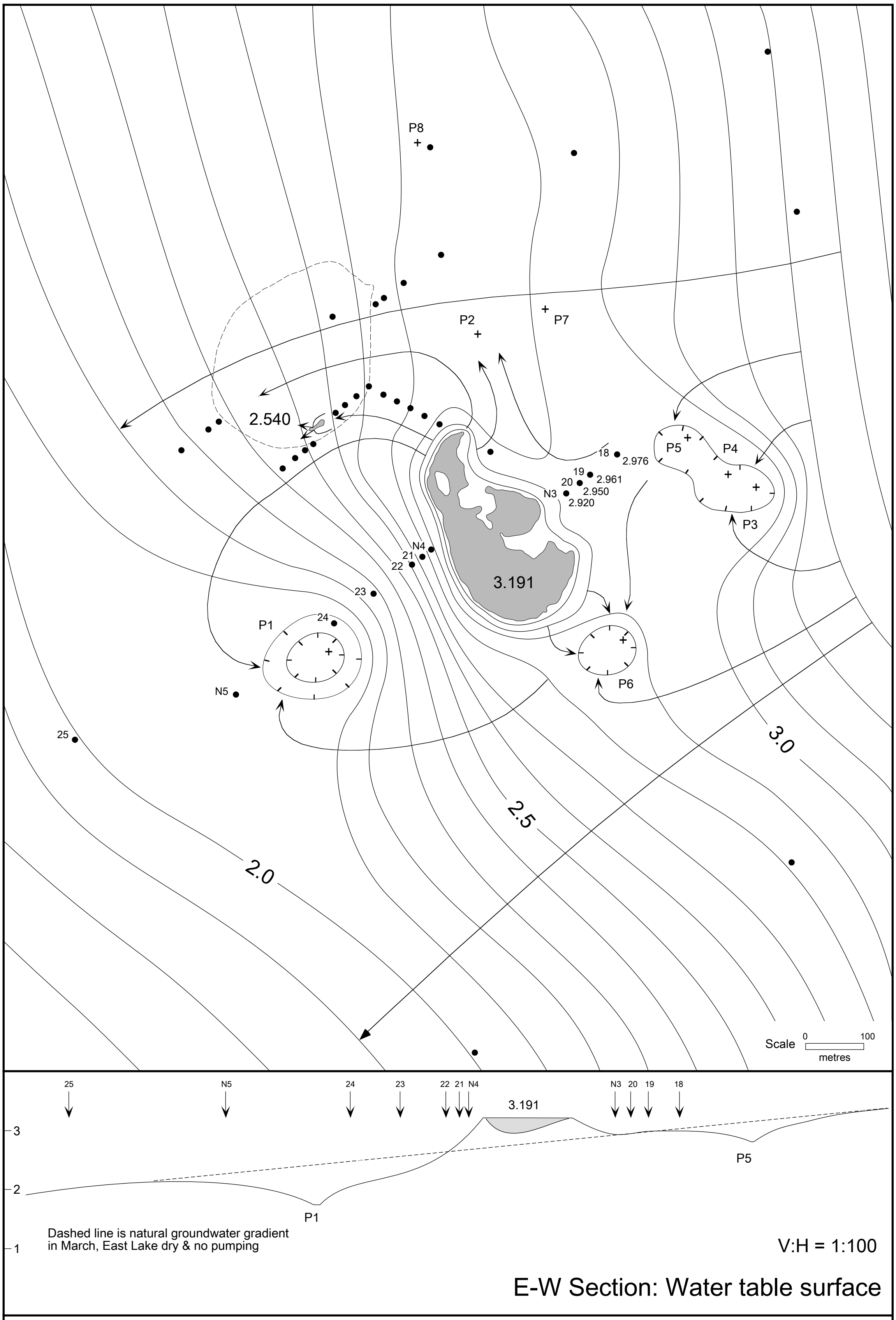
In this example the water table between East Lake and P3-P5 becomes almost flat with a stagnation zone close to W19. Recharge from East Lake is drawn towards P2 and P6 along with inter-lake flow into West Lake. This example is typical of extreme summer conditions in which East Lake has only recently been topped up and every irrigation bore is operating.



February 17, 1997 Flow Regimes: East Lake = R West Lake = F-T Figure 7.15a

Monday, all irrigation pumps operating following weekend top up pumping into East Lake. The natural water table lies about 0.3m below the deepest portion of East Lake which would normally have been dry by late December. East Lake is not only locally mounded by about 0.5m but also surrounded by cones of depression around the bores. The plan and cross sections illustrate the long standing difficulty which has plagued the wetland managers attempting to ensure some water in East Lake over summer by pumping from local bores. Water can only be maintained by persistent pumping. The harder the pumping, the greater the local head and groundwater gradient between the lake and bores and the faster water drains from the lake.

When P2 & P7 are turned off, flow lines from the NE sector of East Lake pass through vicinity of piezo next N1. This in part may explain the isotopic enrichment east of West Lake.



Dashed line is natural groundwater gradient in March, East Lake dry & no pumping

E-W Section: Water table surface

March 3, 1997 Flow Regimes: East Lake = R West Lake = F-T Figure 7.15b

Monday, the irrigation pumps operating are the same pumps used over the weekend to top up East Lake. This pattern is identical to that occurring during top up. SWL from wells 18-20 & N3 confirm there is a shallow divide between well 18 and the zone of depression around bores 3-5. The situation is similar to February 17, with operating bores increasing the effective head in East Lake.

West Lake has shrunk to almost the seasonal lowest point (absolute low was 2.511 on March 16 when top up was initiated in West Lake). A flow-through regime persists with ratio of recharge:discharge fluctuating as head between East & West Lake varies.

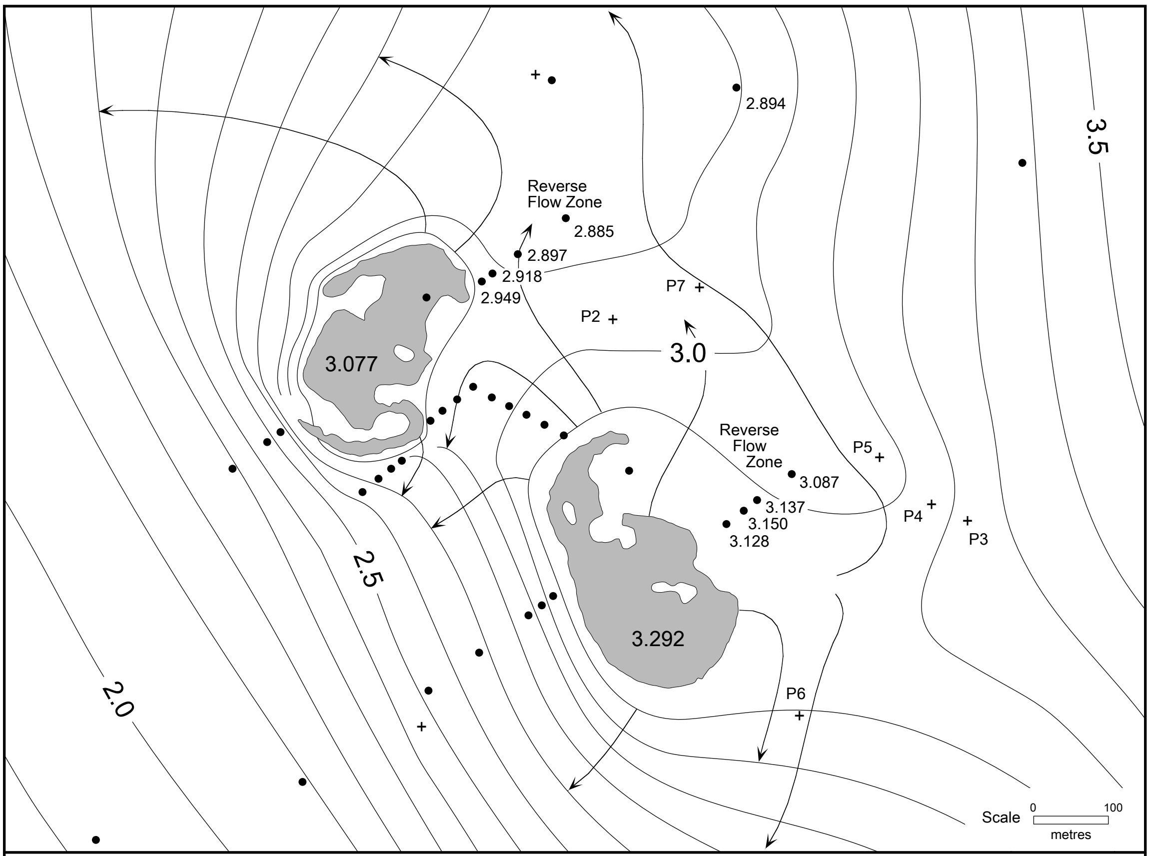
Figure 7.15b shows a similar Monday morning situation where the bores used to top up East Lake over the weekend have been left running and switched to lawn irrigation. P2, P7 and P8 have yet to be switched on.

Extreme summer storm events

Extreme summer thunderstorms can introduce more water in an hour than an entire weekend of top up. The example in Figure 7.15c is the Monday morning situation after a weekend of heavy rain and top up pumping. The wetland managers set the top up pumps to operate automatically over the weekend. Early Saturday morning heavy rain commenced which continued into Sunday. Early Monday morning the pumps have shut off but there remains remnant depressions around P2-P5. P6 and P7 were not operating. Both East and West Lake have filled and are mounded from storm water inputs. East Lake has also received top up water resulting in a head difference between the two lakes of 0.215m. Under normal winter conditions the two lakes have a natural head difference of about 0.1m. East and West Lake are in recharge, with a large release zone which extends beyond the boundaries of the map. The extreme head in East Lake results in flow lines which envelop West Lake. This was the largest example of a mutual release zone identified over 20 months of detailed monitoring.

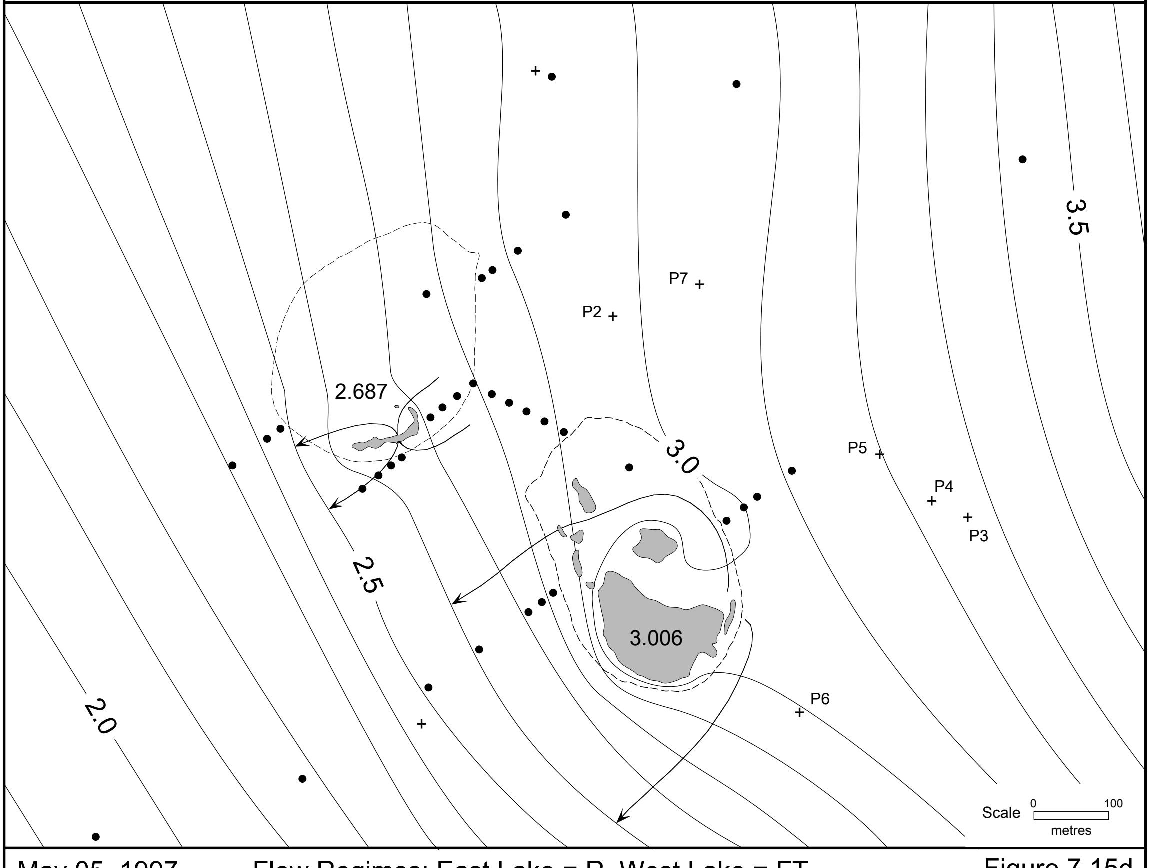
A similar situation occurred June 02 (Figure 7.15e). Here East Lake had received top up the previous week during the pump test May 27-29. This was followed by three days of heavy rain May 30 to June 1 totalling 73mm in the East Lake gauge. Despite the pump testing, head difference between East and West Lake was only 0.118m. Pumps P2-P8 had not been run for several weeks, so there were no pump induced depressions of the water table up gradient of either lake. This combined with the lower head difference between the lakes resulted in a smaller and less irregularly shaped mutual release zone than that mapped on March 31. A mutual release zone was predicted by Townley *et al* (1995) and appears to be a common early winter phenomenon which occurs in response to high stormwater flows into dry or nearly dry lake basins. Prior to the introduction of storm drains it is doubtful such flow patterns would ever have occurred.

Figure 7.15d shows the current 'normal' late summer and early winter flow pattern. East Lake is periodically maintained with top up and is in recharge flow state. This was generally restricted to just enough water to keep the South Basin flooded. The release zone is small and confined to the immediate vicinity of the lake. West Lake is confined to a small residual pond and is in flow-through status. There is no inter-lake flow despite the large inter-lake head difference of 0.319m.



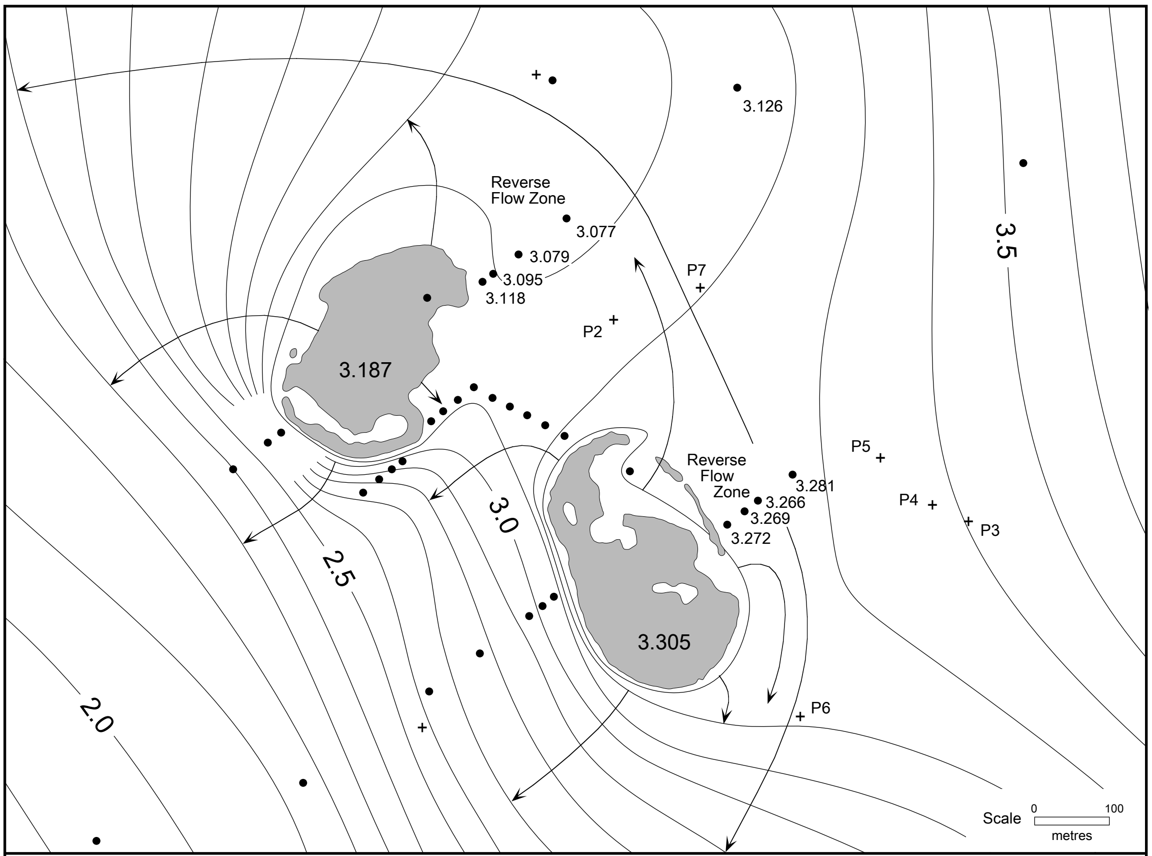
March 31, 1997 Flow Regimes: East Lake = R West Lake = R Figure 7.15c

Major rain event March 29-30 (63.8mm) coincided with top up to East & West Lakes. Contours reflect remnant pump induced groundwater depression with reverse flow from N1 to PL1 and N3 to 18. Low gradient zone beneath the Alderbury Flats has formed in response to mounding in West Lake, recent pumping in P2, P7 & P8 and direct recharge from heavy rain



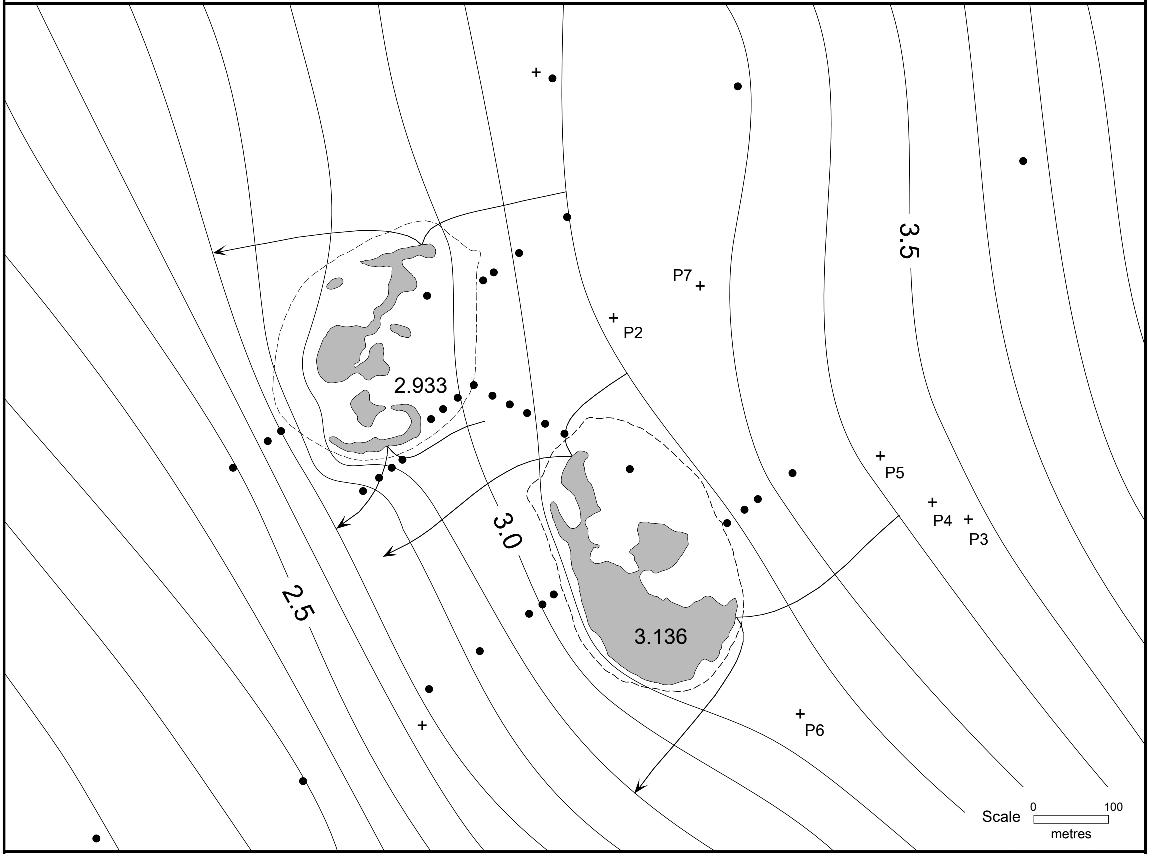
May 05, 1997 Flow Regimes: East Lake = R West Lake = FT Figure 7.15d

Following top up April 29 and rain May 1 & 3 (12.0mm) East Lake reverts to weak recharge status. West Lake remains a small flow-through pond. Storm drain inputs to West Lake seep into the NE section of the dry lake basin and do not reach the open water. Situation is almost identical to early summer (December 21b).



June 02, 1997   Flow Regimes: East Lake = R West Lake = R   Figure 7.15e

Heavy rain totalling 73.0mm May 30-June 2 were preceeded by top up to East Lake (water discharged from 48hr pump test) May 27-29. Both Lakes are mounded, West Lake from storm water inputs only. This is an extreme case where the lakes share a common release zone. Extensive reverse groundwater gradients occur NE of both lakes.



June 30, 1997   Flow Regimes: East Lake = FT West Lake = FT   Figure 7.15f

Insignificant rain fell since June 11. Last top up to East Lake was June 15. Regional water table has risen sufficiently to recapture lakes. Weak flow-through regime established in both lakes. West Lake probably comprises a number of separate FT regimes in disjointed smaller ponds.

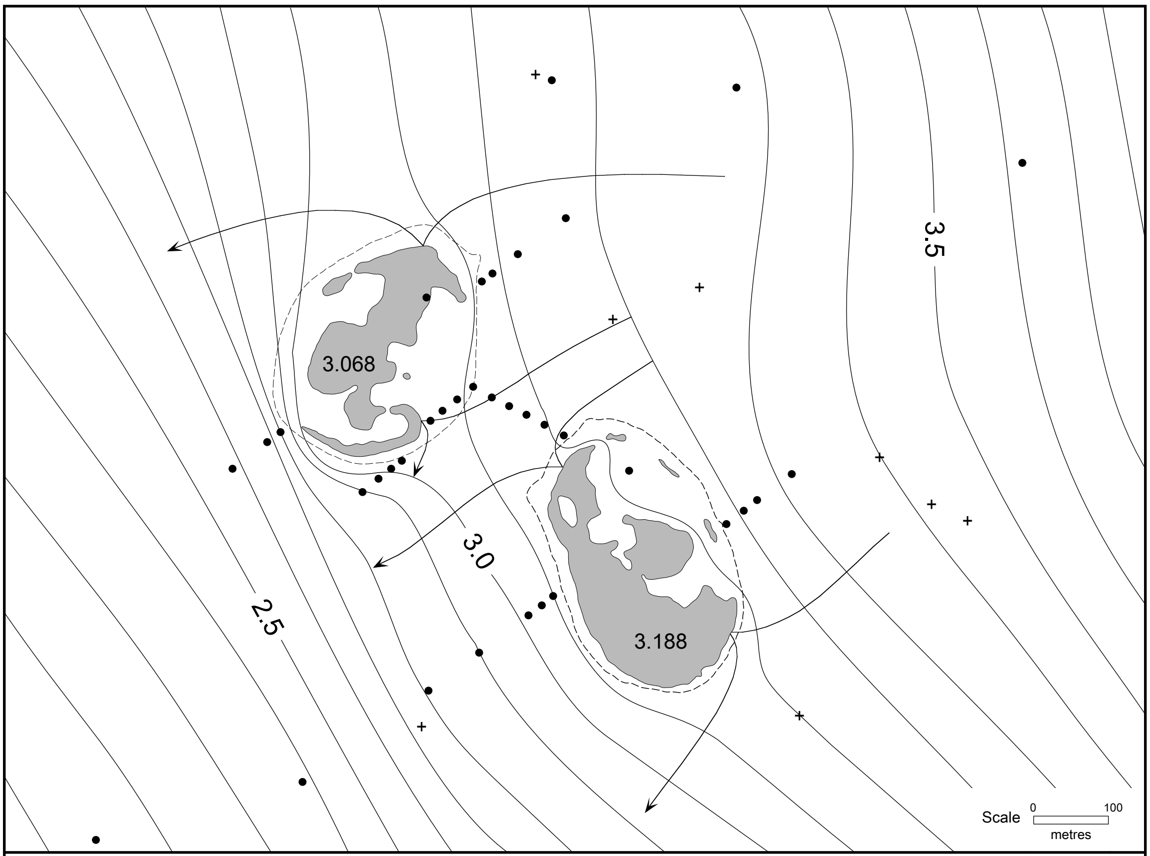
Establishment of natural winter patterns

Following further early winter rain a typical winter flow regime pattern is established in both lakes by late June (Figure 7.15f). The integrated balances (Figure 7.13) indicate that East Lake oscillated between recharge and flow-through status during June before settling into a permanent winter flow-through regime. Rainfall over winter 1997 was below average. Separate capture and release zones appear to have persisted until early August (Figures 7.15 g, h&i) although there is really insufficient monitoring well density to confirm this beyond doubt. Certainly by early September (Figure 7.15j) capture and release zones had coalesced This occurred before the lakes and local water table reached their peak winter elevation on September 10. Periodic storm water inputs shift both lakes towards (but never into) recharge status. Notice how the position of the dividing stream line at the north end of East Lake (constrained by the SWL in W17) shifts relative to the August 25 (Figure 7.15i) and September 15 (Figure 7.15k) positions. A similar shift occurs in West Lake. The up gradient excursion of the dividing stream line towards recharge status was in direct response to rain and storm water inputs several days earlier.

This pattern of common capture and release zones persisted into late October (Figures 7.15 l, m&n) and beyond the start of pumping for lawn irrigation October 20.

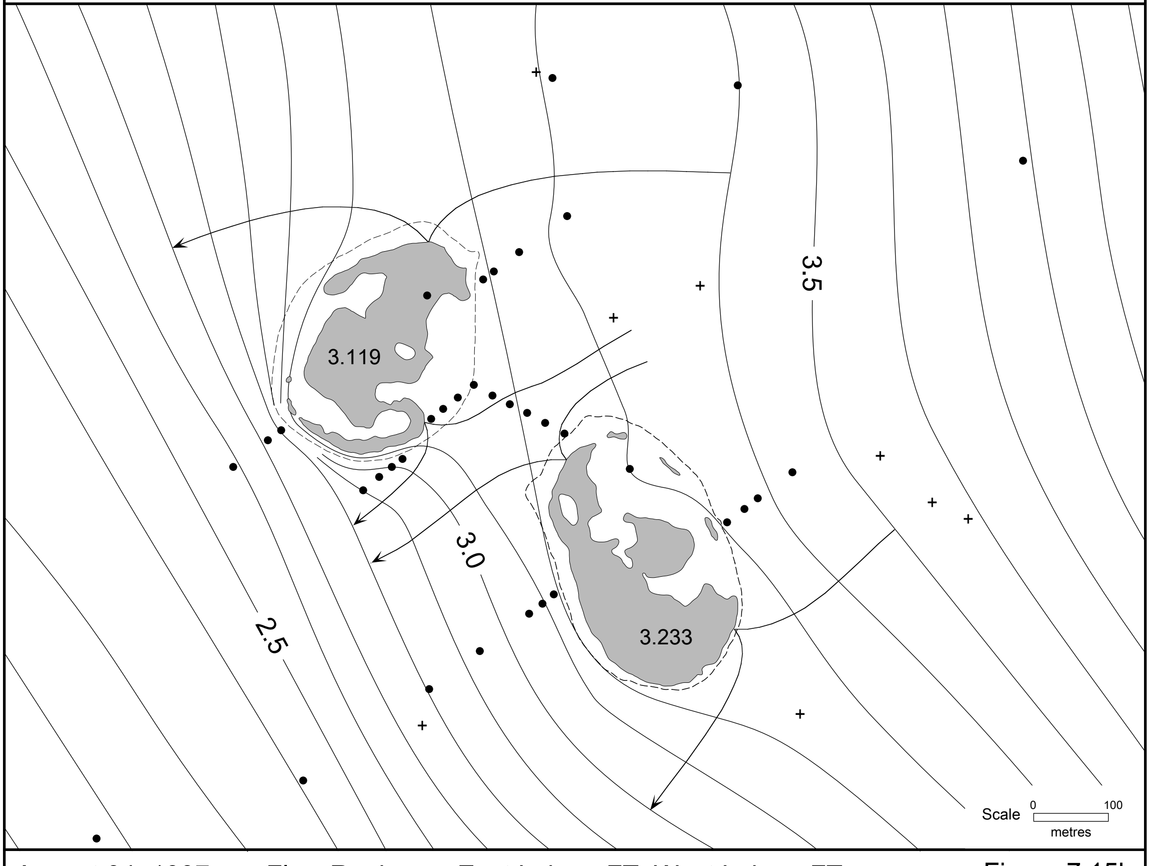
Shrinking lakes and the approach to dryness

In early November separate capture and release zones are re-established (Figure 7.15o). Monitoring well data was augmented from November 11 onwards by the detailed mini piezometer data (Figures 7.11 a-c). On November 23 (Figure 7.15p) West lake detached into two ponds and the Central Basin became hydrologically detached from East Lake with a local discharge regime becoming established. Three days later the NW Arm also detached and became (along with the Central Basin) local discharge basins sitting within the East Lake capture zone. By December 8 (Figure 7.15q), the East Lake capture zone had shrunk, and was now controlled only by the South Basin. A separate flow-through regime has established in the former Central Basin and the remnant pond which was formerly part of the NW Arm has become a discharge pond. West Lake is slowly approaching dryness and in so doing is breaking into a number of separate ponds, still encompassed by common capture and release zones. As these ponds approach dryness transient discharge regimes are established for a few days similar to those observed in East Lake (Figure 7.15r).



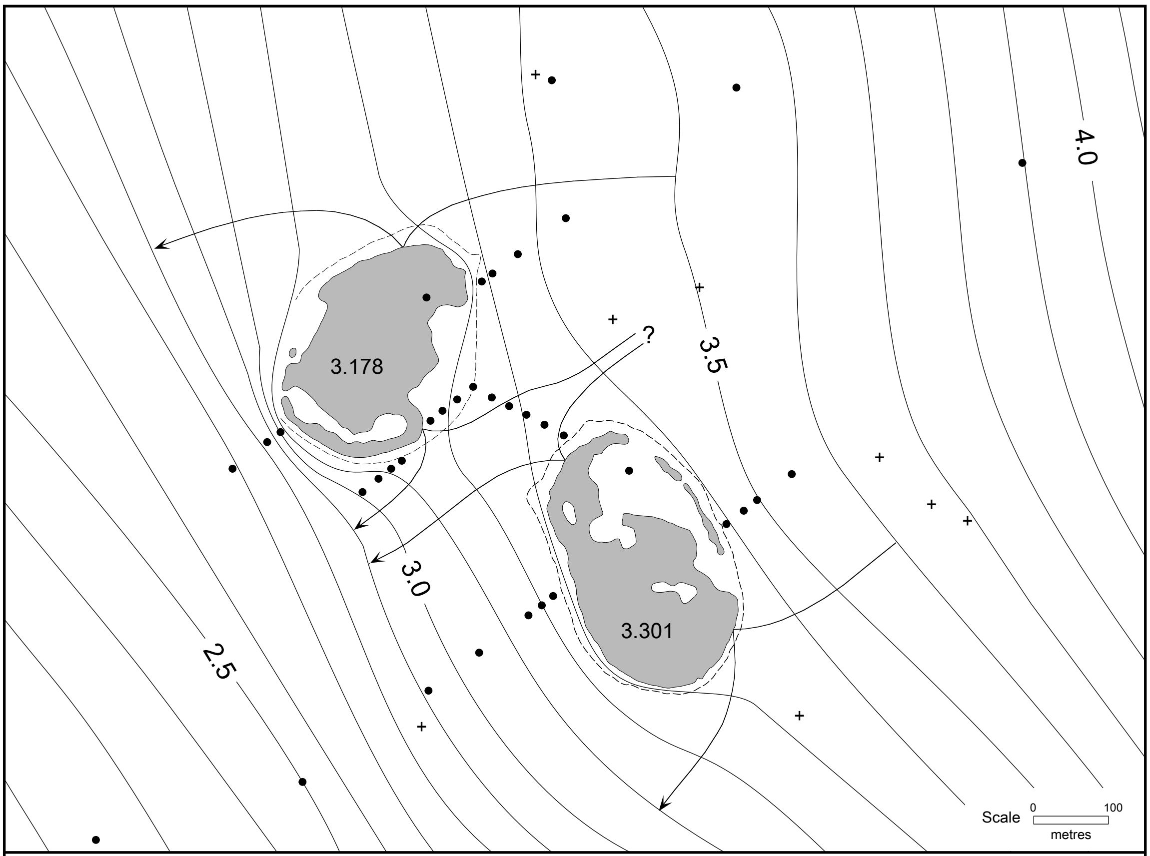
July 21, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15g

Dry conditions since July 13 when a 20.9mm rain event pushed lake levels to 3.157 & 3.240m. During this event FT flow status was maintained however the position of the dividing stream line shifted NE indicating an increased proportion of recharge to discharge. West Lake is on the verge of becoming a single, sinuous water body.



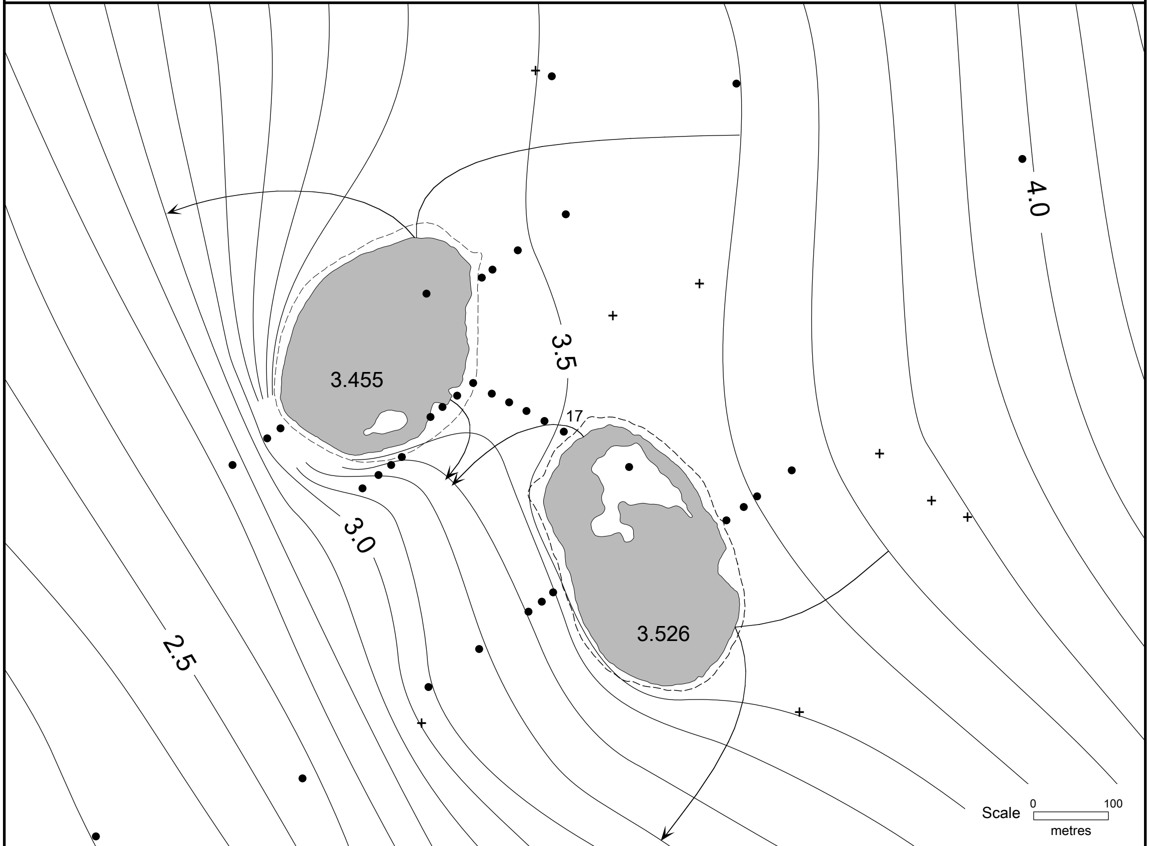
August 04, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15h

Lake levels rising slowly in response to regional groundwater rise. Stable winter flow-through regimes with separate capture and release zones established in both lakes.



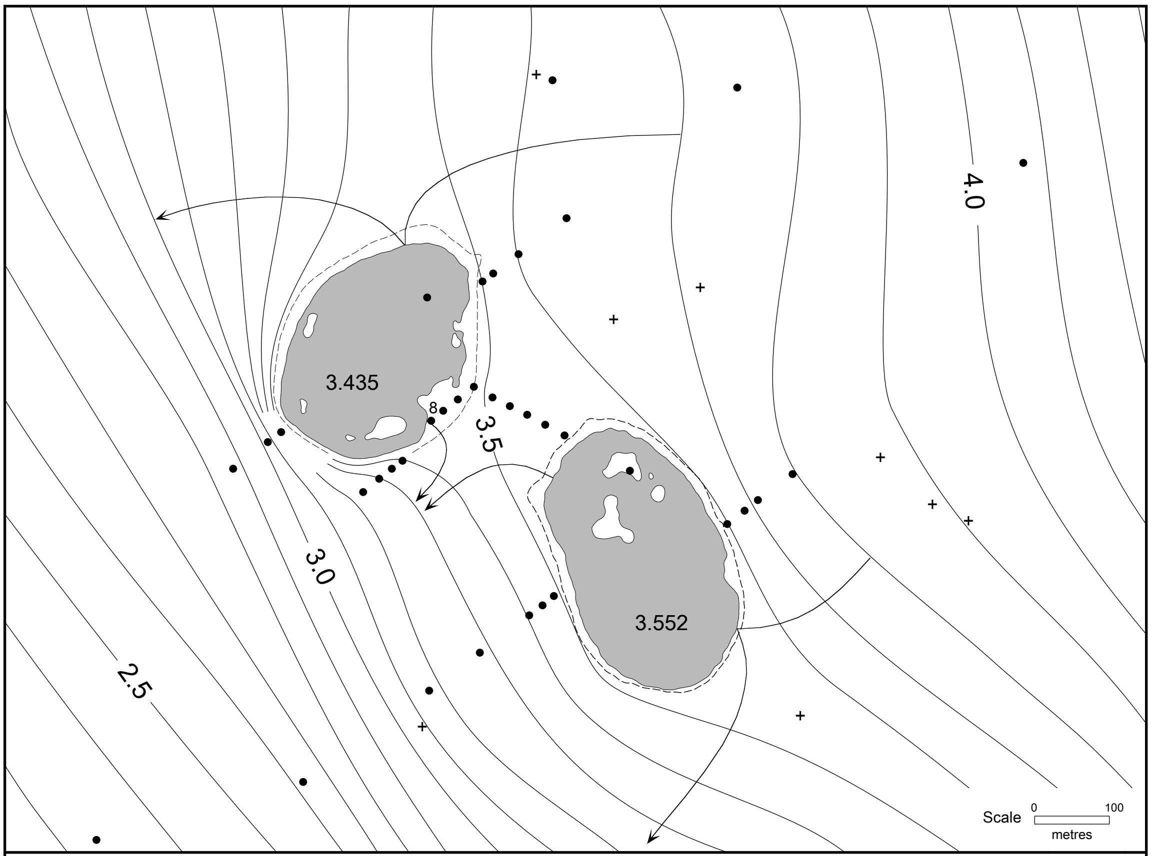
August 25, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15i

Levels rising in response to regional groundwater rise. No significant rain since August 14. Lakes exhibit stable winter flow-through regimes.



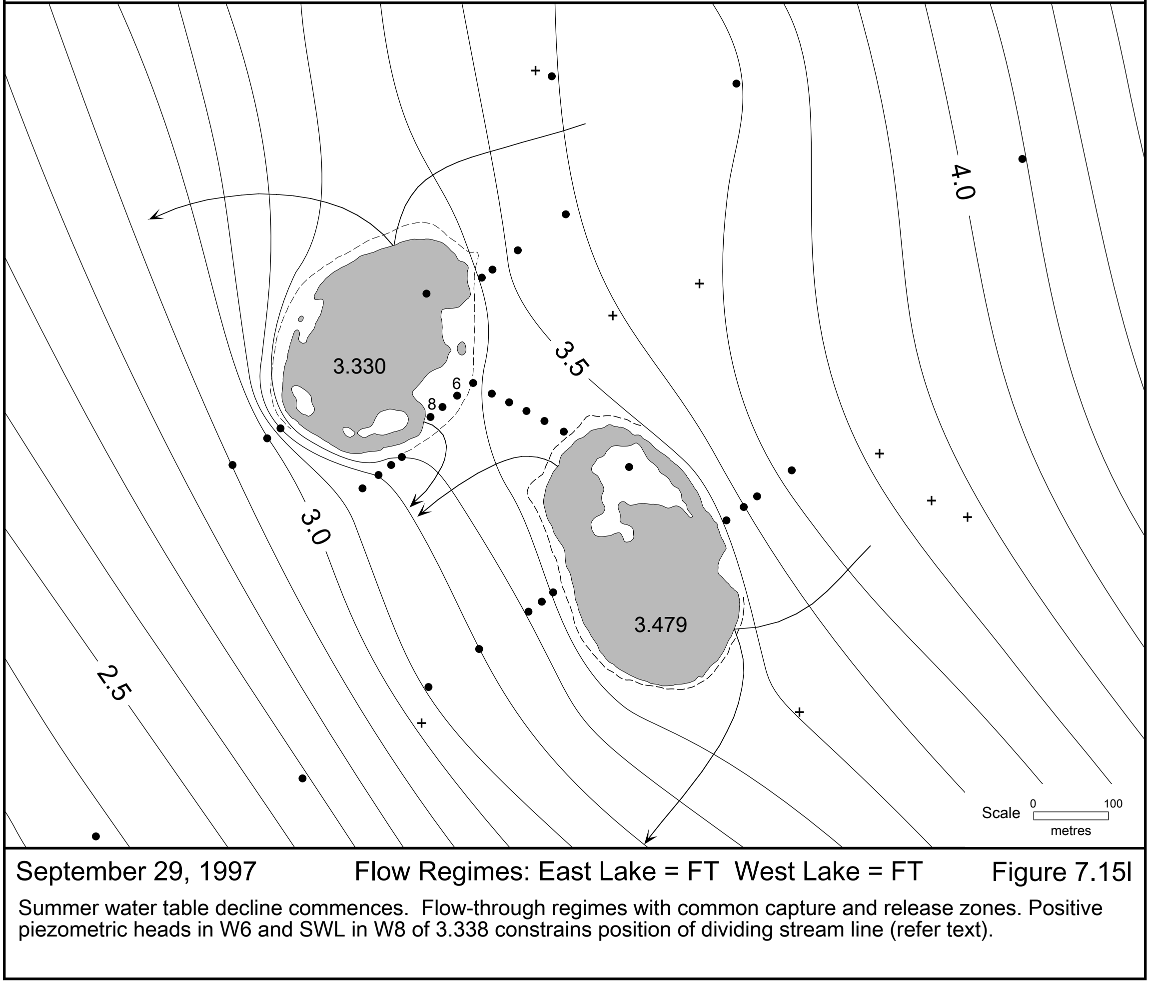
September 08, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15j

Both lakes rising towards annual peak stage on September 10. Capture and release zones merge. Notice how the position of the dividing stream line at the N end of East Lake (constrained by the level in W17) shifts relative to the Aug 25 & Sept 15 positions. A similar shift occurs in West Lake. These shifts are in direct response to storm water inputs (rain 20.3mm Sept 1-2 & 66.6mm Sept 5-8) which shift the lakes towards recharge flow regimes.



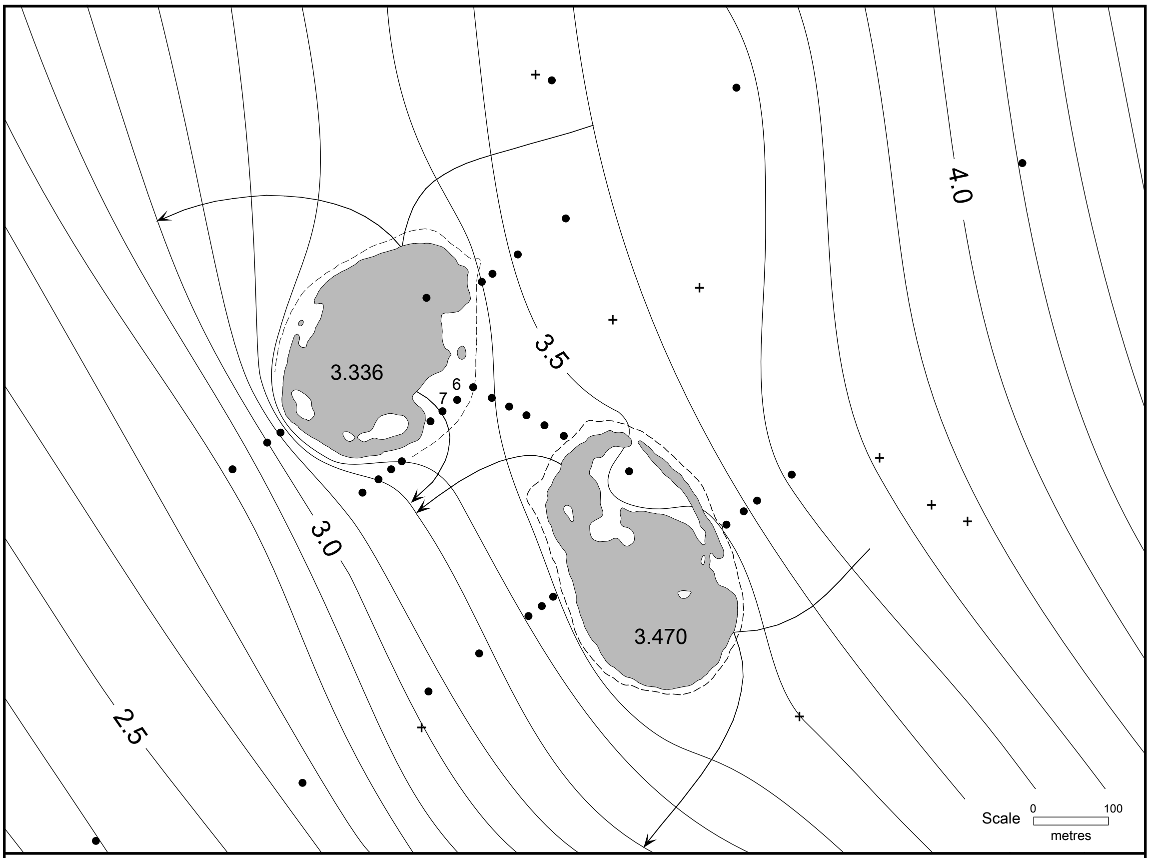
September 15, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15k

West Lake and East Lake commence summer decline following winter peak stages of 3.492 & 3.575 on Sept 10 in response to final major winter frontal passage (114mm rain over 9 days). Both lakes probably reverted to recharge flow regimes briefly before reverting to flow-through regimes with common capture and release zones. The summer groundwater decline is co-incident with spring leaf burst of fringing deciduous trees on Sept 8. SWL in W8 3.436 = DSL.



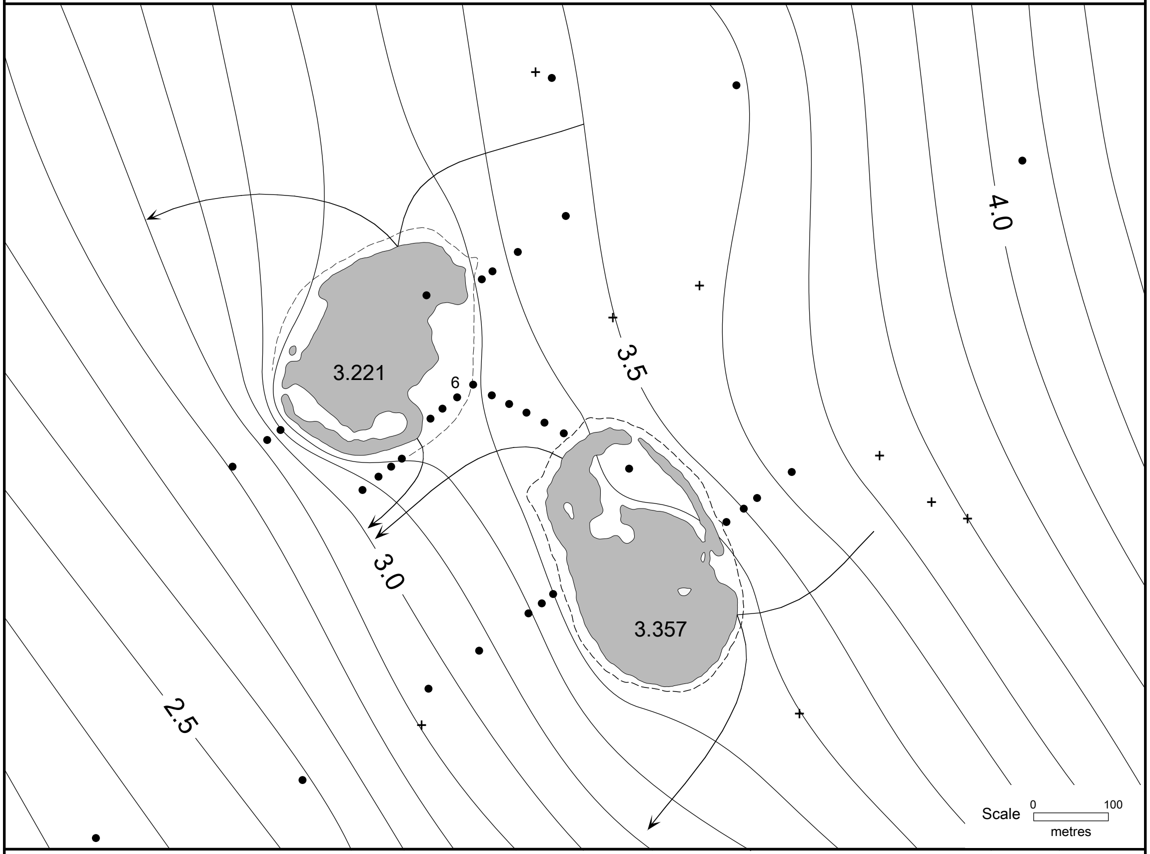
September 29, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15l

Summer water table decline commences. Flow-through regimes with common capture and release zones. Positive piezometric heads in W6 and SWL in W8 of 3.338 constrains position of dividing stream line (refer text).



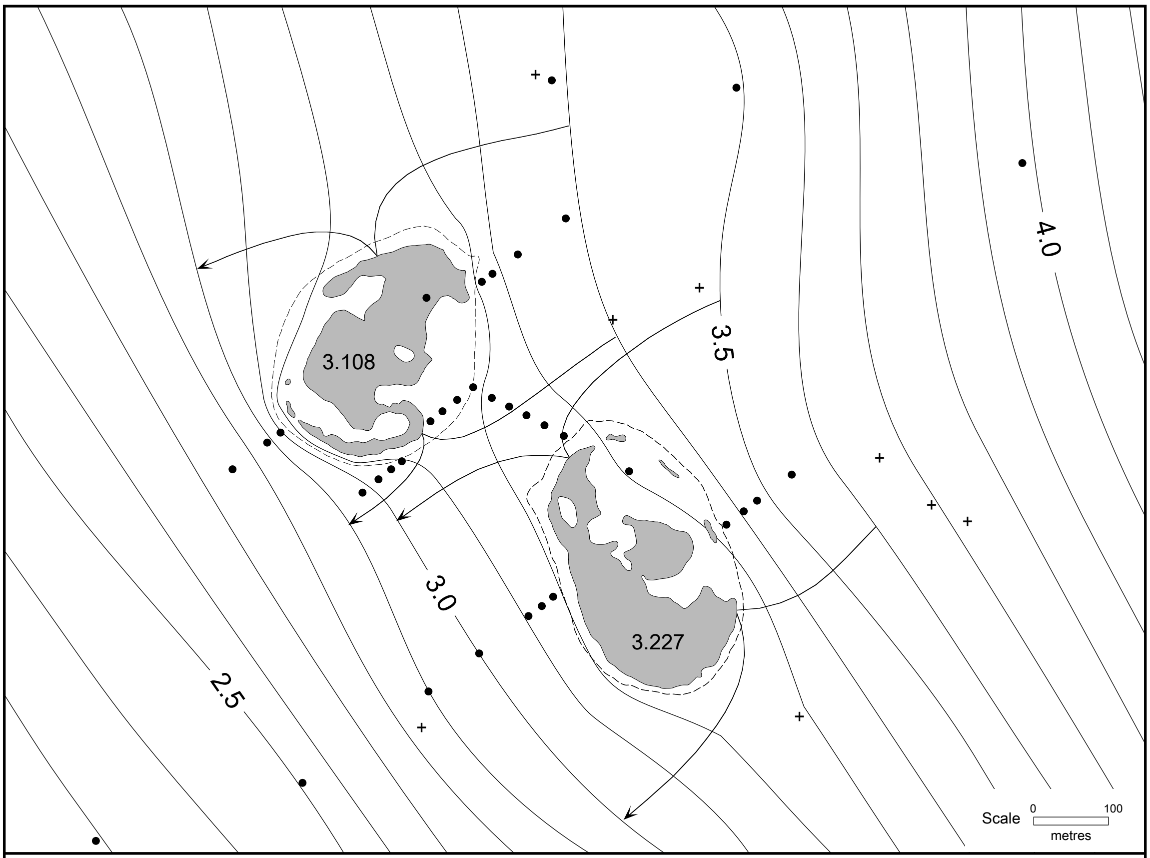
October 12, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15m

Flow-through regimes with common capture and release zones. Positive piezometric head in W6 & level in W7 of 3.336m (same as West Lake) constrains & defines position of dividing stream line.



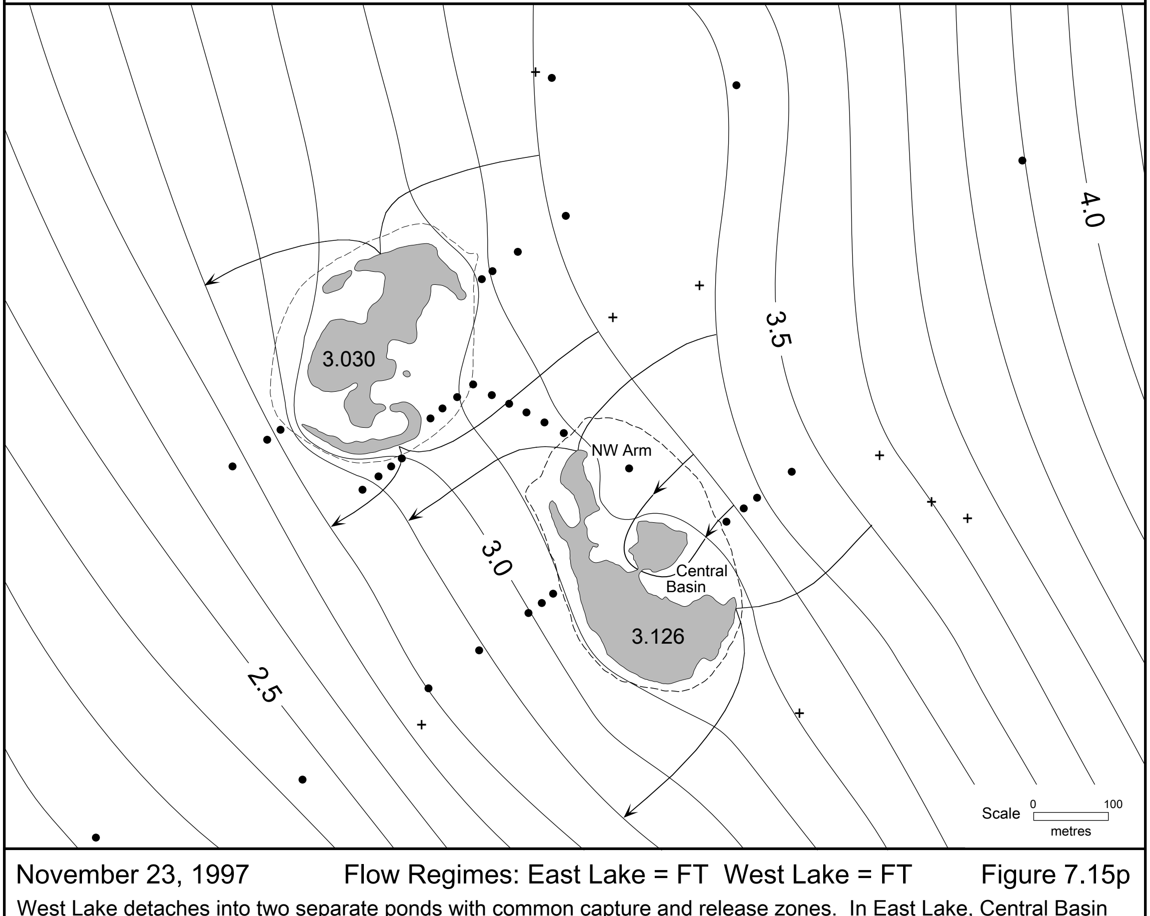
October 26, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15n

Levels in both lakes start to decrease rapidly as rainfall decreases and evaporation increases. Groundwater extraction for lawn irrigation commenced October 20. Positive piezometric heads in W6 constrains position of dividing stream line in West Lake.



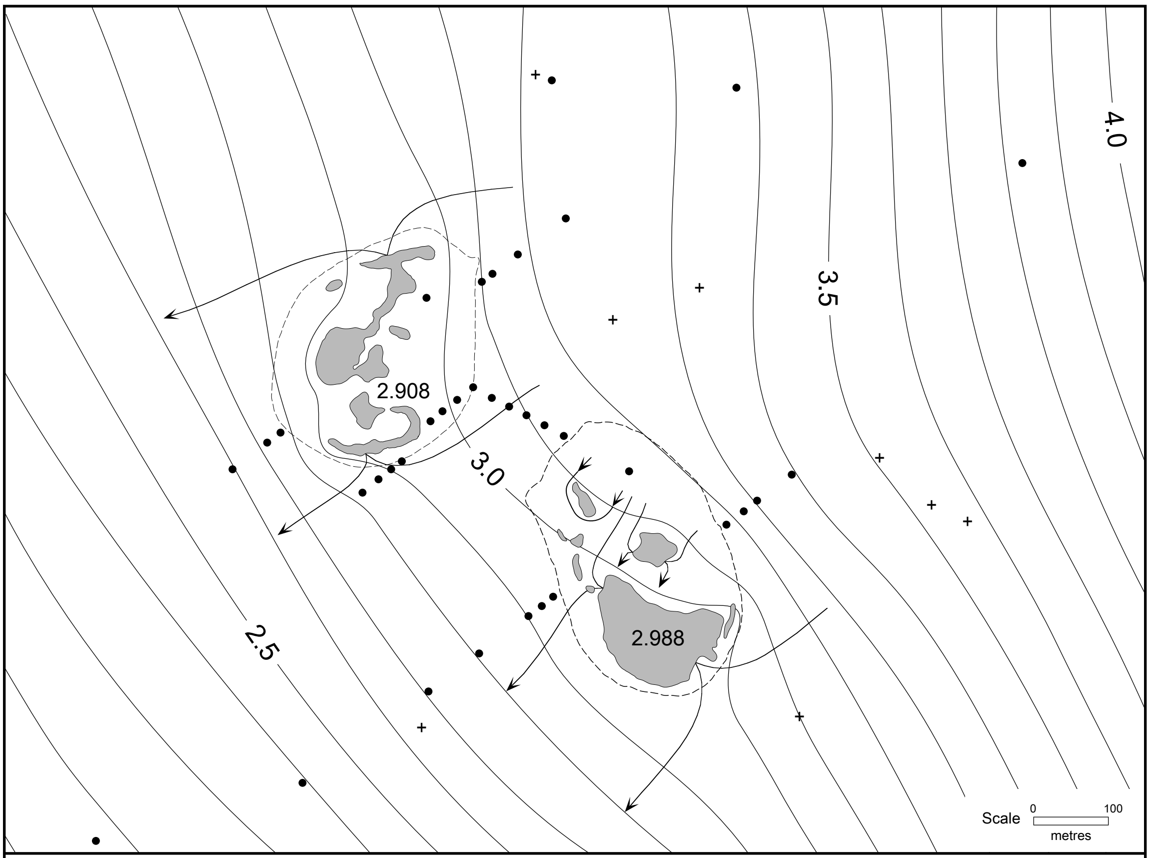
November 09, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15o

Separate capture and release zones re-established.



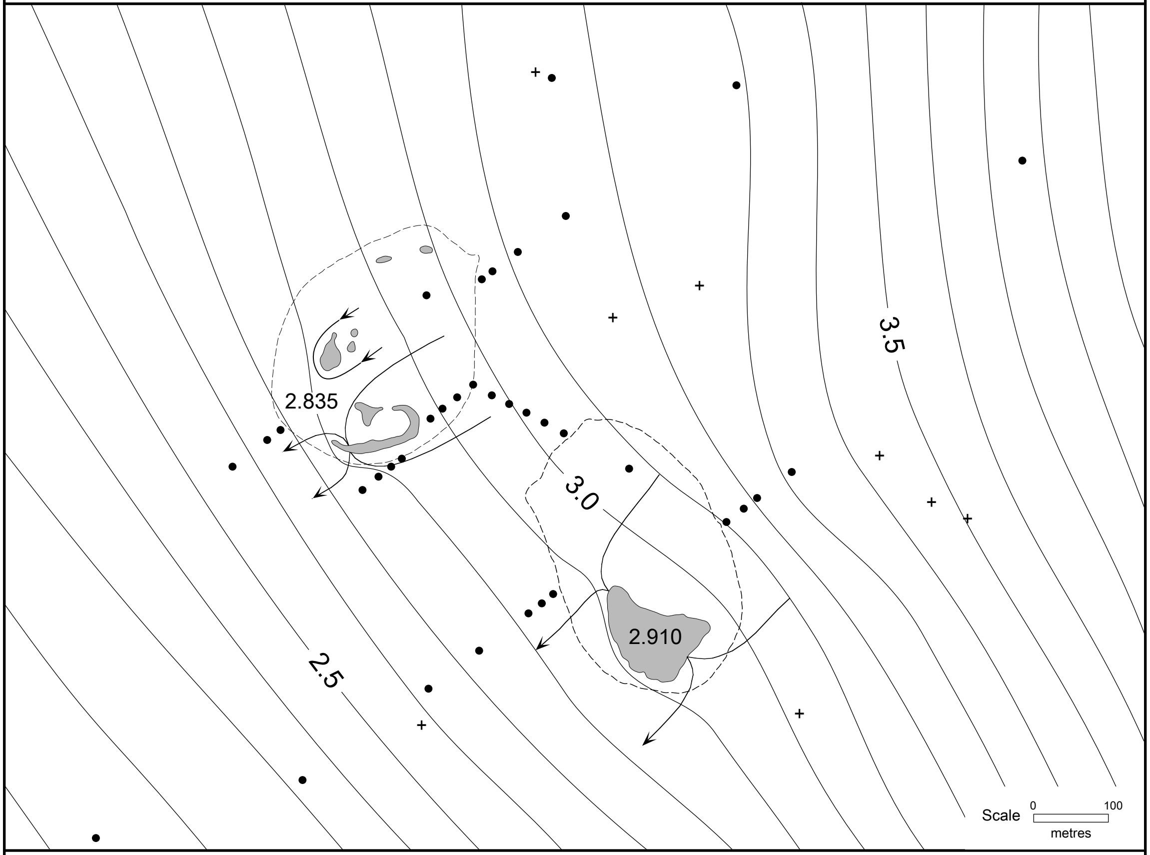
November 23, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15p

West Lake detaches into two separate ponds with common capture and release zones. In East Lake, Central Basin is hydrologically separated and becomes pond with discharge flow regime, refer Dividing Stream Line (DSL) Study. NW Arm separates Nov 26.



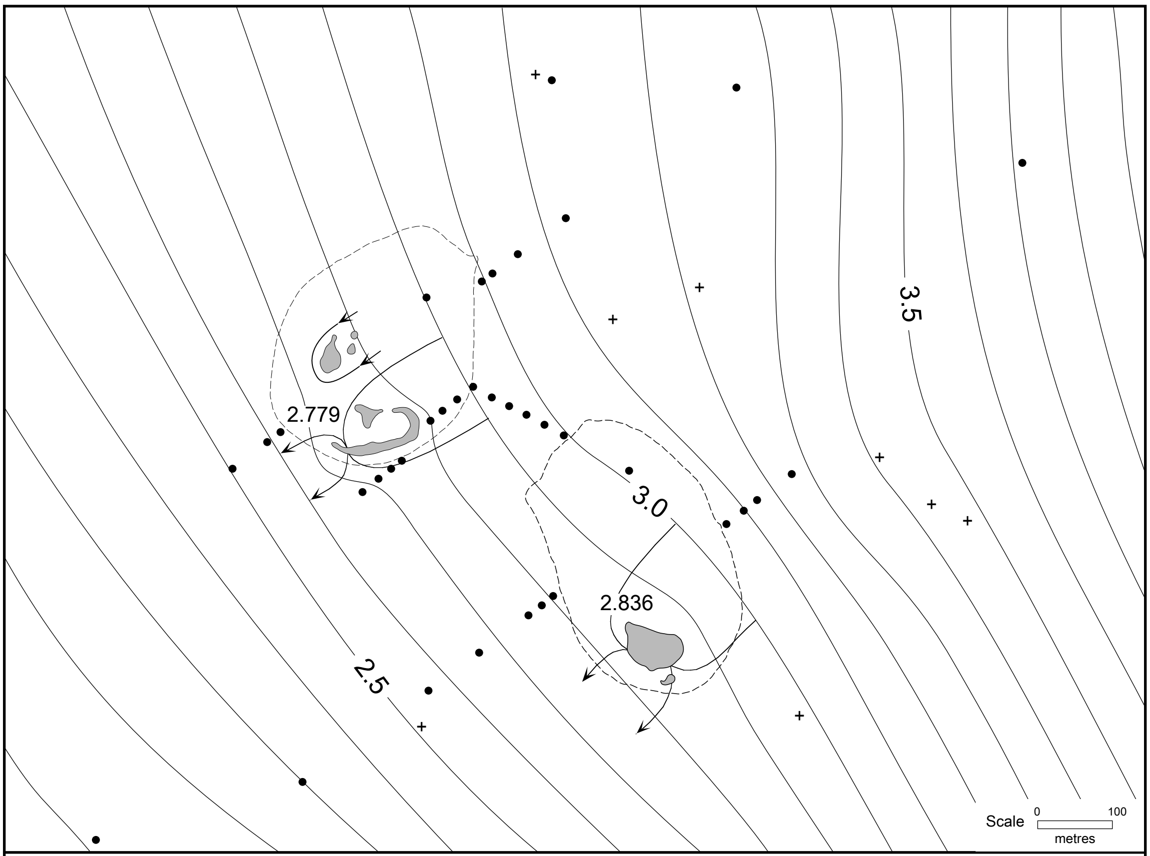
December 08, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15q

West Lake breaks into three separate ponds. Flow-through regime is confirmed in the most southerly (refer DSL study). East Lake also breaks into three major ponds. Discharge regime persists in northerly pond (ex NW Arm), Flow-through regime in Central Basin is nested within capture zone to South Basin.



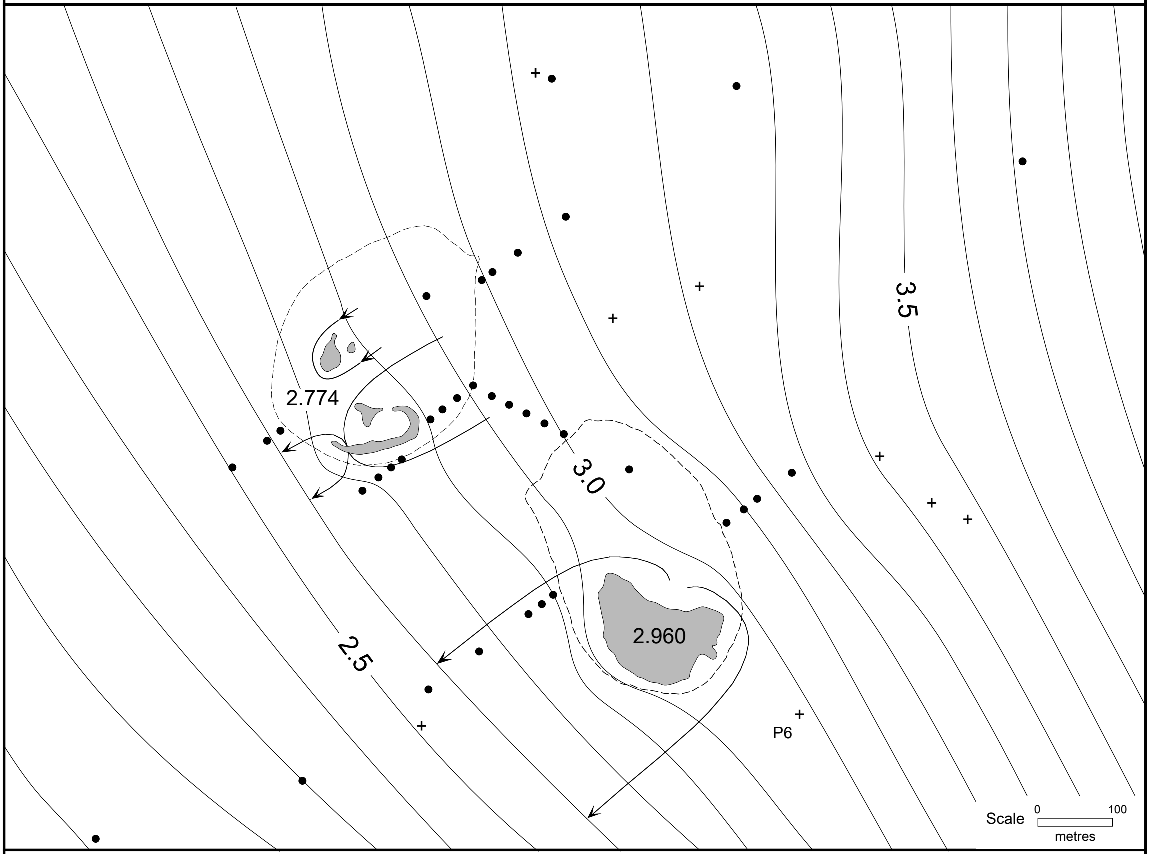
December 14, 1997 Flow Regimes: East Lake = FT West Lake = FT Figure 7.15r

West Lake ponds shrinking, discharge regime postulated in remnant SW Basin as dryness is approached. Remnant SW pond in West Lake operates as flow-through pond. East Lake is now confined to South Basin which continues to operate as a flow-through pond.



December 21a, 1997 08:00hr Flow Regimes: East Lake = FT West Lake = FT Figure 7.15s

East Lake stage reaches lowest recorded minimum of 2.836 (area 6160m^2, volume 357m^3, av depth 58mm). DSL has migrated as flow regime moves towards discharge status. East Lake is now becoming hydrologically isolated from the aquifer, sitting completely within low K lake lining clays. It is likely that if allowed to proceed to dryness, a discharge regime would be established for a few days. Dryness would have been achieved approximately December 25.



December 21b, 1997 16:00hr Flow Regimes: East Lake = R West Lake = FT Figure 7.15t

Summer lake level maintenance commenced 09:00hr, bore 6 only, input 72m^3/hr. East Lake becomes recharge lake. West Lake remains as a small flow-through pond. Remnant ponds perched on low conductivity clays postulated as discharge regimes.

Return of artificial lake maintenance

Throughout December both East and West Lakes continued to shrink and approach dryness. Flow-through regimes (or at least the potential for flow-through regimes) were maintained as evidenced by mini piezometer data. Our agreement with the Town of Cambridge stipulated that top up into East Lake would commence when the long necked tortoises (*Chelodina oblonga*) appeared to be endangered. Top up commenced December 21 (Figures 7.15 s&t). A recharge regime was immediately re-established. Had East Lake been allowed to proceed to dryness it is likely that a transient discharge regime might have been established similar to those observed in other remnant ponds.

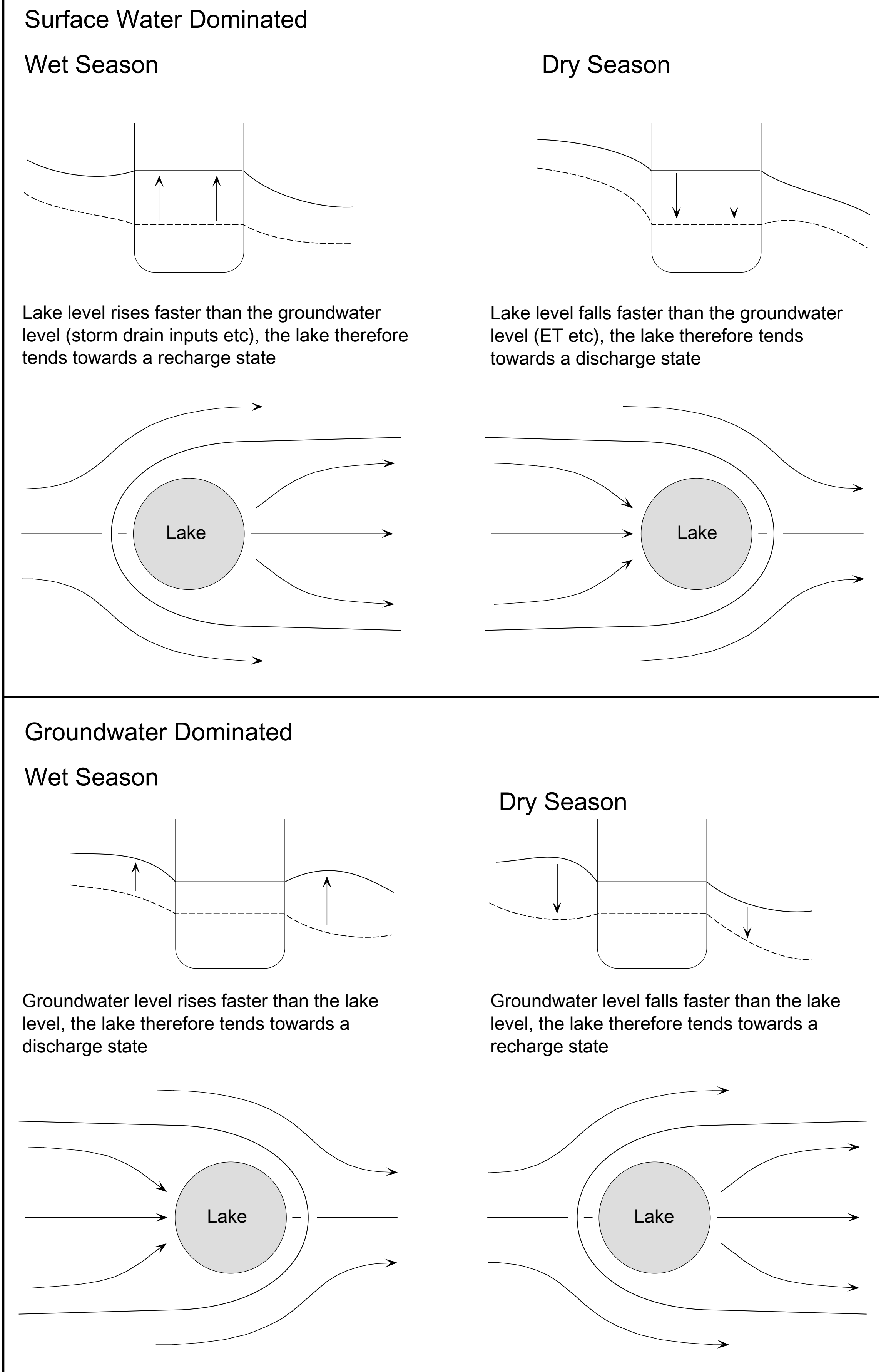
7.4 LAKE-AQUIFER COUPLING

7.4.1 Concepts of Surface and Groundwater Dominated Wetlands

Townley *et al* (1993b) suggested that lakes may be either groundwater or surface water dominated (Figure 7.16). The water level in a groundwater dominated lake reflects the surrounding water table. Therefore depending on lake-aquifer coupling the lake levels will lag to a greater or lesser degree behind the nearby groundwater levels. In the winter a groundwater dominated lake will lag behind rises in the surrounding water table. As a result the lake may tend towards discharge flow regimes. In summer groundwater levels fall faster than the lake and the lake then tends towards recharge regimes. This classification should not be confused with regime dominance concepts such as Born *et al* (1979) where a 'groundwater dominated lake' is one where groundwater simply dominates in the lake water budget.

Surface water dominated lakes are characterised by large lake volume changes in response to surface water inputs. In urban areas this is almost exclusively from storm drains. In winter surface water dominated lake levels rise ahead of and drive level changes in the surrounding aquifer. The lake therefore tends towards recharge regimes. In summer the lake may become an evaporative sump, falling more quickly than the surrounding water table and therefore tending towards discharge regimes.

In their natural state most lakes on the Swan Coastal Plain had no riparian inputs and therefore probably tended towards being groundwater dominated. The advent of storm drains (and at Perry Lakes summer top up) means most lakes are now surface water dominated, at least over winter.



Surface Water Dominated

Wet Season

Lake level rises faster than the groundwater level (storm drain inputs etc), the lake therefore tends towards a recharge state

Dry Season

Lake level falls faster than the groundwater level (ET etc), the lake therefore tends towards a discharge state

Groundwater Dominated

Wet Season

Groundwater level rises faster than the lake level, the lake therefore tends towards a discharge state

Dry Season

Groundwater level falls faster than the lake level, the lake therefore tends towards a recharge state

Seasonally different behaviour of surface water dominated and groundwater dominated lake-aquifer systems

Figure 7.16

Sketches adapted from Townley et al (1993b) p70

7.4.2 Coupling Signals in East Lake

The way in which lakes react to pumping and evapotranspiration (ET) provides a direct measure of the degree of coupling between the lake and the aquifer. It can also provide some measure of aquifer homogeneity or heterogeneity. Lake stage hydrographs are difficult to interpret in detail. They tend to be extremely noisy, a combined result of wave action, seiche effects, pump start up spikes and evapotranspiration, all superimposed on a longer scale trend of rise or decline. East and West Lake hydrograph records were compared to data from nearby monitoring wells. There is an almost instantaneous correlation between pump start up spikes in observation wells and Perry Lakes (Figures 7.18 a&b). These hydrographs suggest (but do not quantify) a strong hydrological coupling between the lakes and the aquifer. We would expect this because both lakes have a sandy rim created by stripping the original clay lining and re-contouring during the 1960's (refer Chapter 2). Examining the East Lake hydrographs in detail (see Figure 7.20) confirms that these spikes persist into March and April when East Lake is strongly mounded. This suggests that despite weekly excursions towards dryness followed by weekend top up and extreme local mounding, East Lake never detaches from the aquifer but rather, always remains in hydraulic connection with it. Rosenberry (2000) reported that lakes can be partially perched along their margins. He described a small pond that grew rapidly in response to heavy rain, expanding to cover sediment of greater permeability than the lake lining (a situation analogous to East Lake). The pond water rapidly infiltrated the more permeable sediments, trapping adjacent partially saturated 'wedges' located beneath the lower permeability lake lining. A similar situation may occur in East Lake.

Similarly data from September 1997 to February 1998 was examined to compare the strong evapotranspiration signal in W26 to any similar signal in East Lake. This monitoring well was equipped with a high resolution capacitive probe specifically for monitoring evapotranspiration in the non flooded portion of the East Lake basin. This is examined in detail in Chapter 11. The ET signal in W26 had a consistent almost sinusoidal wave form. Levels commence dropping just after sunrise. On a typical sunny warm day this drawdown continued until just before sunset. Days with no pumping and little wind provided the best data. Most of the time the ET signal is swamped by the larger effects of wave noise. The data indicates that response in the lake is roughly synchronous with that in the surrounding water table again indicating strong lake-aquifer coupling. In the November example portions of the sandy high conductivity basin rim were still flooded. By December 16 the lake was approaching dryness and was reduced to a small pond within the clay lined South Basin. Despite this there is still a near synchronous ET signal. Strong ET signals are also evident in West Lake in late

December and in hydrograph records for W3, 15, 18, 20 and 21 over weekends in November and December 1997 including two four day non irrigation periods over Christmas and New Years (Figures 7.18 a&b).

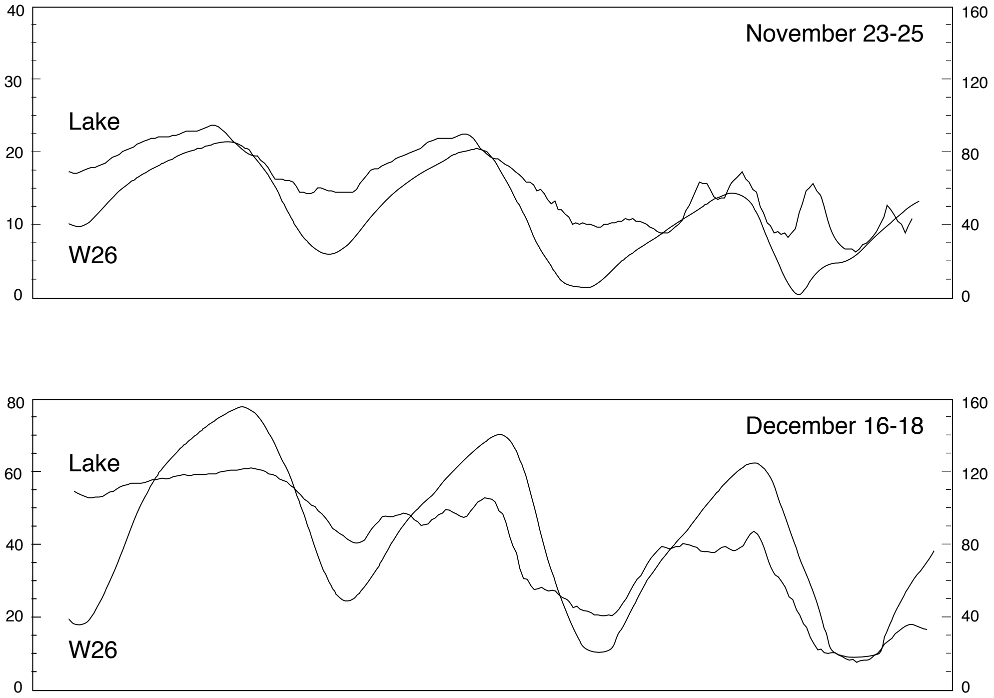


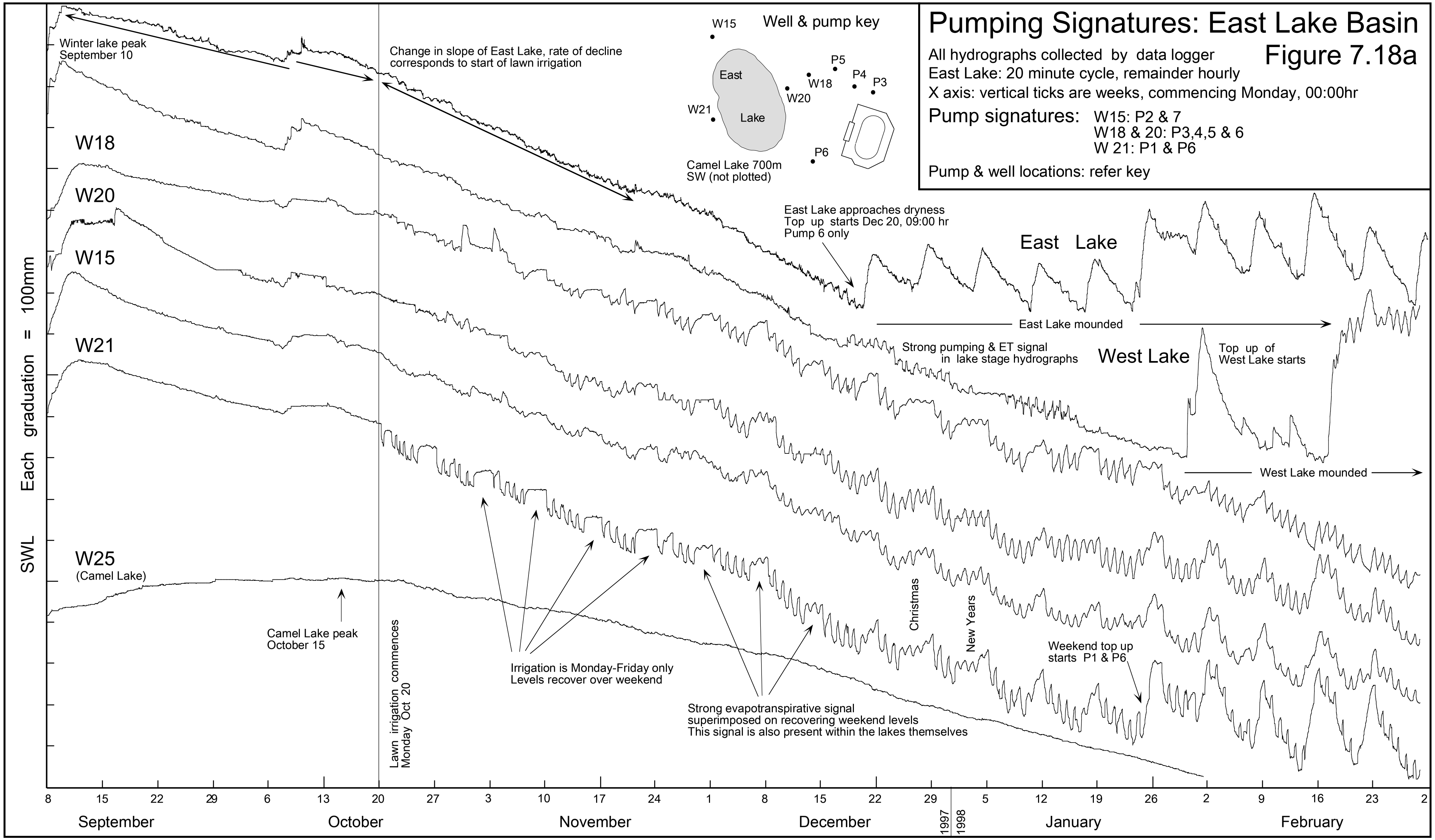
Figure 7.17 Hydrograph records of East Lake and monitoring well W26 located in the *Typha* dominated sumplands in the northeast East Lake basin (Figure 7.15a). Note that left hand y axis is lake stage which has been exaggerated vertically 4x and 2x relative to W26 (right side y axis). Peaks are sunrise (end of overnight recovery), low points are late afternoon. November data spans Sunday-Tuesday. Lake signal is disrupted Tuesday by superimposed noise. Pumping signals are superimposed on the December data.

7.5 GROUNDWATER EXTRACTION AND WETLANDS

In September 1997 the Town of Cambridge was asked and agreed to delay East Lake level maintenance (normally commenced in October). This allowed a number of additional experiments to be conducted as summarised below.

- comparison of the natural rate of lake level decline with the summer seepage rate under artificial maintenance regimes
- investigate the effects of lawn irrigation pumping on lake decline (*i.e.* is there a measurable lake level recovery on weekends?)
- allow the groundwater flux to be more accurately measured in the water balance calculations without the complicating effects of artificial maintenance
- provide some baseline data for studies of lake-aquifer coupling

All of these pertain to the question 'does pumping affect Perry Lakes and if so to what extent?' This was the key issue posed by the Perth City Council when they approached CSIRO in 1992. It remains the central management issue at Perry Lakes.



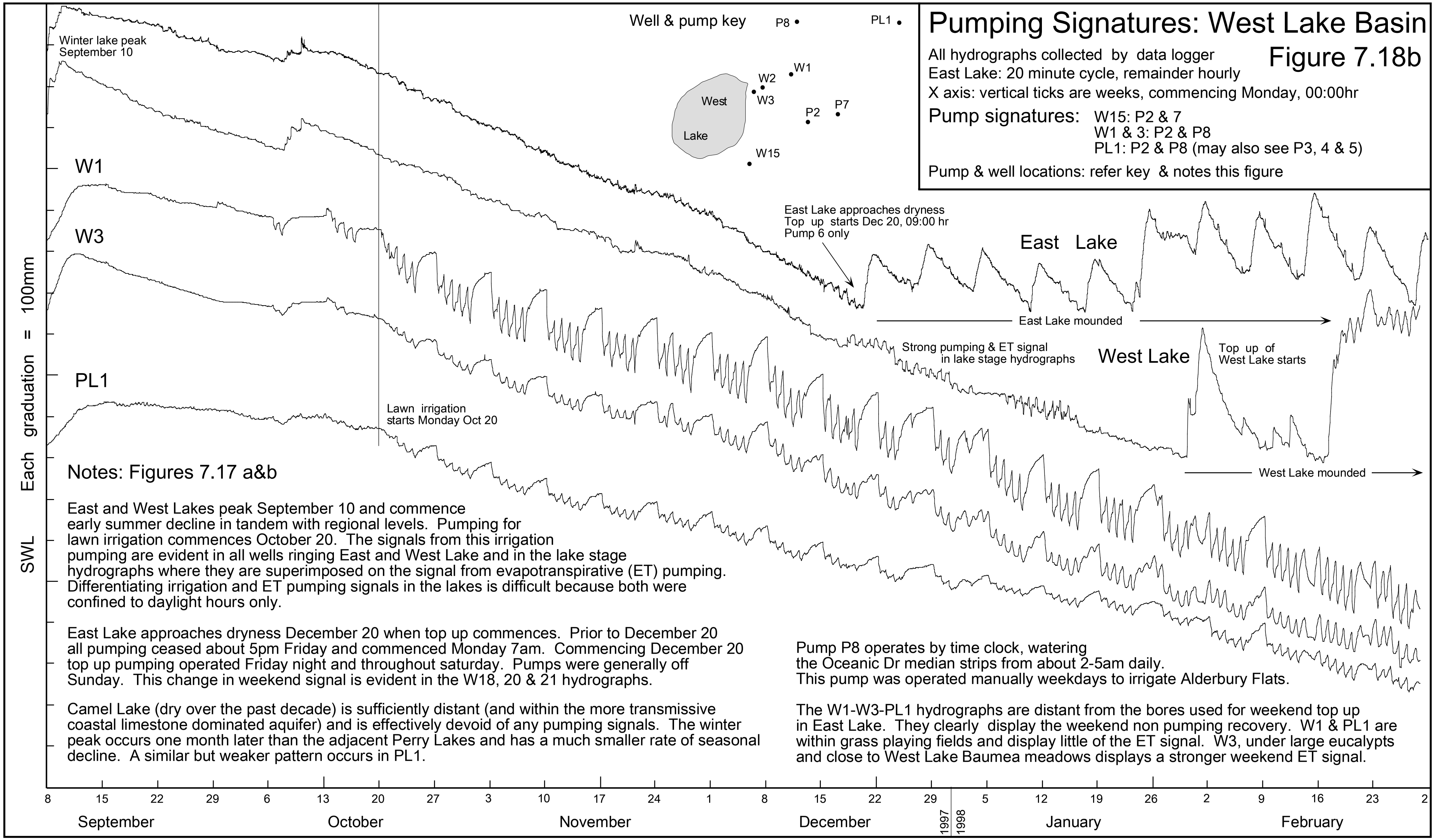
Pumping Signatures: East Lake Basin

Figure 7.18a

All hydrographs collected by data logger
East Lake: 20 minute cycle, remainder hourly
X axis: vertical ticks are weeks, commencing Monday, 00:00hr

Pump signatures: W15: P2 & 7
W18 & 20: P3,4,5 & 6
W 21: P1 & P6

Pump & well locations: refer key



Pumping Signatures: West Lake Basin

Figure 7.18b

All hydrographs collected by data logger
East Lake: 20 minute cycle, remainder hourly
X axis: vertical ticks are weeks, commencing Monday, 00:00hr

Pump signatures: W15: P2 & 7
W1 & 3: P2 & P8
PL1: P2 & P8 (may also see P3, 4 & 5)

Pump & well locations: refer key & notes this figure

Notes: Figures 7.17 a&b

East and West Lakes peak September 10 and commence early summer decline in tandem with regional levels. Pumping for lawn irrigation commences October 20. The signals from this irrigation pumping are evident in all wells ringing East and West Lake and in the lake stage hydrographs where they are superimposed on the signal from evapotranspirative (ET) pumping. Differentiating irrigation and ET pumping signals in the lakes is difficult because both were confined to daylight hours only.

East Lake approaches dryness December 20 when top up commences. Prior to December 20 all pumping ceased about 5pm Friday and commenced Monday 7am. Commencing December 20 top up pumping operated Friday night and throughout saturday. Pumps were generally off Sunday. This change in weekend signal is evident in the W18, 20 & 21 hydrographs.

Camel Lake (dry over the past decade) is sufficiently distant (and within the more transmissive coastal limestone dominated aquifer) and is effectively devoid of any pumping signals. The winter peak occurs one month later than the adjacent Perry Lakes and has a much smaller rate of seasonal decline. A similar but weaker pattern occurs in PL1.

Pump P8 operates by time clock, watering the Oceanic Dr median strips from about 2-5am daily. This pump was operated manually weekdays to irrigate Alderbury Flats.

The W1-W3-PL1 hydrographs are distant from the bores used for weekend top up in East Lake. They clearly display the weekend non pumping recovery. W1 & PL1 are within grass playing fields and display little of the ET signal. W3, under large eucalypts and close to West Lake Baumea meadows displays a stronger weekend ET signal.

7.5.1 The 'Natural Seasonal Decline' Experiment

As monitoring proceeded over winter 1997 it was evident (based on summer 1995 and 1996 data) that both lakes would be dry by about late December. Allowing lake levels to decline naturally had three objectives. Firstly, we wanted to observe the subtle changes in flow regime as East Lake approached dryness. It was unknown for example if a flow-through regime would be maintained or if a discharge regime might establish as ET increased. Secondly, we wanted to monitor the subtle changes in the position of the dividing streamline and lastly we wanted to measure the current early summer rate of lake decline under typical conditions of lawn irrigation pumping. These objectives were unachievable using the normal Town of Cambridge management prescription under which limited top up commences in early November, increasing as lake levels fall. Our studies required wetland conditions approaching those of an unmanaged wetland. The wetland managers agreed to withhold top up until East Lake had almost reached dryness. Lawn irrigation would proceed weekdays as usual. Weekly manual measurements of all wells was done Sunday afternoon (from October 12, 1997 onwards), thereby giving levels about 36 hours to recover from irrigation pumping.

Artificial top up commenced December 20 after East Lake reached a stage of 2.829m (area 5650m^2, volume 315m^3, average depth 5.5cm).

7.5.2 Current Groundwater Extraction at Perry Lakes

Pumping signals are evident in most monitoring wells within Perry Lakes Reserve (Table 7.8). Figure 7.19 shows the approximate extent of depression cones around the irrigation bores.

Table 7.8 Pumping Signals in Monitoring Wells

Monitoring Well	Pumping Signals
W1, W2, W3, Pl2, W13-17	P2 (minor signal from P7)
W1	P8
W18, W19, W20	P3, P4, P5
W21-24	P1

The pumping clearly shows the pattern of weekday irrigation and weekend recovery (Figures 7.18 a&b). Pumping does draw the lakes down on a daily basis. More importantly however, the general rate of groundwater decline within Perry Lakes Reserve clearly increases once irrigation commences, and this rate is much greater than any other rate which was observed regionally (Figure 7.19a). The almost instantaneous correlation between pump spikes in observation bores and adjacent East and West Lake confirms the strong lake-aquifer coupling.

Figure 7.15a demonstrates how summer pumping depresses the water table around the lakes. Hydraulic head is the sum of the elevation head and pressure head. Pumping increases both the head in East Lake and the hydraulic gradient (remembering that the lakes appear to be closely coupled and apparently do not detach). Darcy's law states that specific discharge υ is directly proportional to hydraulic head (Freeze & Cherry 1979 p16):

$$\upsilon = -K\frac{dh}{dl} \tag{7.3}$$

where h is hydraulic head, and dh/dl is the hydraulic gradient. Darcy's law shows that the rate of outflow (recharge to groundwater) of a mounded lake must increase if the head increases. Therefore when pumping lowers the water table around a lake it must theoretically also affect the level within the lake by increasing outflow.

We have no long term records of extraction apart from those estimated for 1993-94 (Townley *et al* 1995) and 1996-97 (this study). When bores were first drilled in 1961-62 it is likely that relatively small amounts of water were extracted. There are two reasons for this. Firstly groundwater levels were much higher so the water table was within about 1m of the surface below much of the lawn areas. Grass may have been maintained over summer largely through capillary rise. Secondly anecdotal evidence from early PCC grounds staff suggests there was not the same 'culture' of lush green lawn in a Mediterranean climate that prevails today. Lawn irrigation was more concerned with simply maintaining grass over summer. Over summer 1993-94 irrigation and top up were estimated to be 250,000m^3 and 60,200m^3 (Townley *et al* 1995). In 1996-97 this had increased to 390,530m^3 and 180,750m^3 respectively, an increase of 84%.

The regional water table on the Swan Coastal Plain displays a characteristic annual cycle. The water table rises during the winter from direct recharge and storm drain inputs to wetlands and storm water recharge basins. Over summer the water table declines in response to evapotranspiration and extraction from bores. This annual cycle can be approximated by a sin function, whose amplitude varies from area to area depending on the local recharge-discharge balance.

Where the vertical depth to the water table is great, such as beneath thick limestone ridges, the annual amplitude is low, reflecting low (or nil) winter recharge (McFarlane 1984) and nil evapotranspiration. Where the water table lies at shallow depth, both recharge and discharge increase as does the amplitude of the annual cycle. Wetlands represent an extreme case. They not only receive recharge directly as rain, but frequently have large additional inputs from storm drains. In summer they loose water directly from open water evaporation and evapotranspiration from fringing and nearby phreatophytes and soil. In summer such wetlands may act as evaporative sinks. In such cases the rate at which water is lost exceeds the rate at which it can be replaced from elsewhere in the aquifer.

Another way of visualising this is to consider a flow-through lake. As summer approaches the lake will receive more and more water from the aquifer to compensate for evaporative losses and recharge less and less back. The dividing streamlines will migrate towards the down gradient side. Flow regimes might shift from FT1 to FT3 and the lake is described as 'tending towards a discharge state'. The wetland and its surrounding basin (sumplands and damplands of Semeniuk 1987) does the same thing. If pumping is occurring close to a lake, the effects of this pumping must be additive to the natural evaporative pumping. Even in wetlands well removed from any extraction, evapotranspiration imposes a distinct signal on the open water surface and adjacent water table (Meyboom 1967).

The magnitude of daily open water evaporation and transpiration were estimated for Perry Lakes and their associated lake basins (Table 7.9) and compared to extraction from bores P1-P8 (Figure 7.19). Irrigation and top up clearly exceed natural evaporative losses. In the Perry Lakes basins extraction exceeds natural evapotranspiration by up to 19 times on a monthly basis. Intuitively this suggests that pumping should have an impact on local wetland water levels.

Table 7.9 Natural and artificial pumping (m^3), Perry Lakes Basin

Month (1997)	Evaporation	ET	Irrigation	Top Up	Ratio
January	9340	5380	49680	27210	5.2
February	4170	3310	51580	28240	10.7
March	4050	3420	77820	42610	16.1
April	3740	1550	42980	23530	12.6
May	1900	1150	38260	20950	19.4
June	3260	650	7010	3840	2.8

The figures include East and West Lakes and their associated basins. Evaporation is from open water, calculated from floating Class A pan, evapotranspiration from sumpland vegetation is estimated by hydrograph separation (Chapter 11) for East Lake and doubled to incorporate West Lake, lawn irrigation estimated from electric power consumption (Chapter 13), and lake maintenance 'top up' pumping measured from flow metres.

Area of strongly transpiring *Typha/Baumea/E. spp* sumpland taken to be 60,000m^2 split equally between each lake.

'Ratio' (Column 5) is the ratio of extraction (irrigation + top up) compared to natural loss (E + ET).

Evapotranspiration from the parkland outside the lake basins was not estimated as these areas are well irrigated and most vegetation presumably draw considerably from irrigation water in the vadose zone over summer.

7.5.3 Historic Regional and Wetland Rates of Summer Decline

Superimposed on seasonal water table cycles are longer term variations reflecting changes in climate and land use (Chapter 2). The key question is: does the intensive pumping for lawn irrigation close to Perry Lakes significantly affect summer water levels? The question must be divided into two parts:

- pre early 1990's when (most years) the local water table remained above the lake beds and top up was not required
- more recently when the lakes would have been completely dry for months every summer

We have already examined the second question. It is clear that East Lake, when locally mounded, remains strongly coupled, and that the rate of decay of this local mound is strongly influenced by enhanced local heads associated with pumping. What remains unanswered is:

- historically, have Perry Lakes suffered summer water levels lower than would otherwise have been the case?
- in years when the lakes dry up, is the date of complete dryness hastened by pumping?

One approach to answering this is to examine historic hydrograph records for Perry Lakes and compare them to nearby local monitoring well records. It can be argued that the early summer rate of daily water table decline at any location is a combination of aquifer wide decline superimposed upon local effects (phreatophytes, extraction, aquifer heterogeneity). If these local effects change over time, we should observe a modified rate of summer decline in comparison to nearby monitoring wells. Such changes might include extensive clearing of natural bush for housing, sealing of roads, conversion from septic to reticulated sewerage and installation of bores.

We also know that evaporation from wetlands imposes a strong local signal on the aquifer. This signal should change where formerly permanent wetlands become seasonally dry. This is because transpiration cannot exceed (and seldom equals) potential evapotranspiration (Fleming 1997). Often, plants and soils cannot meet the atmospheric demand on their evaporating surfaces. Therefore losses from open water will generally exceed any evapotranspiration from the surrounding basin. At Perry Lakes, for example, summer evapotranspiration from *Typha-E. rudis* sumpland is only 30-50% of evaporation from adjacent open water (Chapter 11). In a natural wetland the transition from permanent to seasonal lakes should, therefore, be accompanied by a reduction in open water losses and an attenuation in the rate of summer decline in historic records.

Historic Rates of Summer Decline 1963-1998

The rate of water table decline for West Lake[5] (mm d^{-1}) was calculated for the 60 day period covering December and January from 1963 to 1998. Complete records are not available spanning the same period for any nearby monitoring well. We wanted a well with similar aquifer hydrology. This precluded wells down gradient such as GE-1 in Bold Park (Appendix 2.1) where the aquifer transmissivity is significantly greater (Davidson 1995, p56).

All historic Water Authority, now Water and Rivers Commission (WRC) bore hydrographs were examined. None provide a complete record 1963-1998 and most are close to known pumping wells. Data from two wells was examined. The Floreat Bowls Club monitor, located 850m northeast of East Lake, data covers 1963-1969 and the Lemnos St. monitor, located 1300m southeast of East Lake, data covers 1970-1986 (WRC) and 1996-1998 (this study).

West Lake displayed an average early summer rate of decline of 4.9mm d^{-1} for the period 1969-1989. Earlier data 1965-1968 are only 2.0m d^{-1}. This was ignored as it corresponds to the period of maximum flood remediation pump station operation (Figure 2.13), which reduced the winter peak levels. There is an obvious increase in the rate of decline in 1977 to 6.3mm d^{-1} when the Perth City Council (PCC) first trialed summer maintenance pumping (Chapter 2), rising to 9.0mm d^{-1} by 1996. Bowls Club figures 1963-1969 averaged 4.2mm d^{-1} but the well monitored is believed to have been adjacent to a newer production bore (Floreat Bowls Club staff pers com) and this figure is therefore possibly misleading. The Lemnos St. monitor remained as the most likely 'best indicator' of annual aquifer characteristics close to Perry Lakes. This well is removed from any significant pumping and is surrounded by open bushland comprising an army storage depot, Subiaco waste water treatment plant, old Water Authority workshops, dog cemetery and native bushland reserve. SWL (1997) averaged about 5m below ground level. The early summer decline rate averaged 2.6mm d^{-1} for the years 1970-1986. By 1997-98 this had risen to 4mm d^{-1}. Figure 7.19b shows the West Lake and Lemnos St. data with best fit ($R = 0.69$ & 0.68) polynomial curves. Comparing these two data sets is problematic due to the gap in data for Lemnos St. 1987-1996. The West Lake data also display much greater variance (2.24, $n = 27$) compared to Lemnos St. (0.49, $n = 16$).

Two clear trends are evident:

1: the rate of decline has increased over time at both locations

2: the rate at Lemnos St. has been near linear while at Perry Lakes it has been non linear and is now increasing rapidly

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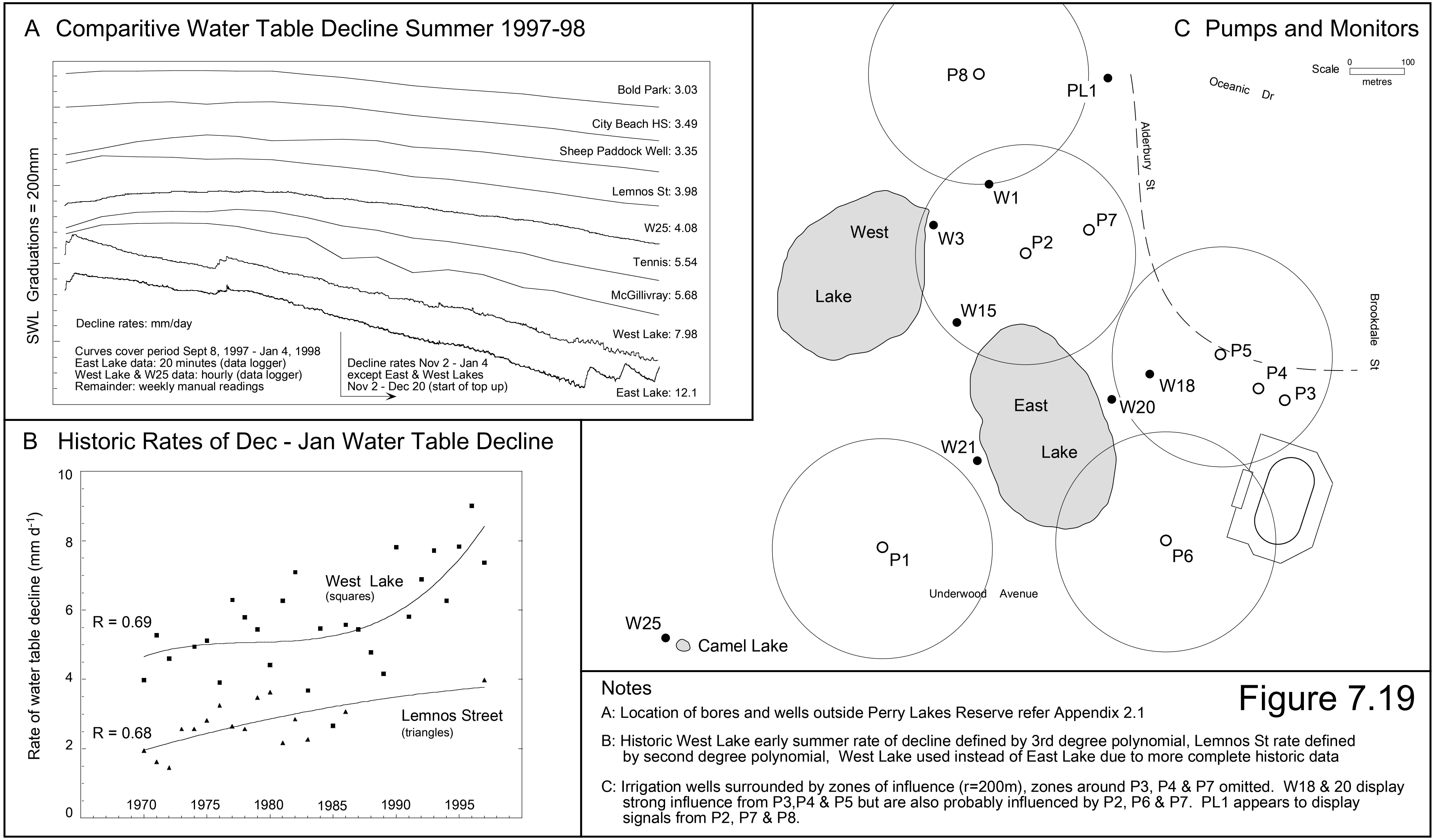
[5] the records for West Lake are more extensive (refer Chapter 2).



Notes

A: Location of bores and wells outside Perry Lakes Reserve refer Appendix 2.1

B: Historic West Lake early summer rate of decline defined by 3rd degree polynomial, Lemnos St rate defined by second degree polynomial, West Lake used instead of East Lake due to more complete historic data

C: Irrigation wells surrounded by zones of influence (r=200m), zones around P3, P4 & P7 omitted. W18 & 20 display strong influence from P3,P4 & P5 but are also probably influenced by P2, P6 & P7. PL1 appears to display signals from P2, P7 & P8.

Figure 7.19

Simple linear regression leads to the same general conclusions. The West Lake and Lemnos St. trends diverge (slopes 0.11 & 0.07) but with poorer fit (R = 0.59 & 0.67).

The change in regional rate reflects long term changes in the water balance of this sector of the unconfined aquifer. Prior to urbanisation there should have been an approximate state of dynamic equilibrium and the difference in rates should have been constant over time. In any year the difference between the regional rate and the Perry Lakes rate would simply have reflected the added local stress on the aquifer from natural (E + ET) pumping. Urbanisation imposes a state of disequilibrium. The changes at Perry Lakes reflect these added stresses, of which pumping is the most obvious. The data suggests (but does not prove) that increased summer pumping has hastened the rate of summer lake level decline.

Rates of Decline, Summer 1997-1998

By way of comparison, Figure 7.19a shows hydrograph and daily rate of early summer decline for Perry Lakes and seven nearby monitoring wells, including Lemnos St. over summer 1997-1998. Bold Park and City Beach High School are located within the higher transmissivity coastal section of the aquifer. The Bold Park well is far removed from any bores, while the City Beach High School well is an abandoned bore 2m from the current production bore. Despite this the rates are low and almost identical to Bold Park suggesting that extracted water is more readily replaced from elsewhere in the aquifer in this area.

The sheep paddock well (UWA Field Station), Lemnos St. and W25 (at Camel Lake) are all considered 'typical' of aquifer conditions close to Perry Lakes. There is little or no extraction close by. In comparison 'Tennis' and 'McGillivray' (Figure 7.15a) are currently operating irrigation bores with aquifer hydrogeology similar to Perry Lakes. Despite the fact they were always monitored at least 12 hours after pumping ceased, their increased summer decline rate suggests that groundwater extraction occurs at a greater rate than replenishment.

The rate of decline in East Lake observed from 1997 winter peak stage (September 10) is far greater than that observed regionally. Accelerated rates close to wetlands are normal (Davidson 1995) and represent greater evaporative and transpirative losses which occur where the water table lies close to the surface. This results from capillary rise and evaporation from soil, direct surface evaporation and water use by phreatophytes. In East Lake however there is also a distinct steepening of the hydrograph slope coincident with the October 20 start of lawn irrigation (Figure 7.18a) suggesting that pumping does accelerate summer lake level decline.

Discussion

Clearly the greatest problem with interpretations of this sort is the paucity of long term data. We believe however that apart from climate, groundwater extraction and regional recharge appear to be the factors which have changed significantly over the past 40 years. Urbanisation through vegetation removal and increased impervious shedding surfaces promotes recharge to the unconfined aquifer (McFarlane 1984). Despite this the mean annual water table level in the Perry Lakes area has decreased steadily since the 1960's (Chapter 2). Climate change (reduced rainfall) and bores (increased groundwater extraction) are the only obvious causes. Climate change issues are explored in Chapter 13.

Exploitation of the unconfined aquifer for potable water commenced in 1979 and is therefore a very recent phenomenon, summarised in Table 7.10. Construction of bores for domestic garden irrigation and public open space also increased markedly from 1970 onwards. Restrictions on the use of mains water for gardens during 1977-79 led to an explosion in private bores from about 24,000 to 63,000 by 1980 (Cargeeg *et al* 1987). The latest estimate is 130 000 domestic bores within the Perth metropolitan area (Water and Rivers Commission 1998b). The first bores were drilled in Perry Lakes Reserve for lawn irrigation about 1962.

Table 7.10 Perth water supply summary history 1829-2000

Period	Perth Water Supply Sources
1829-1895	springs, dry wells and wetlands
1895-1940	artesian water 60%, supplemented from hills dams
1940-1970	steady rise in surface water from hills catchments and decrease in artesian to 10% by 1970
1979-2000	steady rise in use of unconfined groundwater which now supplies 70% of reticulated water

Source: Allen (1997)

Domestic bores are not licensed. Therefore we have no records of when bores were constructed in Floreat. McFarlane (1984) provides data from Nedlands-Dalkeith and Subiaco-Shenton Park showing that the majority of bores were constructed in the decade 1970-80, with most constructed 1978-80 (Table 7.11) in direct response to drought and water restrictions between 1977 and 1979. Anecdotal evidence from drilling contractors suggests that a similar pattern prevailed in Floreat.

Table 7.11 Domestic bore installation western suburbs

Date & Suburb	1940-50	1950-60	1960-70	1970-81	Unknown
Nedlands-Dalkeith	4	13	7	70	6
Subiaco-Shenton Park	12	0	13	63	12

The decade 1970 to 1980 corresponds to a very marked decline in groundwater levels at Perry Lakes (Figure 2.10). It was a period of significant drought (and therefore significantly increased lawn and garden irrigation), and initiation of the first summer top-up trials at Perry Lakes. Natural systems display an approximate dynamic equilibrium. This equilibrium is affected by any unnatural activity such as groundwater extraction (Bredehoeft *et al* 1982). The question of 'sustainable yield' in relation to Perry Lakes is a vexed one and is further examined in Chapter 13.

7.6 SUMMER WATER LEVEL MAINTENANCE ISSUES

Summer maintenance relies on maintaining a local groundwater mound. An 'ideal' lake might be considered as one in which there was an impermeable bottom allowing nil seepage back to the aquifer. Such lakes actually present wetland managers with great problems because water is only lost through evaporation, promoting the build up of salt and nutrients. In contrast there is a strong hydraulic connection between Perry Lakes and the unconfined aquifer such that the lake oscillates between flow-through and recharge flow regimes on a daily and seasonal basis.

7.6.1 Natural and Artificial Local Groundwater Mounds

At Perry Lakes groundwater mounds occur either from excess storm water or top up. Both are essentially 'artificial'. The storm water induced mounds are large, with radii of 3-4 lake diameters (Figures 7.15 c&e). Prior to urbanisation natural mounds would have been rare, induced only by direct rainfall and local surface runoff during sustained very heavy storms.

Hydrograph data suggest that as a mound becomes more localised its slope steepens. At Perry East, the top up induced mounding appears asymmetric (Figure 7.21e), becoming very steep on the east (up regional gradient) side. Such asymmetry would be expected when a mound is superimposed on a sloping water table. The asymmetric shape may also reflect the greater hydraulic conductivity of the upper sand unit west of Perry Lakes (Chapter 3).

Experiments on March 13, 1997 comprised digging holes to the local water table in mud along a line parallel to the regional gradient when the lake was very low (stage 2.960m). The observed gradient on the east side was 0.118m over 10m or approximately 0.012. This is an order of magnitude greater than the average regional gradient of about 0.001. The gradient on the western (down regional gradient) mound slope was 0.5-0.6m over 100m (about 0.005).

Figure 7.21e includes an estimated position of the water table on April 30, 1998 if no top up had occurred, based on data to December 20, 1997. At lake stage 3.0m the water surface was about 1.8m above its predicted natural position. It is important to remember that the cross section incorporates a 10x vertical exaggeration. The mound is in reality a very subtle feature on the regional phreatic surface, a small very slight bulge rather than a pimple!

7.6.2 Rates of Mound Decay

Storm water and top up induced mounds take very different forms. Storm water induced mounds occur whenever there is significant rain. Large volumes of water enter the lake in just a few minutes possibly doubling or tripling the lake volume. During extreme events such as March 31 and June 02 1997 (Figures 7.15 c&e) East and West Lake form a combined mound which extends up gradient several lake diameters and exhibits reverse gradients similar to those observed normally on the regional water table. In comparison to storm events, summer top up is an extremely slow process. The same lake stage change effected by storm water in under an hour may take 48 hours to achieve by top up pumping. The rate of mound decay very quickly approaches the rate of top up. The result is a mound which is extremely localised.

Rates of mound decay were expected to vary depending on the hydraulic head created by the mound, temperature (and hence water viscosity) and the proportion of clay and sand comprising the lake bed. Lake lining sediments particularly around the lake perimeters are highly disturbed. Perimeter clay lining was removed and the lakes deepened and expanded in the early 1960's (Chapter 2). The deeper portions however contain extensive recent and in situ palaeosediments up to 3.2m thick in East Lake and 2.2m thick in West Lake (Figures 3.6 a&b). Four situations were considered:

- Stable winter flow-through regimes
- Winter recharge regimes where a well defined local recharge mound persists following large storm water inputs
- Summer top up where the entire basin is filled
- Summer top up where the lake is wholly contained within the clay lining

The first three situations provide a 'basin averaged' figure since varying proportions of peripheral sandy rim and central clay lining are involved and a wide range of temperatures. Case four involves the thicker clay lining only and effects of warmer temperatures. Experimental estimates of K_Z for these two sediment types were determined by permeameter (Chapter 3) to be approximately 9.5 and 0.011 m d^{-1} respectively.

Rates of storm water induced winter mound decay were used as part of the storm drain calibration process (Figure 5.6). At lake stages of 3.3 to 3.4m decay rates were about 13mm d^{-1}. By comparison Table 7.12 shows rates of mound decay from summer top up.

Table 7.12 Average mound decay statistics at varying lake stages

Stage (m AHD)	Area (m^2)	Loss (mm d^{-1})	Hourly Loss (m^3)	Daily Loss (m^3)
2.8	3840	10	2.1	50
2.9	11220	17	8.0	191
3.0	20110	27	22.6	543
3.1	32580	35	47.5	1140
3.2	39920	38	63.2	1517
3.3	47000	47	92.0	2209
3.4	53440	51	113.6	2725
3.5	58220	54	131.0	3144

data compiled from 1996-1998 lake hydrograph data

The summer top up induces rates of mound decay which are three to four times those observed over winter from storm events.

7.6 3 Limits to Artificial Summer Maintenance

Pumping Capacity

As soon as top up pumping commences, the competing effect of mound decay (plus the ever present evapotranspiration) becomes operative. The extent to which artificial summer levels can be maintained is limited by pumping capacity. Perry Lakes Reserve bores P1-P8 have an estimated open pipe (non pressurised) combined capacity of about 620m^3 h^{-1}. Actual top up rates however are limited by the 6 inch (152mm) ring main and narrow (80 and 100mm) top up outlets (Figure 5.1a). The wetland managers frequently operated five bores simultaneously with a combined theoretical capacity of about 400m^3 h^{-1}, however the maximum measured top up rate was never observed to exceed 235m^3 h^{-1} (5640m^3 d^{-1}).

In summer the rate of mound decay increases as the head (effectively lake stage) increases (Table 7.12). Figure 7.20 also demonstrates how the rate of mound decay increases with stage height and effective head. Note how in top up cycle 'A' filling the lake to about 3.0m resulted in a decay rate of 22mm d^{-1}. Three months later a similar top up

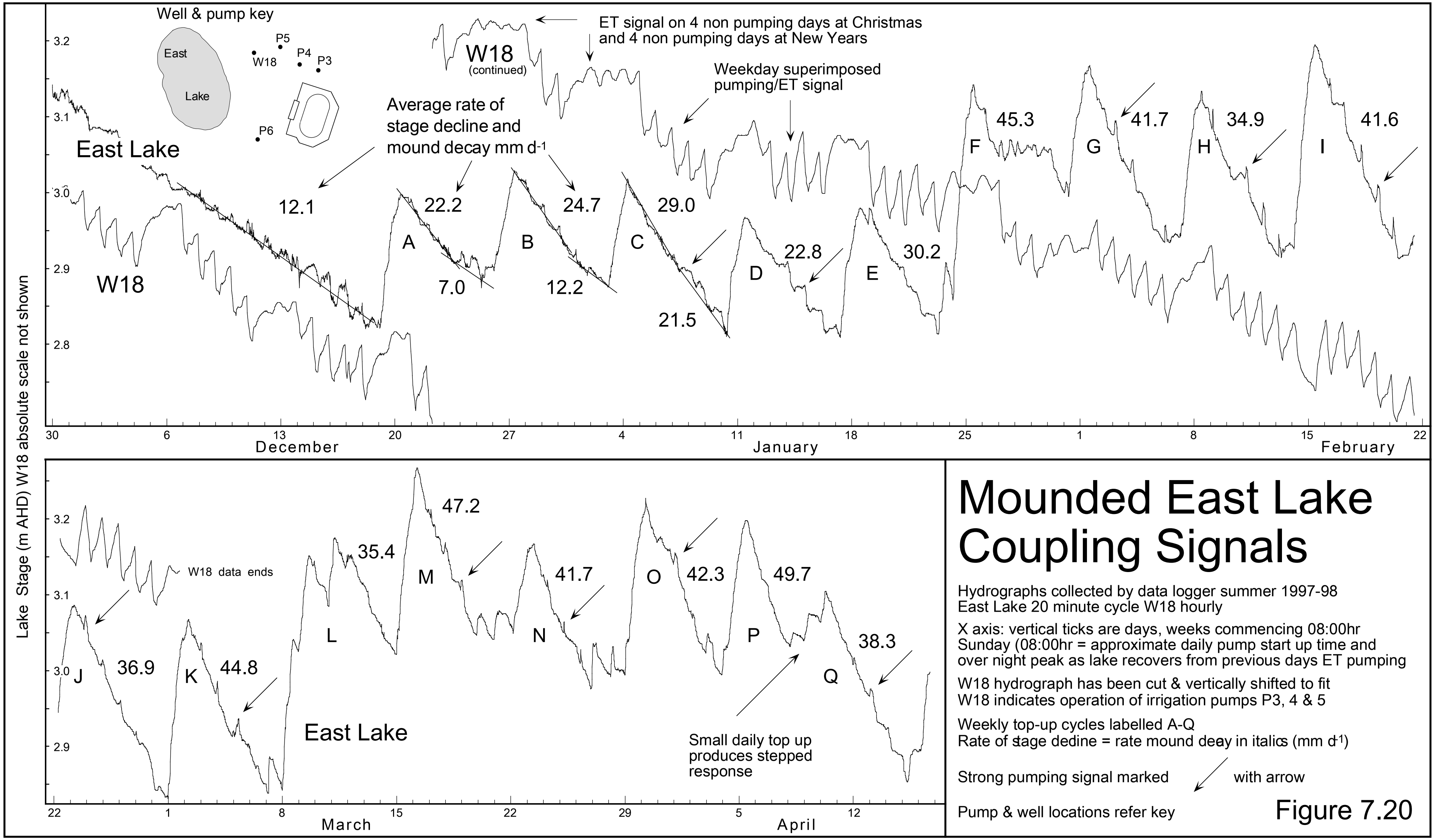
(cycle 'K'), the rate had doubled to 45mm d^{-1}. This reflects the fact that in three months the natural position of the water table had fallen so that a top up to 3.0m in March creates a much higher mound than a similar top up in December.

The East Lake hydrograph for December 1997 (Figure 7.20) shows the natural rate of lake and local water table decline up to the commencement of top up pumping on December 20. The initial five top up cycles (A to E) all raised the lake level about 200mm. Average mound decay was 25.8mm d^{-1} or about double the natural rate of decline of 12.1mm d^{-1}. The initial three cycles all display a change in decay rate over time. At the top up peak stage of about 3.0m lake waters were in contact with the sandy basin rim. It is tempting to speculate that the change represents diminished seepage as the waters became completely constrained by the clay lining. This argument does not hold water however, as this effect was not evident during natural decline and disappears after top up cycle C. Reasons for this seemingly transient effect remain unclear. Decay rates clearly increase with higher lake stages. Small changes in rate between seemingly identical top up cycles such as J & K and those noted above reflect the effects of nearby pumping and differences in evaporation, water temperature and experimental error.

Models of lake maintenance performance were developed which predict lake stage in hourly time steps (Figure 7.21b). The models use observed seepage losses at summer water temperatures and evaporation rates (Figure 7.21d). Curves plot typical measured top up rates (maximum 235m^3 hr^{-1}). These models, in practice, are considered to be conservative. This is because seepage losses increase when top up commences at very low lake levels. Under such conditions approximately 25-40% of top up water enters the lake basin through the north outlet. Much of this seeps directly into the lake bed before eventually puddling and joining the expanding main body of the lake within the South Basin. Detailed observations of this on March 16, 1997 indicated that much of this water was returning to the aquifer via large mud cracks. Top up pumping commenced at a lake stage of 2.867m, at an average rate of 222m^3 hr^{-1} (139m^3 h^{-1} south outlet and 93m^3 hr^{-1} north outlet). It took 7 hours for the two expanding bodies of water to join. This occurs when the NE Arm fills and overflows into the South Basin. The model predicts a stage of 2.96m under such conditions, measured stage was 2.931m. The extra losses are those described above. The model curves agree well with observed top up hydrographs (Figure 7.21c). In practice top up seldom proceeds continuously for more than 48 hours (one weekend).

Temperature and Viscosity:

The hydraulic conductivity of any porous medium is affected by temperature which controls water viscosity. Viscosity decreases with temperature such that warmer water passes more easily through the sediment pore spaces. As the water temperature increases, so too does hydraulic conductivity. Temperature effects on hydraulic conductivity are



Mounded East Lake Coupling Signals

Hydrographs collected by data logger summer 1997-98
East Lake 20 minute cycle W18 hourly

X axis: vertical ticks are days, weeks commencing 08:00hr Sunday (08:00hr = approximate daily pump start up time and over night peak as lake recovers from previous days ET pumping

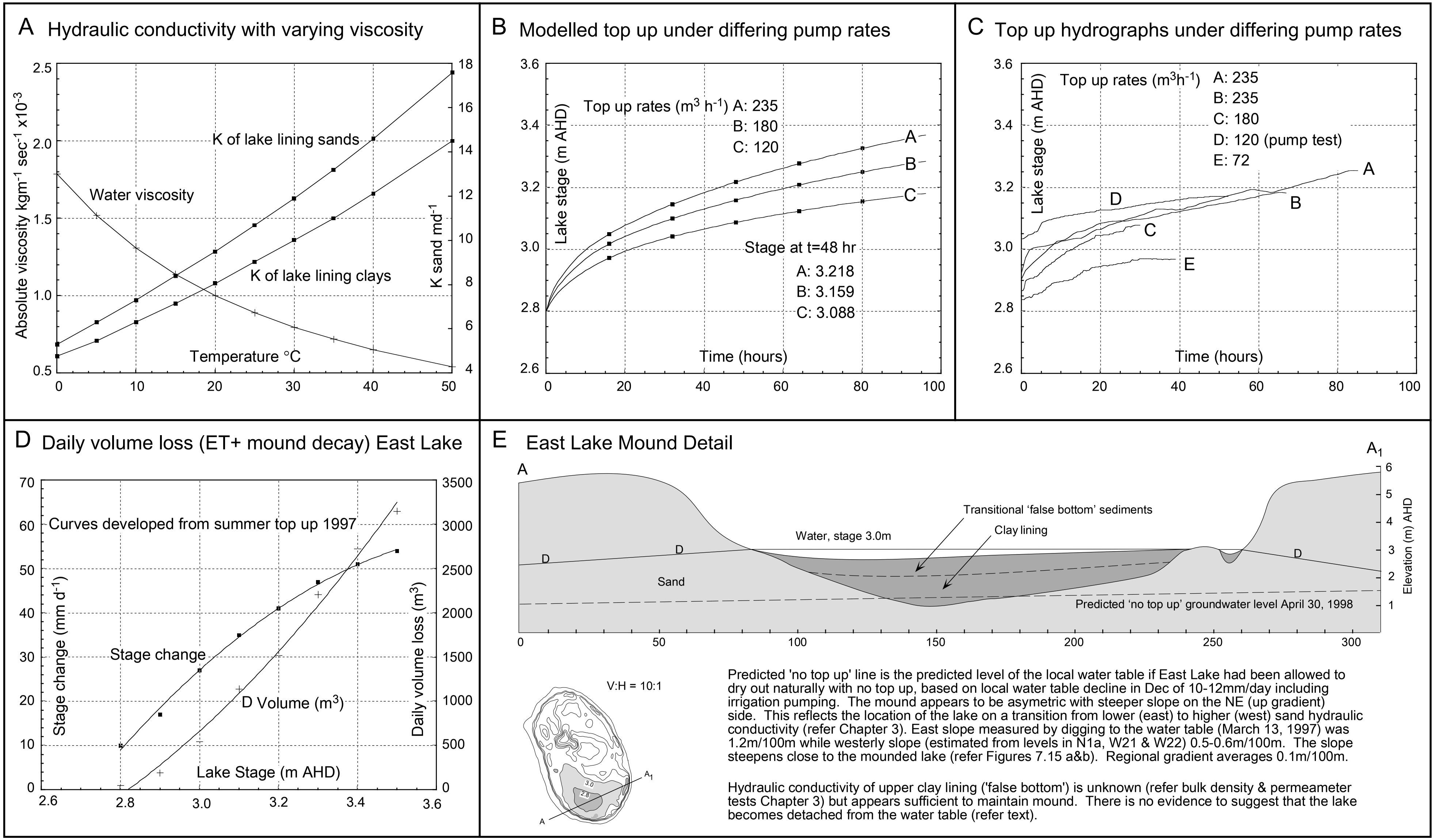
W18 hydrograph has been cut & vertically shifted to fit
W18 indicates operation of irrigation pumps P3, 4 & 5

Weekly top-up cycles labelled A-Q
Rate of stage dedine = rate mound decay in italics (mm d-1)

Strong pumping signal marked ↙ with arrow

Pump & well locations refer key

Figure 7.20



Predicted 'no top up' line is the predicted level of the local water table if East Lake had been allowed to dry out naturally with no top up, based on local water table decline in Dec of 10-12mm/day including irrigation pumping. The mound appears to be asymetric with steeper slope on the NE (up gradient) side. This reflects the location of the lake on a transition from lower (east) to higher (west) sand hydraulic conductivity (refer Chapter 3). East slope measured by digging to the water table (March 13, 1997) was 1.2m/100m while westerly slope (estimated from levels in N1a, W21 & W22) 0.5-0.6m/100m. The slope steepens close to the mounded lake (refer Figures 7.15 a&b). Regional gradient averages 0.1m/100m.

Hydraulic conductivity of upper clay lining ('false bottom') is unknown (refer bulk density & permeameter tests Chapter 3) but appears sufficient to maintain mound. There is no evidence to suggest that the lake becomes detached from the water table (refer text).

Figure 7.21

often ignored, however in shallow lakes with large seasonal changes in average daily temperature, the effect becomes significant. If hydraulic conductivity is determined at 20°C, the change due to viscosity is given by Bouwer (1978) as:

$$K_t = \frac{K_{20}\mu_{20}}{\mu_t} \tag{7.4}$$

where K_t and μ_t are hydraulic conductivity and viscosity at temperature t. Vertical K_{20} for East Lake lining clays and sands was estimated by permeameter (Chapter 3) to be 0.0108 and 9.5m d^{-1} respectively. The range of water temperature within East Lake (1996-1998) was 9.2 to 40.9°C. Over this temperature range the hydraulic conductivity of lining clays and sands varies between 0.008 to 0.017m d^{-1} and 7.1 to 14.8m d^{-1} respectively (Figure 7.21a). Therefore over the range of water temperatures occurring seasonally, lining hydraulic conductivity potentially doubles under extreme summer conditions. At depth, average temperature also increases within the clay lining (Chapter 9).

For wetland managers struggling to maintain water levels over summer, the cards are stacked against them. The lake is the visible top of a local groundwater mound which pumping attempts to maintain against a falling regional water table, locally depressed further by pumping, increased transpiration and open water evaporation. The rate of mound decay is further enhanced by reduced water viscosity and higher effective lining hydraulic conductivity.

7.7 WETLANDS ON THE SWAN COASTAL PLAIN - NEW INFORMATION

In Chapter 2 some anecdotal evidence was presented which implied that the position of wetlands within the landscape is not arbitrary. The most striking feature of regional maps is the well defined general north-south orientation of the major wetland systems. These include the Wanneroo chain of wetlands (Loch McNess to Lake Goollelal), including the more ill defined chain from the Carine Swamps to Herdsman Lake and south of the Swan River, the East Beeliar chain of wetlands from North Lake to The Spectacles. Many of the wetlands themselves display the same north-south elongation, in particular Lake Joondalup. It has long been recognised that these wetland chains decrease in age towards the coast (Allen 1981). It is also evident that some of the larger lakes lie on or close to the surface expression of geologic boundaries. Lakes Pinjar and Jandabup and the East Beeliar chain of lakes occupy the contact between Bassendean Sand and the leached sand facies of the Tamala Limestone. Lake Joondalup, the Carine Lakes including Lakes Karrinyup and Gwelup and Perry Lakes lie on the Tamala Limestone, on or close to the surface contact between calcarenite and basal sands (Figure 1.2).

Drillers in the City Beach-Ocean Reef area frequently comment that the upper 20m of the aquifer contains thin hard silcrete bands, but is also the most porous zone and often the only zone producing reasonable yields. Below this level it is often difficult to obtain useable flows (M. Davies, W. Brandt pers com). Davidson (1995) notes that the eastern margin of the Tamala Limestone is characterised by finer grained sand (and correspondingly lower hydraulic conductivity). Around Jackadder Lake which lies within this contact zone, drill contractors report poor yields in the near surface residual Tamala sands of 300-400m^3 d^{-1} (K. Wintergreen, pers com). Similarly Haselgrove (1981) notes a thin eastward dipping unit of clayey sand which occurs between Tamala Limestone and Bassendean Sand in the Kwinana area. He suggests that an abrupt change in aquifer hydraulic gradient in this area reflects lower aquifer transmissivity possibly due to this layer which is described as a 'barrier' to westward groundwater movement.

These hydraulic barriers produce a local steepening of the water table gradient. The detailed regional surveys show this effect west of Herdsman and Jackadder Lakes (Figures 2.5 & 2.6). At Perry Lakes a similar barrier effect (steepened gradient) occurs immediately southwest of both lakes. This is readily evident in many of the winter water table contour maps comprising Figure 7.15. This barrier zone is evident immediately adjacent to West Lake between wells N2 and W5 and about 200m southwest of East Lake between wells W24 and N5.

These effects are quite subtle and are not evident on regional scale maps. At Perry Lakes these data appear at first glance to be at variance with the pump test and grain size analyses which indicate an increase in hydraulic conductivity in this area. Regionally increased transmissivity in coastal limestone is well documented (Davidson 1995), and not disputed. This is an extremely localised zone and appears to define the boundary between Tamala Fm sand (to the east) and calcarenite ('limestone') to the west. Its position on a geologic contact, immediately west and down hydraulic gradient from Perry Lakes has obvious similarities to other areas. East of such barriers there is a local water table rise. This corresponds precisely to the position of the East Beeliar, Herdsman-Jackadder and Perry Lake systems. It suggests that hydrogeology plays a subtle but important role in defining the position of wetlands in the landscape.

7.8 CONCLUDING SUMMARY

Lake-aquifer interaction is an intrinsic characteristic of water table lakes. It can be described and modelled mathematically as a continuum of 'flow regimes'. This continuum is bounded by recharge lakes and discharge lakes which form end its members. The physical characteristics of both the lake and the aquifer and their respective water balances represent a plethora of factors which operate in combination to determine the flow regime prevailing at any time. These include (but are not limited to:

Characteristics of the lake and its water balance

- lake length and depth
- distribution and resistance of the lake lining
- horizontal flux ratio
- rainfall and evapotranspiration

Characteristics of the aquifer and its water balance

- wetted thickness
- anisotropy
- hydrogeology (sand, limestone, clay layers)
- slope of the phreatic surface
- recharge (function of climate and land use)

Landscape effects

- proximity to nearby lakes
- geologic boundary effects

Anthropologic effects

- effects of nearby pumping
- effects of artificial stimulation such as storm water drains and summer 'top up'

Perry Lakes are now characterised by recharge regimes for much of the time, either in response to storm water inputs and/or artificial summer 'top up'. Both have the effect of forcing the lakes to tend towards (or become) local groundwater mounds. Excessive local groundwater extraction further enhances this effect. In winter flow-through regimes occur but are highly non symmetric with recharge always exceeding discharge, again in response to large storm water inputs.

CHAPTER

8

THERMAL BALANCE

8.0 INTRODUCTION

In this chapter thermal balance concepts are introduced and thermal balance data for Perry Lake East is presented. A technique for determining the difficult to measure sediment term *Qse* is developed and its importance in estimating evaporation by thermal balance discussed. This is expanded in Chapter 9.

A thermal balance relies on the measurement of all sources of incoming and outgoing thermal energy plus changes in energy storage. It is considered to be one of the most accurate methods for estimating evaporation from a water body when integrated over long periods of time (Harbeck *et al* 1958, Winter 1981). In such studies all thermal terms are measured except evaporation. The residual in the balance is then considered to be the heat used to evaporate water. In many studies however, heat advected in the difficult to measure ground water components (discharge into the lake and recharge from the lake back to the aquifer) are either ignored or poorly estimated. Sturrock *et al* (1992) noted that 'the importance to the heat budget of groundwater flux to and from lakes has not been evaluated at all'. Likewise heat conducted from the lake into the sediments and from the sediments back into the water column has been generally ignored. Heat flux from sediments can comprise a significant source of heat to the water (Geiger 1965). Hughes (1967) noted that the importance to a lake energy budget of heat flux to and from the sediments had been addressed in only a few studies.

At East Lake evaporation was measured directly by floating pan. Likewise groundwater components were independently measured and their temperature throughout the year well documented (Chapter 9). Therefore heat used for evaporation and heat transported via groundwater were known. The thermal contribution of the lake sediments could then be estimated as the balance residual.

In most studies where it has been addressed, the sediment term has represented a very small component of the energy balance. At Pretty Lake (Indiana) Ficke (1972) concluded that bed conduction was seasonally important but did not include it in the final balance. In extensive studies at Perch Lake (Ontario) Robertson & Barry (1985) considered bed conduction to be insignificant. At Williams Lake (Minnesota) Sturrock *et al* (1992) found that bed conduction varied seasonally and reduced calculated evaporation by 2-7%. All of the lakes in these surveys are located in glacial clay till aquifers and all appear to function as flow through lakes. Also these lakes were much deeper than Perry Lakes with well defined temperature stratification. Their temperature at depth changed very slowly and the sediments did not receive direct solar radiation. Perry Lakes are the exact opposite. They are very shallow and always well mixed. In very shallow water bodies much of the daytime radiation absorbed by the water is conducted to the underlying sediments and at night both the water and sediments may release sufficient heat energy not only to offset the net long-wave radiative loss at the surface but also to support continued evaporation throughout the night (Oke 1987, p103). Ficke (1972) found that 50% of thermal energy transfer was occurring in the top metre of sediment, but effects were still measurable below 5.3m. We believed that the excessive short term area/volume changes experienced in East Lake would render the sediment thermal effects extremely difficult to quantify directly, further substantiating the case for a thermal balance.

Jacobs *et al* (1998) applied simple models to study thermal regimes within a standard Class A evaporation pan. The principal characteristics of such pans are similar to a small very shallow lake where the water generally remains well mixed. During the day incoming short wave radiation is the driving force. This is absorbed at the surface, within the water column, and on the upper sediments. At the water surface long wave radiation (incoming and outgoing) and sensible and latent heat exchange processes take place. Wind mixing in very shallow water largely precludes stratification. At night under calm conditions, long wave radiative cooling at the water surface becomes the driving force. As the surface layer cools, its density increases. Over the night this mixing layer descends and continues to decrease in temperature retaining a generally well mixed water column. Pilot investigations confirmed that the sediments have large diurnal temperature cycles and may be either warmer or cooler than the water column. This was first noticed while wading barefoot in sediments that were noticeably warmer than the water column. This led directly to the hypothesis that in very shallow lakes sediments may act diurnally as both heat sinks and heat sources. The net daily sediment heat flux could be positive (net heat flux into the water column), or negative (net heat flux into the sediments). Taking into account the seasonal changes in flow regime, the hypothesis was expanded to include net seasonal changes in flux direction.

Measurement of the sediment term is potentially very difficult and can be achieved at varying levels of accuracy. Chapter 9 includes an expanded discussion on methodology and the significance of sediment heat regimes in the study of wetland flow regimes. As the sediment term was to be determined as the balance residual it was crucial that all other components of the thermal balance were determined as accurately as possible.

8.1 THEORY AND METHOD

The thermal balance or heat budget method is described by Anderson (1954 a&b), Harbeck *et al* (1958), Harbeck *et al* (1959), Hughes (1967), Ficke (1972), Sturrock *et al* (1992). These describe large government funded studies on reservoirs and lakes in the United States. In Australia thermal balance studies have also been completed on a number of large lakes and reservoirs including Mundaring near Perth (Hoy & Stephens 1979).

A thermal balance relates net energy transfer into and out of a water body to changes in stored energy and takes the general form:

Sensible and latent heat lost from the lake surface = Net incoming radiation + Net heat transport through other surfaces - Change in stored heat

At Perry Lakes this was expanded, taking the form:

$$E = \frac{(Q_s - Q_{sr} + Q_a - Q_{ar} - Q_{bs}) + (Q_{rn} + Q_{sd} + Q_{tu}) + (Q_{dc} - Q_{rc} + Q_{se}) - Q_x}{\rho[L(1 + R) + c(T_e - T_b)]} \qquad (8.1)$$

where

Q_s	incoming short wave radiation
Q_{sr}	reflected short wave radiation
Q_a	incoming long wave radiation
Q_{ar}	reflected long wave radiation
Q_{bs}	long wave radiation emitted from the water
Q_{rn}	heat in rain falling directly on the lake
Q_{sd}	heat in storm drain flows
Q_{tu}	heat in summer top up water
Q_{dc}	heat in groundwater discharged to the lake
Q_{rc}	heat in lake water recharged to the aquifer
Q_{se}	heat conducted into and out of the lake sediments
Q_x	change in heat energy stored in the lake
ρ	density of evaporated water at surface water temperature T_o
L	latent heat of evaporation of water
R	Bowen ratio, dimensionless (sensible heat flux Q_h / latent heat flux Q_e)
c	specific heat of water at surface water temperature T_o
T_e	temperature of the evaporated water, taken as equal to surface water temperature
T_o	see below
T_b	arbitrary base temperature set to 0°C, therefore (T_e-T_b = T_o)

The denominator derives from a compositing of the non-radiative surface heat loss terms which cannot be measured directly:

Q_e energy used for evaporation = ρEL (8.2)

Q_h energy conducted from the water as sensible heat = RQ_e (8.3)

Q_w energy advected from the water body via evaporated water = $\rho cE(T_e - T_b)$ (8.4)

Computational Notes:

The brackets in (8.1) group (solar radiation), (surface flows), (groundwater flows) and (storage) terms. It is standard practice to express heat budget terms in watts m^{-2} *(*$W\ m^{-2}$*).*
For computational purposes all terms in the numerator of (8.1) were expressed as Megajoules $day^{-1}\ m^{-2}$ *and the denominator in Megajoules* $day^{-1}\ m^{-3}$ *yielding evaporation E in metres. Refer Appendix 8.1.*

8.2 DETERMINATION OF THERMAL BUDGET TERMS

8.2.1 Incoming short and long wave radiation Q_s & Q_a

Incoming short wave radiation Q_s and long wave radiation Q_a were measured at the Swanbourne automatic weather station (AWS) site using a Middleton model CN9 short wave pyranometer and Eppley model PIR long wave pyrgeometer. Both instruments were calibrated in the Bureau of Meteorology laboratories prior to installation. Outputs were amplified 100x and 200x respectively using calibrated Carter-Scott amplifiers (refer Appendix 8.2 for instrument specifications). Instrumentation was installed and monitored specifically for this study by the Department of the Environment (DEP). The data sampling rate for both instruments was 1 second, stored in a data logger as 10 minute averages. Swanbourne AWS is 3km southwest of Perry Lakes. Experiments by Rosenberry *et al* (1993) indicate that solar radiation measured up to 100km distant from a study lake may only present a 2-3% change in annual calculated evaporation. Siting the solar instrumentation at Swanbourne was considered to introduce negligible error.

No long wave data was recorded over the period 15:00 hr August 8 to 12:00 hr August 13 1997 due to instrument malfunction. Data for the week preceding instrument failure was also suspect. Long wave radiation over this period was estimated using the Brunt (1944) equation where the atmosphere is treated as a grey body and using Stefan's law, the only variable becomes air temperature:

$$\frac{Q_a}{\sigma T_a^4} = c + d\sqrt{e_a} \tag{8.5}$$

where

Q_a incoming long wave radiation

σ Stefan Boltzmann constant

T_a air temperature °K

c & d constants

e_a vapour pressure of the air

Equation (8.5) was applied as modified by Koberg (1964) where *c* (cloud factor) is determined from a family of curves defining the ratio of measured Q_s to theoretical Q_s adjusted for day, latitude and air temperature and *d* is taken as 0.0263 (as determined by Anderson 1954a).

8.2.2 Reflected short and long wave radiation Q_{sr} & Q_{ar}

Reflected short wave radiation Q_{sr} was calculated using the method of Anderson (1954a) as modified by Koberg (1964). Koberg presented a family of curves defining the relationship (in cal cm^{-2} day^{-1}) between incoming and reflected radiation for clear sky (<20% cloud) and cloudy sky (>20% cloud). Polynomial expressions were developed describing these relationships in watts m^{-2} allowing clear sky and cloudy sky Q_{sr} to be calculated directly from daily averaged Q_s. Final value used was the average of expressions developed for clear and cloudy sky (<20% cloud and >80% cloud). Details in Figure 8.2c.

Reflected long wave radiation Q_{ar} was calculated as 3% of incoming long wave radiation as determined by Gier & Dunkle cited Anderson (1954a).

8.2.3 Emitted long wave radiation Q_{bs}

Long wave radiation emitted from the water surface Q_{bs} follows the Stephan-Boltzman fourth power law (Monteith & Unsworth 1990 p25):

$$Q_{bs} = \varepsilon \sigma T_o^4 \tag{8.6}$$

where

ε emissivity of the surface, taken as 0.97, dimensionless (Sturrock *et al* 1992)

σ Stefan-Boltzman constant 5.67 x 10^{-8} W m^{-2} $°K^{-4}$ s^{-1}

T_o water surface temperature in degrees Kelvin

8.2.4 Change in stored heat energy Q_x

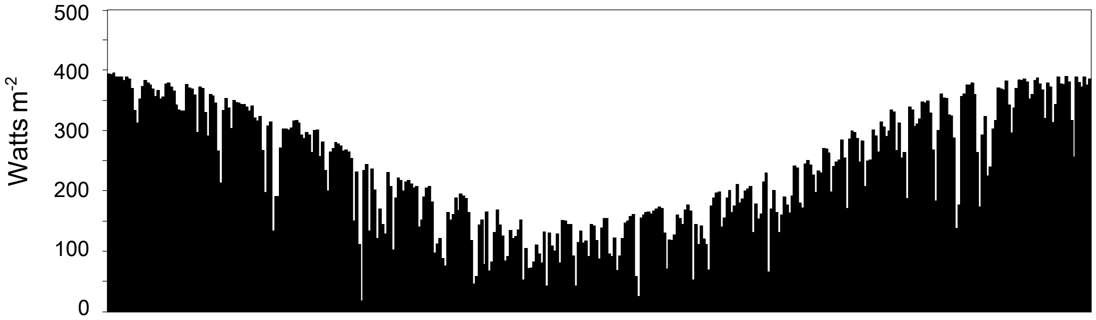
Thermal balance studies of large lakes and reservoirs typically measure the change in stored energy by extensive periodic manual surveys (Table 8.1). East Lake is extremely small. At a mean annual stage (1997) of 3.18m it has an average surface area of only $38600m^2$ (3.86ha) and a volume of $7975m^3$. Mean annual depth is 0.2m and maximum depth over the survey period was always <1m. Lake size is a principal determinant of acceptable balance period. In large lakes Q_x, the change in thermal energy stored in the water body (as indicated by water temperature) may be small compared to measurement error. Therefore minimum balance periods of 2-3 weeks are recommended (AWRC 1970). In smaller lakes such as East Lake, short term changes in Q_x may be quite large in

Thermal Balance Components

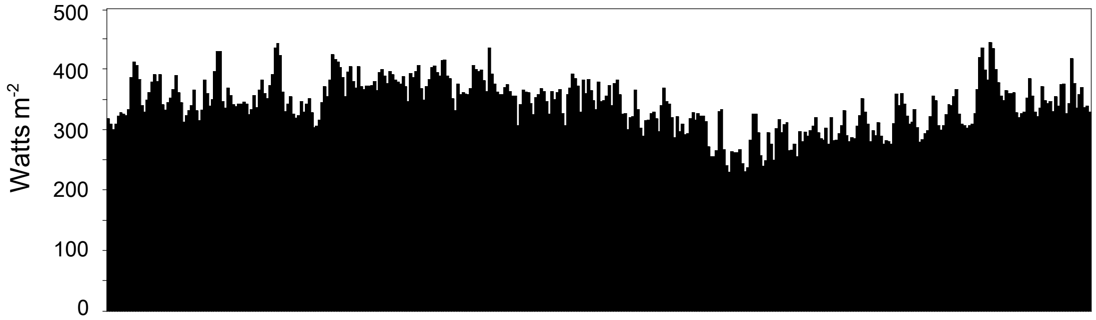
Dec 22 1996 - Jan 3 1998

Figure 8.1

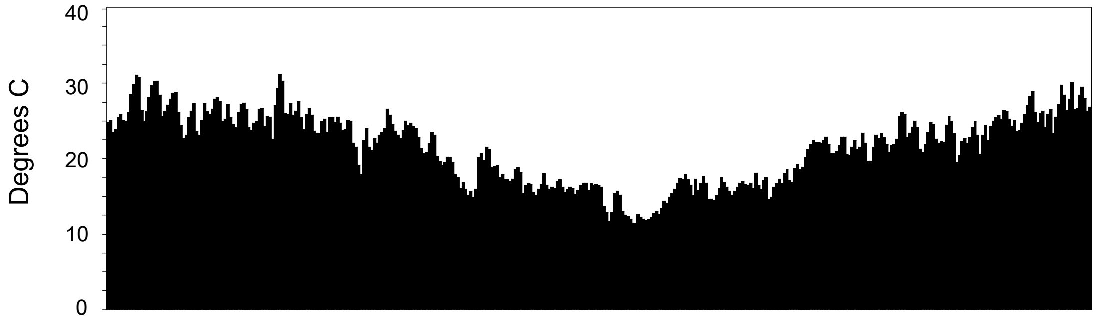
A Incoming Short Wave Radiation Qs 08:00 hr - 08:00 hr
Sampled every second, daily average of 86,400 readings



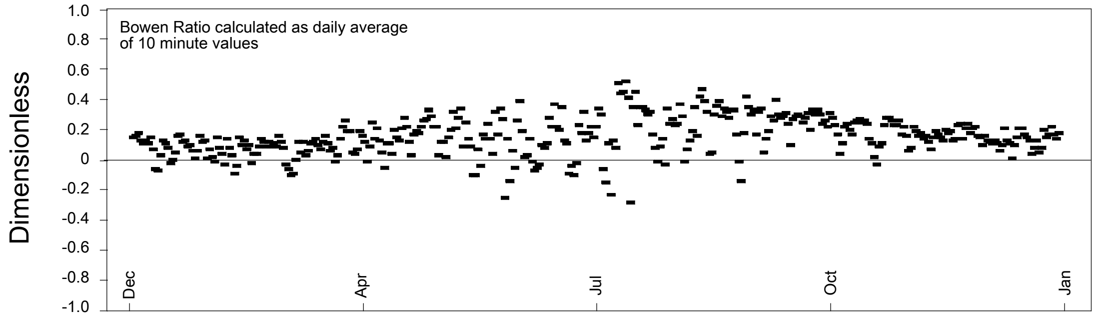
B Incoming Long Wave Radiation Qa 08:00 hr - 08:00 hr
Sampled every second, daily average of 86,400 readings



C Daily Average Lake Surface Temperature 08:00 hr - 08:00 hr
Average of 10 minute data



D Daily Average Bowen Ratio 08:00 hr - 08:00 hr



comparison to measurement error and shorter balance periods are feasible. At East Lake daily thermal balances were achieved.

Table 8.1 Determination of *Qx*

Study	Ref	Area (ha)	Av D (m)	Determination of *Qx*	Frequency
Salton Sea (California)	1	89000	8.3	35 profiles, 0.6 & 1.2m layers	10-29 days
Lake Mead (Nevada)	2	63900	55.8	30 profiles, 5m layers	30 days
Lake Hefner (Oklahoma)	3	1050	9.6	16 profiles, no layer data	10 days
Rifle Creek Reservoir (Qld)	4	190	5.0	5 profiles, 0.9m layers	30 days
Lake Wyangan (NSW)	4	98	2.0	5 profiles, 0.3m layers	30 days
Pretty Lake (Indiana)	5	74	7.8	24 profiles, 0.76m layers	7-56 days
Williams Lake (Minnesota)	6	36	5.2	16 profiles, no layer data	14 days
Blue Lagoon (Victoria)	4	13	3.5	5 profiles, 0.9 layers	21-112 days
Perry Lake East		3.8	<1	mid level temperature at 1 site	10 min, av daily

1: Hughes (1967), 2: Harbeck *et al* (1958), 3: Anderson (1954a), 4: Hoy & Stephens (1979), 5: Ficke (1972), 6: Sturrock *et al* (1992)

Surface, mid and bottom level temperature records (Chapter 9) confirm that the lake is almost always well mixed. The single mid level temperature recorded every 10 minutes was taken to be mean lake temperature at any given time. Even in a much larger (36ha) and deeper (mean 5.2m) lake, Rosenberry *et al* (1993) found that the use of one central temperature profile resulted in less than a 1% change in daily evaporation compared to profiles at 16 stations. The change in stored heat was calculated for each daily balance period using average mid level temperature at average volume and area minus the equivalent calculation for the previous day.

It is evident from Table 8.1 that Perry East is extremely small compared to other thermal balance sites. Harbeck (1954) provides criteria, summarised in Table 8.2 for judging the suitability of a lake for energy balance studies.

Table 8.2 Criteria for Energy Balance Studies

Mass Balance Components	Lake Form	Physiography
accuracy extremely importance	ideally circular	low surrounding relief
no bank storage	min 5x8km if not circular	small catchment
small transpirative losses	area>25km^2 & <125km^2	arid climate
accurate area:capacity curve	depth 80%>3m	long periods of low rainfall
advected components<<lake volume		unfrozen in winter

In addition Harbeck recommended that the error in the monthly difference between total surface and sub surface inflow and outflow including changes in storage should be less than 5% of the mean monthly evaporative loss. Overall it was considered that accurate evaporation figures could only be obtained from lakes where highly accurate mass balances could be guaranteed *i.e.* lakes with small or nil groundwater components and surface flows which were small compared to the lake volume and which could be accurately measured. Deep lakes were considered preferable because they implied a large volume relative to the surface flows and small changes in stored energy relative to the total. Early oceanic thermal balances (for example Sverdrup 1940) relied on yearly balance periods or water bodies within which the net advected energy was either negligible or constant.

Perry East satisfies none of these criteria. Surface flows and groundwater fluxes can comprise a large proportion of total volume. It is extremely shallow with a mean annual depth of only 0.2m. Hence diurnal heating and cooling produce large diurnal changes in stored heat energy. Despite this, by constructing highly accurate area capacity curves, accurately measuring all fluxes, and providing evaporation calibration data from daily floating pan measurements, useable thermal balances were compiled.

8.2.5 Heat advected in surface water *Qrn, Qsd & Qtu*

These terms include rain falling directly on the lake surface, storm water in drains and pumped summer level maintenance. A polynomial expression was developed to allow thermal capacity to be easily calculated for any given temperature (Figure 8.2a). Advected heat energy (in Mj m^{-3}) was calculated for all three terms and divided by the lake area at 08:00hr at the finish of each daily balance period. Compatibility with the solar energy terms required final conversion to Watts m^{-2} (Mj m^{-2} day^{-1} x 11.574).

Rainfall Qrn

Various methods have been used to estimate rain water temperature. These include mean daily dry bulb temperature (UNESCO 1984), wet bulb temperature (Harbeck *et al* 1958, Sturrock *et al* 1992) and flat plate radiometer temperature (Anderson 1954a). Raindrops fall at terminal velocities varying from about 3.3 to 9.8 m sec^{-1} for drop diameters of 0.8-4.0mm (Maidment 1993). Evaporation from the surface of the drop should cause its temperature to approach that of a wet bulb thermometer. Examination of wet and dry bulb screen temperatures and corresponding storm water temperatures suggested that the wet bulb temperature probably provides the best approximation of precipitation temperature. In Figure 8.2d (panels 1-3), wet and dry bulb temperatures are plotted with storm water temperatures for major late summer, mid winter and spring rain events. In late summer storm water is 2°-5° warmer than the wet bulb temperature. Here dry bulb temperature tracks the storm water temperature more closely (within 1°-2°) but always with the storm water warmer suggesting heating of the run-off on pavements and within the storm drain system. In winter (panel 2), the dry bulb temperature is variously warmer and cooler than the storm water. Wet bulb temperature however is consistently 1°-2° cooler than the storm water which reflects pipe and pavement heating. In spring, significant pavement heating is apparent with both wet and dry bulb temperatures 1°-5° cooler than the storm water.

Rainfall was read daily in standard funnel gauges. Therefore it was not directly evident when rain fell over the period. This was estimated by pro rating total 24 hour rainfall against hourly storm drain flow volumes. Rainfall thermal energy was calculated using corresponding average hourly wet bulb temperatures.

Storm water Qsd

Stormwater temperature was measured directly using continuously operating LM35 temperature sensors and data loggers in the East Main and Basketball drain sediment traps (Figure 5 1a). Up to April 15 1997, the East Main (EM) drain only was instrumented. Over this period temperatures measured in the EM drain were applied to all four drains. The Basketball (BB) drain temperatures were measured from April 16 onwards. Over this period BB temperatures were applied to the remaining unmonitored drains. There was typically a 1°-2° difference in the temperature of water flowing in the EM and BB drains (Figure 8.2d panels 1-3) but with no consistent pattern of one warmer than the other. This probably reflects different local storm intensity and pavement heating of run-off. Storm water thermal content was calculated by applying thermal capacity and temperature to the corresponding flow volume in each drain, integrated over two minutes.

Lake level maintenance Qtu

Groundwater extracted from bores screened close to the base of the superficial aquifer within Perry Lakes Reserve is consistently 20.5°-21.0°C. Variations as measured manually by laboratory thermometers at the north and south outlets reflect heating or cooling within the extensive shallow irrigation ring main system. Measurements were made opportunistically and varied from 19.9° to 21.5° (Figure 8.2b). Where temperature data was absent, average values of 20.8° (north outlet) and 20.7° (south outlet) were used.

8.2.6 Heat advected in groundwater discharge *Qdc*

Groundwater discharge into East Lake could only be calculated every four days using the integrated mass-solute-isotopic balance data (Chapter 6). The four day total was pro rated against daily apparent groundwater flux (Appendix 6.2) to estimate daily discharge. The temperature of discharged water was estimated from monthly temperature profiles in piezometer N3c (Figure 9.8b). The average of 1m measurements between the water table and 22m varied by less than 1°C over a year (19.35° to 20.25°).

8.2.7 Heat advected in lake water recharge *Qrc*

Lake water recharged to the aquifer was also calculated every four days from the integrated mass-solute-isotopic balances. Again the four day total was pro rated against daily apparent groundwater flux (Appendix 6.2) to estimate daily recharge. Recharge water temperature was taken to be the daily average (10 minute samples) mid level temperature from station HT5 in the centre of the South Basin (Figure 5.1a).

8.2 8 Heat conducted to and from the lake sediments *Qse*

Lake evaporation was measured independently using a floating Class A pan (Chapters 5 & 10). Heat conducted to and from the lake sediments (*Qse*) is the residual in the thermal balance where all other components have been measured independently, including evaporation. In equation (8.1), *E* was set equal to floating pan evaporation, yielding *Qse*.

8.3 BOWEN RATIO

The Bowen Ratio is the ratio of energy conducted to the air (as sensible heat) to the energy lost through evaporation and is given by Bowen (1926) as:

$$R = \frac{cP(T_o - T_a)}{1000(e_o - e_a)} \tag{8.7}$$

where

c constant, generally taken to be 0.61

P air pressure in mb

T_o lake surface temperature

T_a dry bulb air temperature

eo saturated vapour pressure at the temperature of the water surface

e_a vapour pressure of the air

Perry East Bowen Ratios were calculated every 10 minutes based on instantaneous T_o T_a e_o and e_a (measured at East Lake) and air pressure P measured by the Bureau of Meteorology at Mount Lawley and adjusted to mean sea level (Perry Lakes is only ± 3m ASL). Vapour pressure e_a was calculated from the relative humidity:

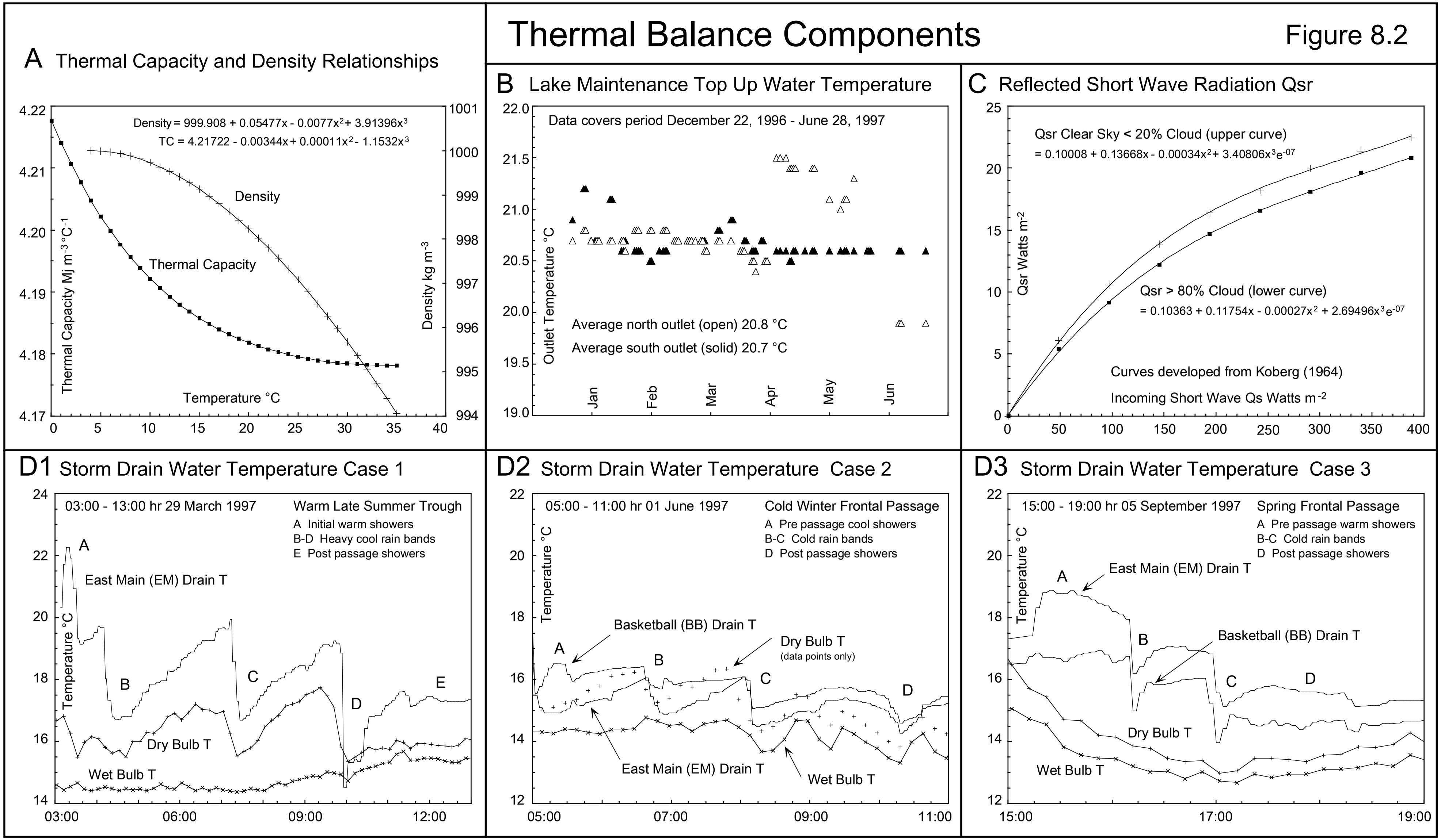
$$r = \frac{m}{m^*} \cong \frac{e}{e^*} \tag{8.8}$$

where

r relative humidity

m, m^* actual mixing ratio and mixing ratio in water vapour saturated air

e, e^* actual vapour pressure and saturation vapour pressure at air temperature T



Thermal Balance Components

Figure 8.2

Saturation vapour pressure was calculated using the expression of Richards (1971), cited Brutsaert (1982 eqn 3.24a):

$$e^* = 1013.25\,exp(13.3185t_R - 1.9760t_R^2 - 0.6445t_R^3 - 0.1299t_R^4 \qquad (8.9)$$

where $t_R = 1 - (373.15 / T)$ in which T is the temperature in °K. The thermal balance used daily average R, calculated from the daily average of 10 minute ratios.

There is considerable discussion in the literature regarding the validity of the Bowen Ratio generally (Anderson 1954a, Ficke 1972, Angus & Watts 1984) and the value of the constant c, which has limits of 0.58 and 0.66 and is generally taken to be 0.61. For R<<1, small errors in R in equation 8.1 have little effect on evaporation. At values of R approaching unity however errors in the determination of R can have an increasingly large influence on computed evaporation. Average daily Bowen Ratios are plotted in Figure 8 1. The maximum was 0.52; minimum, -0.28. This indicates that on a daily basis evaporation always exceeded sensible heat as a means of dissipating energy from the water-air interface. Negative values indicate that the two fluxes have different signs. At Perry Lakes the summer and winter 10 minute data typically exhibit negative morning values when the sun is warming the surface water (negative sensible heat flux). The daily average however is usually positive as the sensible heat flux becomes positive during the afternoon and over night. Summer negative daily Bowen Ratios occurred when very hot days were followed by cloud cover at night and very high minimum over night temperatures. In winter large negative daily values can occur in the 24 hours preceding a major frontal passage characterised by warm, cloudy conditions and easterly winds preceded by a clear cold night.

The Bowen Ratios calculated for Perry East lie well within the range of $-1.0 < R < 1.0$ which is considered typical (Bowen 1926, Crago & Brutsaert 1996). Where ten minute data was outside these limits, data was clipped at -5.0 and 5.0. The daily average Bowen Ratio used in the thermal balance calculations is the average of ten minute calculations based on instantaneous values of T_a, T_o, e_a and eo. Alternative calculations using daily averaged values of these parameters to calculate a daily average R were found to be very similar but not identical. The difference in the final thermal balance using either method is probably insignificant.

All parameters in a thermal balance will include some measurement error. Harbeck *et al* (1958) estimated that the greatest error lay in the Bowen Ratio (up to 20%) followed by reflected solar radiation (<10%) and reflected long wave radiation (<10%). Overall Harbeck *et al* estimated total annual error to be less than 10%. Given the small size of East Lake annual error is also probably less than 10%.

Table 8.3

Thermal Balance Summary

East Lake

Bal	Start Date	Days	Med Area	Med Vol	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	Total E_{Tb}	Daily E_{Tb}	Total E_p	Daily E_p	E_{Tb} - E_p	E_{Tb} : E_p
1996																									
20	December 22	12	44775	11672	4077.4	122.3	5302.8	4522.8	257.3	0	0	134.7	0	240.3	-175.4	-3.7	2325.6	206.1	104.7	88.2	7.4	82.7	6.9	0.5	6.7
1997																									
21	January 03	12	40989	9336	4321.6	129.6	5419.8	4418.0	254.1	0	0	329.1	0	376.8	-353.3	-70.6	2269.8	214.0	108.6	91.8	7.7	80.8	6.7	0.9	13.6
22	January 15	12	38921	8175	4134.7	124.0	5265.2	4224.6	248.7	0.3	0	350.9	0	374.9	-244.2	-63.2	2260.7	159.7	99.9	88.1	7.3	80.3	6.7	0.6	9.7
23	January 27	12	28627	4978	4426.7	132.8	5321.7	3860.9	238.0	0	0	382.2	0	403.9	-508.9	-84.9	1957.2	107.2	88.4	86.0	7.2	69.6	5.8	1.4	23.6
24	February 08	12	25887	3702	4153.0	124.6	5259.0	3971.0	241.5	0.3	0	498.8	0	494.2	-411.2	59.7	1797.1	156.6	78.8	76.7	6.4	63.8	5.3	1.1	20.2
25	February 20	12	38300	8093	4492.0	134.8	5343.3	3133.4	213.9	1.1	1.6	718.6	0	571.4	-581.7	82.0	1376.9	60.5	63.3	65.6	5.5	49.0	4.1	1.4	34.0
26	March 04	12	26336	5826	3982.5	119.5	5232.9	3436.7	226.4	0.2	0	68.7	0	506.3	331.6	-212.8	1714.8	150.5	74.2	50.5	4.2	60.9	5.1	-0.9	-17.0
27	March 16	12	17723	2028	4682.0	140.5	5165.7	3002.5	211.7	4.9	13.9	539.7	0	570.7	-484.0	54.0	1383.7	181.5	57.4	63.7	5.3	49.1	4.1	1.2	29.9
28	March 28	12	31420	5034	4562.2	136.9	5033.9	1975.1	162.1	59.3	156.0	230.0	0	389.0	9.8	96.4	1026.6	116.3	39.6	36.0	3.0	36.3	3.0	0.0	-0.9
29	April 09	12	36197	6666	4613.3	138.4	5153.0	2335.6	185.7	12.7	25.6	381.9	0	445.2	-339.6	-28.7	924.6	169.5	37.9	42.6	3.6	32.8	2.7	0.8	30.0
30	April 21	12	31634	5120	4666.0	140.0	4934.3	1748.9	153.9	11.0	27.0	150.7	0	282.0	-253.2	-77.4	754.4	129.6	26.9	34.0	2.8	26.6	2.2	0.6	27.6
31	May 03	12	27173	3555	4464.6	133.9	4693.8	1775.5	154.3	2.4	11.3	242.7	0	239.9	-364.2	5.6	784.4	103.2	23.1	39.0	3.3	27.6	2.3	1.0	41.4
32	May 15	12	26389	3385	4488.7	134.7	4786.4	1395.0	132.7	22.4	59.0	228.7	0	292.2	-177.6	-26.2	619.2	61.7	19.5	27.4	2.3	21.8	1.8	0.5	25.7
33	May 27	20	35832	7906	6952.8	208.6	7758.1	2110.2	206.0	99.4	221.6	237.9	19.7	338.1	44.0	105.4	902.6	146.0	25.7	30.4	1.5	31.7	1.6	-0.1	-4.1
34	June 16	12	41610	9841	4376.3	131.3	4629.6	1398.4	133.5	5.4	6.0	2.5	5.9	116.7	-282.7	-52.6	496.5	37.0	13.7	26.3	2.2	17.4	1.5	0.7	50.9
35	June 28	12	38650	8037	4210.5	126.3	4488.5	1423.0	135.2	27.7	71.0	0	7.3	72.1	-244.8	-14.8	604.9	81.7	14.2	28.6	2.4	21.2	1.8	0.6	35.0
36	July 10	12	39593	8566	3833.5	115.0	4374.5	1719.6	151.1	13.9	29.4	0	4.2	45.5	-216.0	-9.8	544.8	172.5	11.2	25.0	2.1	19.0	1.6	0.5	31.3
37	July 22	12	38661	8014	3837.1	115.1	4610.8	1707.8	153.5	16.8	31.0	0	7.6	46.9	161.4	35.6	675.8	128.1	18.2	19.0	1.6	23.7	2.0	-0.4	-19.9
38	August 03	16	43803	11248	4644.5	139.3	6152.8	2356.3	206.4	54.3	117.4	1.7	32.3	88.2	659.2	57.9	989.5	227.1	27.1	16.3	1.0	34.8	2.2	-1.2	-53.1
39	August 19	12	48688	14266	3231.2	96.9	4652.2	2204.3	180.8	9.0	17.9	0	28.7	44.7	507.6	20.6	821.6	176.0	23.1	14.6	1.2	28.9	2.4	-1.2	-49.4
40	August 31	12	54920	20856	3410.7	102.3	4673.3	2085.7	172.5	69.5	119.7	0	24.4	70.7	555.6	169.0	842.8	219.4	24.6	14.3	1.2	29.6	2.5	-1.3	-51.7
41	September 12	12	60060	25909	3508.2	105.2	4955.1	2754.8	203.5	0.6	0.4	0	12.3	40.0	420.6	49.9	1038.4	266.9	37.7	25.2	2.1	36.7	3.1	-1.0	-31.3
42	September 24	12	57074	22255	3543.0	106.3	4975.5	3082.2	214.5	2.0	2.2	0	25.0	52.0	288.0	-77.6	1314.1	312.3	48.3	38.5	3.2	46.4	3.9	-0.7	-17.1
43	October 06	12	55180	19962	3621.9	108.7	5002.1	3307.9	222.2	20.5	35.4	0	28.9	69.1	234.0	-17.3	1486.1	318.9	55.4	45.9	3.8	52.5	4.4	-0.6	-12.6
44	October 18	12	51547	16734	3849.2	115.5	5127.0	3561.0	229.2	1.1	1.4	0	21.7	89.2	148.8	-64.9	1732.1	287.4	70.0	57.0	4.8	61.4	5.1	-0.4	-7.1
45	October 30	12	44418	11548	3820.8	114.6	5100.9	3842.6	237.1	0	0	0	1.5	56.7	-23.4	-23.3	1802.4	276.2	72.0	64.5	5.4	63.8	5.3	0.1	1.1
46	November 11	12	37620	7557	4129.7	123.9	5038.8	3538.6	225.3	4.7	13.0	0	7.1	55.5	-306.6	-81.8	1685.4	265.9	65.7	68.7	5.7	59.6	5.0	0.8	15.2
47	November 23	12	29286	4441	4586.3	137.6	5217.9	3870.8	238.4	1.2	1.1	0	0	58.9	-636.0	-47.6	1808.7	325.0	77.9	82.7	6.9	64.2	5.4	1.5	28.8
48	December 05	12	16476	1754	4105.2	123.2	5278.8	4452.0	255.1	0	0.4	0	0	96.0	-1.8	-73.1	2481.3	273.7	109.5	88.2	7.4	88.1	7.3	0.0	0.1
49	December 17	8	10419	812	2792.5	83.8	3560.9	2941.2	169.4	0	0	145.6	0	116.6	-122.0	27.1	1516.1	200.6	69.9	57.6	7.2	53.9	6.7	0.5	6.8
1998																									
50	December 25	9	10593	831	3206.9	96.2	4066.2	3243.4	188.6	0	0	136.5	0	184.3	-275.6	-19.8	1496.6	214.0	71.5	61.5	6.8	53.3	5.9	0.9	15.4

Notes

Lake area in m^2, volumes m^3

All balance periods commence and end at 08:00 hr on date shown

All Q terms expressed in watts per square metre ($W\ m^{-2}$)

Evaporation (E) expressed in millimetres

Total E_{Tb}	Total evaporation calculated by thermal balance ignoring the sediment thermal term (Qse set to zero)
Daily E_{Tb}	Daily evaporation calculated by thermal balance
Total E_p	Total evaporation calculated by floating Class A pan
Daily E_p	Daily evaporation calculated by floating Class A pan
E_{Tb} - E_p	Average daily error (mm) induced by ignoring the sediment heat flux
E_{Tb} : E_p	Error (%) per balance period between thermal balance and pan evaporation

8.4 RESULTS

Thermal balance results by balance period from 08:00 December 22, 1996 to 08:00 January 3, 1998 are summarised in Table 8.3. Appendix 8.1 is the individual daily calculations from which Table 8.3 was derived. The appended data show evaporation (as derived from equation 8.1) with the sediment term *Qse* set to zero. Included is the daily average value for the sediment term required to make thermal balance evaporation and floating pan evaporation equal. This figure multiplied by the number of days in the balance period appears as the *Qse* figure in Table 8.3. Also in Table 8.3 total and daily evaporation are shown both ignoring and including the sediment heat flux term. The final columns are the daily average error in evaporation if the sediment term is ignored, expressed as daily error (mm) and as a percentage of independently measured floating pan evaporation.

For the year 1997, total East Lake evaporation was 1378.8mm. Ignoring the sediment term, the thermal balance estimate of evaporation was 1468.4mm, an over estimate of 6.5%. Over a year, much of the error is cancelled because the thermal balance both over and under estimates evaporation however within individual balance periods the error was much greater (final column Table 8.3). Greatest error was 50.9% over estimate (Balance 34) and -53.1% under estimate (Balance 38). Expressed as daily evaporation, the average daily error over 1997 was 0.24mm however within individual balance periods this rose as high as 1.54mm in Balance 47 (refer column E_{Tb}-E_P in Table 8.3). These errors are significantly greater than those reported by Rosenberry *et al* (1993) who determined that the effect of heat advected to the sediment was generally <3mm d^{-1}. Data is displayed graphically in Figure 8.3.

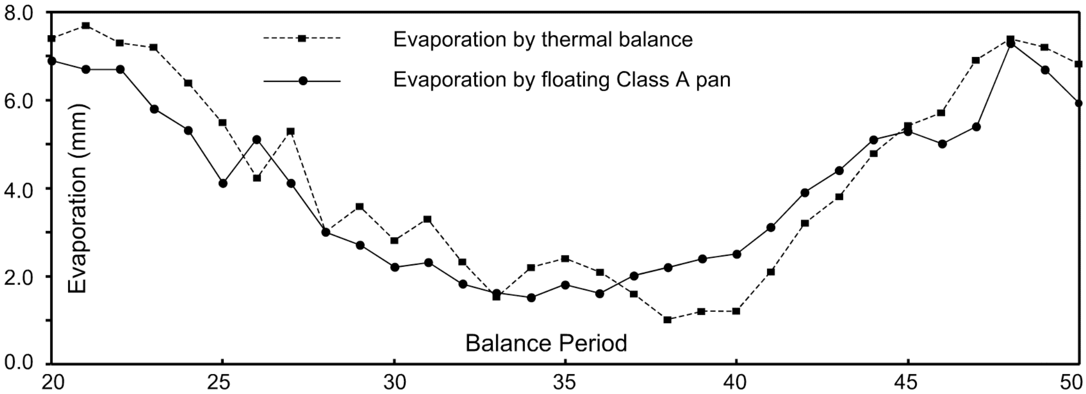


Figure 8.3 Comparison of evaporation by floating Class A pan and thermal balance ignoring *Qse*. The difference is the sediment heat flux expressed as equivalent mm of evaporation

The problem of measuring evaporation by thermal balance, while at the same time attempting to quantify the heat flux to and from sediments in shallow wetlands presents a continuing challenge to wetland research. Parkhurst *et al* (1998) is a recent example with similar problems and implications. Perry Lakes is no doubt an extreme example because of its very shallow water and highly variable surface area. The results confirm quite clearly that the sediment heat flux term is an important component in the thermal balance of such wetlands. Thermal balance estimates of evaporation must include the sediment term, particularly for balance periods of less than one year. The results also confirm the hypothesis that the polarity of the sediment flux varies seasonally. This and other aspects of the sediment thermal regime are examined in Chapter 9.

CHAPTER
9

THERMAL REGIMES IN WETLAND SEDIMENTS

9.0 INTRODUCTION

This chapter investigates and expands upon the difficulties inherent in directly measuring the sediment heat flux and discusses its importance in the thermal balance of shallow wetlands. Concepts of conducted and advected heat flow are introduced and applied to the Perry Lakes data. The thermal patterns in East Lake sediments are presented and used to demonstrate how these reflect daily and seasonal changes in lake-sediment and lake-aquifer interaction.

Wetlands, as the exposed portions of unconfined aquifers, may be conveniently thought of as 'windows on the water table'. Similarly they are also 'windows to the sun'. They intercept solar energy and there is a net transfer of some of this energy into the aquifer. In this sense shallow lakes and wetlands are essentially 'thermal sumps'. Within lake basin sediments, thermal patterns are the combined result of surface water-groundwater interaction and diurnal, seasonal, and even longer term changes in lake water temperature.

Below the land surface, where the vadose zone is relatively thin, solar energy is conducted into the aquifer through the soil. The effective perturbation depth of surface temperature fluctuations is only about 10m (Lovering & Goode, 1963 cited Domenico & Schwartz, 1990). Within the upper 10-20m groundwater temperature may be 1° to 2° higher than the mean local annual temperature. These surface effects are superimposed on the regional geothermal gradient. Below the range of these surface perturbations, there is a steady temperature increase where geothermal heat is conducted upwards from the earth into the aquifer. Our attention is on lakes and *Qse*, the net heat loss through the upper surface of the lake sediments.

Qse is made up of solar energy absorbed directly on the upper surface of the sediments and vertically advected and conducted heat fluxes across the water-sediment interface. The general flux/storage balance predicts that this quantity must be made up from depleted storage within the sediments and heat advected and conducted from the lower surface of the sediments, including geothermal heat from below.

Thermistor strings were installed into the East Lake sediments over winter 1996. The proposed approach was to use these point source data to extrapolate over the entire lake basin employing one or more of the theoretical approaches outlined in Section 9.1. Manipulation of the early data, however, augmented by manual measurements at other points in the lake plus sun and shade distribution observations, quickly pointed to the necessity for a more holistic approach. A carefully executed thermal balance in which all components were individually measured including evaporation (but excluding sediment flux) appeared to be the method most likely to integrate the complex sediment thermal regime. This however necessitated a direct and totally independent measurement of evaporation and lead directly to the design and installation of the floating evaporation pan in December 1996 (Chapters 5 & 8).

9.1 THERMAL REGIMES IN WATERTABLE LAKE SEDIMENTS

9.1.1 Concepts of conduction and advection

In wetlands heat is both conducted and advected. Conduction requires a temperature gradient (Pitts & Sissom 1998). Conduction is a linear process described by Fourier's law (Incropera & DeWitt 1996)

$$H = -\kappa \Delta T \tag{9.1}$$

where H is the heat flux (as heat per unit area), T is temperature, ΔT is the temperature gradient and κ is thermal conductivity, a proportionality constant linking the two. In the present work, the term 'conduction' includes molecular transfer and any 'turbulent' transfer[1] of sensible heat. Diffusion is a more accurate description of this process. Diffusion, as described by Fick's first law (Bird *et al* 1960) also takes the form of equation (9.1). Saturated sediments are essentially two phase systems comprising mineral grains and interstitial water. Within them conducted heat is influenced by the physical characteristics of both.

The thermal conductivity is the quantity of heat transmitted per unit time through a unit cross sectional area under a unit temperature gradient. It considers the volume fractions and conductivities of the solid and liquid phases. It is influenced by many factors including grain size and shape, nature of grain to grain contacts, pore size, porosity, grain specific gravity, grain thermal conductivity, degree of saturation and salinity of the pore water (Lapham 1989, Domenico & Schwartz 1990) as well as direction and, perhaps, the temperature gradient itself. In a saturated sediment, the effective thermal conductivity κ_e

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[1] Such 'turbulent' exchange is often referred to as convection

is used. The divergence ∇ of the conductive heat flux is the rate of loss of heat per unit volume due to diffusive transfer

$$\nabla(-\kappa \nabla T) \tag{9.2}$$

Advection is direct flow of heat with the flow of water. When heat energy moves with water, the advective flux of the water is $\rho \upsilon$ and the advected heat is $\rho c \upsilon T$ where c is the specific heat, ρ is the density and υ is the Darcy velocity. The corresponding divergence and rate of loss of heat by advection is

$$\nabla(\rho c \upsilon T) \tag{9.3}$$

In the partial differential equation of heat balance, equations 9.2 and 9.3 are combined to include the two fluxes, conduction and advection (Bird *et al* 1960). This describes constant flow in the vertical direction for constant κ, ρ and c.

$$\frac{\kappa}{\rho c} \frac{\partial^2 T}{\partial z^2} - \upsilon \frac{\partial T}{\partial z} = \frac{\partial T}{\partial t} \tag{9.4}$$

The right hand term derives from $\rho c \; \partial T / \partial t$, the net rate of accumulation of heat in the sediment volume. Equation 9.4 describes the continuous heat balance in vertical flow with conduction, groundwater discharge, lake water recharge and storage in the sediments.

Heat capacity varies little among mineral solids that typically make up fine and coarse grained sediments. It does however vary considerably depending on bulk density. Sediment thermal behaviour is further influenced by the thermal conductivity and heat capacity under unsteady thermal conditions. Thermal diffusivity $\kappa / \rho c$ is the ratio of thermal conductivity to volumetric heat capacity. A sediment of high thermal diffusivity will change temperature rapidly, in response to a sudden external temperature change. The thermal diffusivity of saturated fine and coarse grained sediments also varies with sediment bulk density.

In wetlands the linked advective (fluid) and conductive (diffusive) components may oppose or augment each other. Figure 9.1 illustrates three simple cases (left to right) where fluid and conductive components oppose each other, augment each other or combine in complex relationships where some or all of the fluxes can have both horizontal and vertical components. Not shown, but implicit in each diagram is a heat storage component in the sediments.

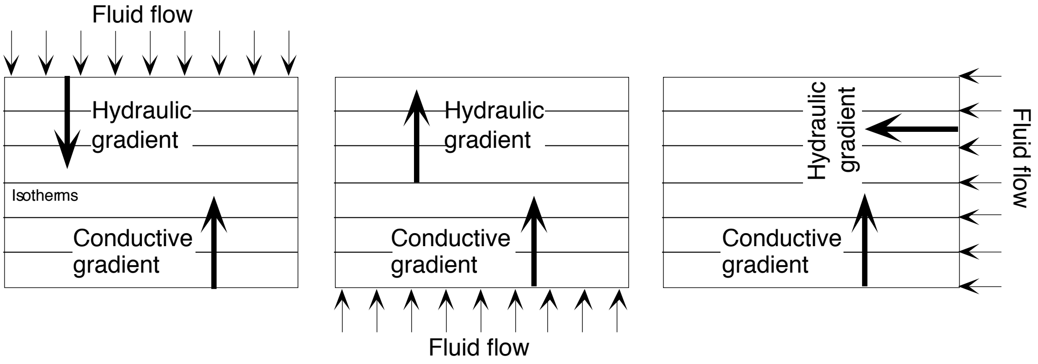


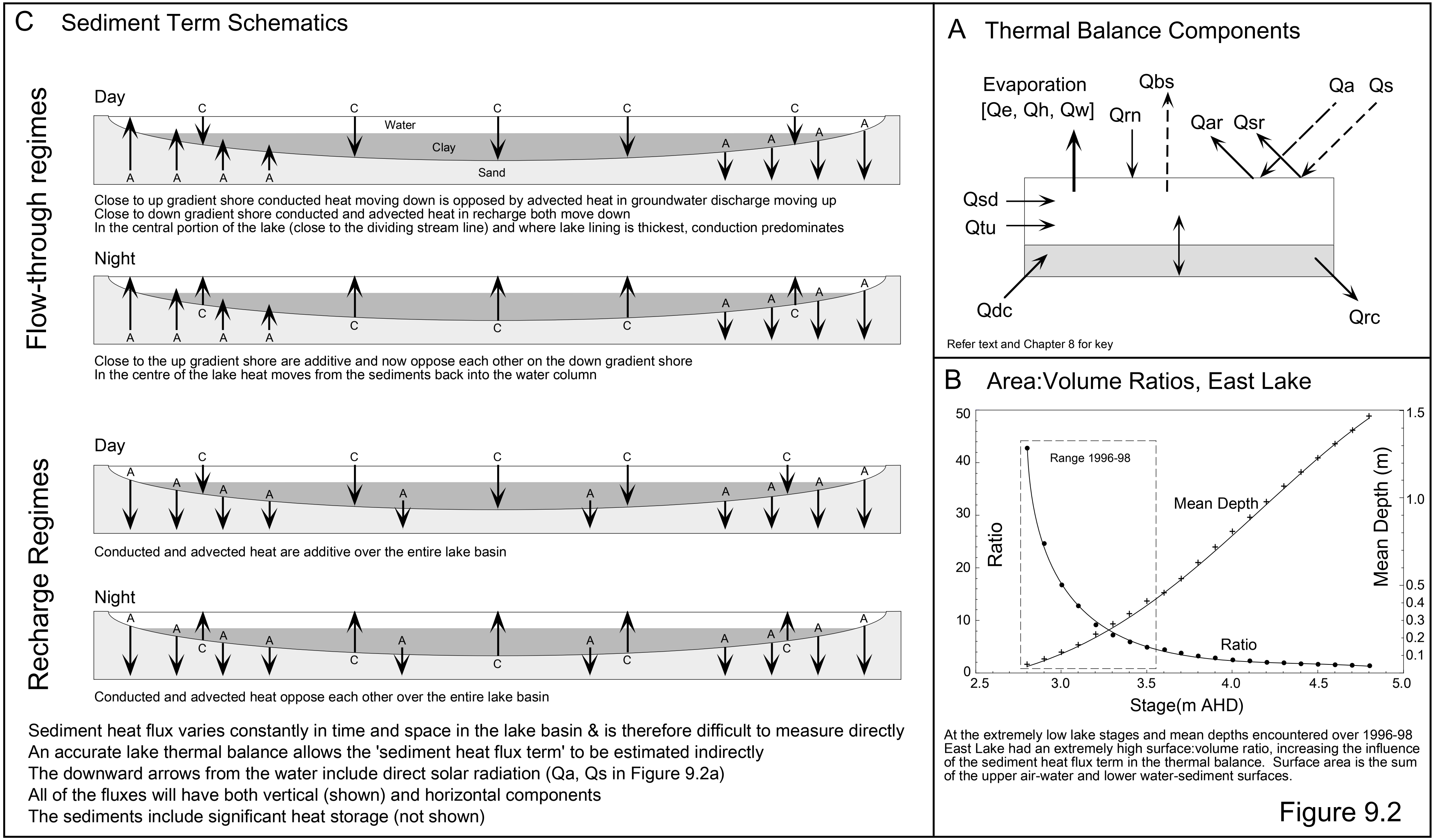
Figure 9.1 Idealised cases of heat advected in fluid flow superimposed on conductive gradients (Figure adapted from Domenico & Schwartz 1990). In real world situations all the fluxes are likely to have both vertical and horizontal components.

9.1.2 Concepts of daily and seasonal variation

Figure 9.2a shows the principal components of the East Lake thermal balance. The solar terms *Qs* and *Qa* are particularly important. The clear, shallow water and extremely high surface area to volume ratio (Figure 9.2b) which varied in 1996-97 from about 4:1 to 40:1 ensures the importance of the solar energy fluxes. The sediments are heated through contact with the water column and directly by solar insolation.

Diurnally, heat is conducted in and out of the sediments. Surface, mid level and bottom water temperatures were monitored in the centre of the South Basin. Close to the dividing stream line lake-aquifer water flows are minimised and conduction between the water column and the sediments and solar insolation predominate. The direction of conducted heat transport varies during the day. In Figure 9.3 the daily temperature difference between bottom water and mid level water is plotted for 06:00 and 15:00 hours. On most days, at 06:00 bottom water is warmer than mid level water. The sediments are also warmer than the water column and heat is conducted from them into the water column which has cooled radiatively over night. During the day solar energy heats the water column so that by mid afternoon the mid level water is almost always warmer than the water-sediment interface. Heat is now conducted downwards into the sediments.

We can now consider the entire lake basin and the combined effects of advected, conducted and radiated heat. Advected heat flow varies spatially and temporally depending on the prevailing flow regime. Schematic cross sections in Figure 9.2c summarise daytime and night time fluxes during flow-through and recharge flow regimes. Conductive and advective fluxes may augment or oppose each other depending on the time of day, location within the lake basin and the prevailing flow regime. The net daily sediment flux also varies from negative (into the sediments) to positive (into the water column). At Perry Lakes the lake lining sediments are up to 3m thick in comparison to the average water depth of 0.2 to 0.5m. They have both a much greater volume and heat capacity than the water and therefore a significant potential to store heat.



Close to up gradient shore conducted heat moving down is opposed by advected heat in groundwater discharge moving up
Close to down gradient shore conducted and advected heat in recharge both move down
In the central portion of the lake (close to the dividing stream line) and where lake lining is thickest, conduction predominates

Close to the up gradient shore are additive and now oppose each other on the down gradient shore
In the centre of the lake heat moves from the sediments back into the water column

Conducted and advected heat are additive over the entire lake basin

Conducted and advected heat oppose each other over the entire lake basin

Sediment heat flux varies constantly in time and space in the lake basin & is therefore difficult to measure directly
An accurate lake thermal balance allows the 'sediment heat flux term' to be estimated indirectly
The downward arrows from the water include direct solar radiation (Qa, Qs in Figure 9.2a)
All of the fluxes will have both vertical (shown) and horizontal components
The sediments include significant heat storage (not shown)

Refer text and Chapter 8 for key

At the extremely low lake stages and mean depths encountered over 1996-98 East Lake had an extremely high surface:volume ratio, increasing the influence of the sediment heat flux term in the thermal balance. Surface area is the sum of the upper air-water and lower water-sediment surfaces.

Figure 9.2

9.2 SEDIMENT HEAT FLUX TERM

9.2.1 Different approaches to measurement

Given the complex nature of heat movement in lake-aquifer systems, many different approaches have been used to quantify the sediment heat flux Qse.

Simple conductive gradients

The simplest expressions for Qse occur in many deep lakes and high latitude lakes where there is effectively little or no diurnal or seasonal change in bottom water temperature. Here Fourier's law (refer equation 9.1) can be applied to describe conduction across a temperature gradient

$$Qse = \kappa\left(T_2 - T_1\right) \tag{9.5}$$

where

κ sediment thermal conductivity

T_1 temperature at the water-sediment interface

T_2 temperature at some depth within the sediments

Examples include arctic lakes (Gibson *et al* 1996), high latitude wetland complexes (Mendez *et al* 1998), and temperate lakes (Likens & Johnson 1969). Similarly Hondzo *et al* (1991) estimated sediment heat flux in a Minnesota lake of similar size to Perry Lakes using temperature time series at the sediment water interface and within the sediments down to 1.5m below the interface. Heat flux was calculated as the rate of change in sediment heat storage obtained by integrating sediment temperature profiles $T(z,t)$

$$\text{sediment heat flux} = \rho_s c_{ps} \frac{\partial}{\partial t}\int_0^{zd} T_s(z,t)\,dz \tag{9.6}$$

where

ρ_s bulk sediment density

c_{ps} sediment specific heat

Diurnal and seasonal fluctuations

Thermal conditions in shallow lakes and rivers which freeze over winter are highly dependent on heat exchange between the water and sediments (Pivovarov 1973). Theoretical calculations predict an almost equal balance between heat lost into the sediments over summer and heat returned to the water column from the sediments over winter (Pivovarov 1973, Fig 9). In such lakes, heat stored in bottom sediments is an important source of winter heat.

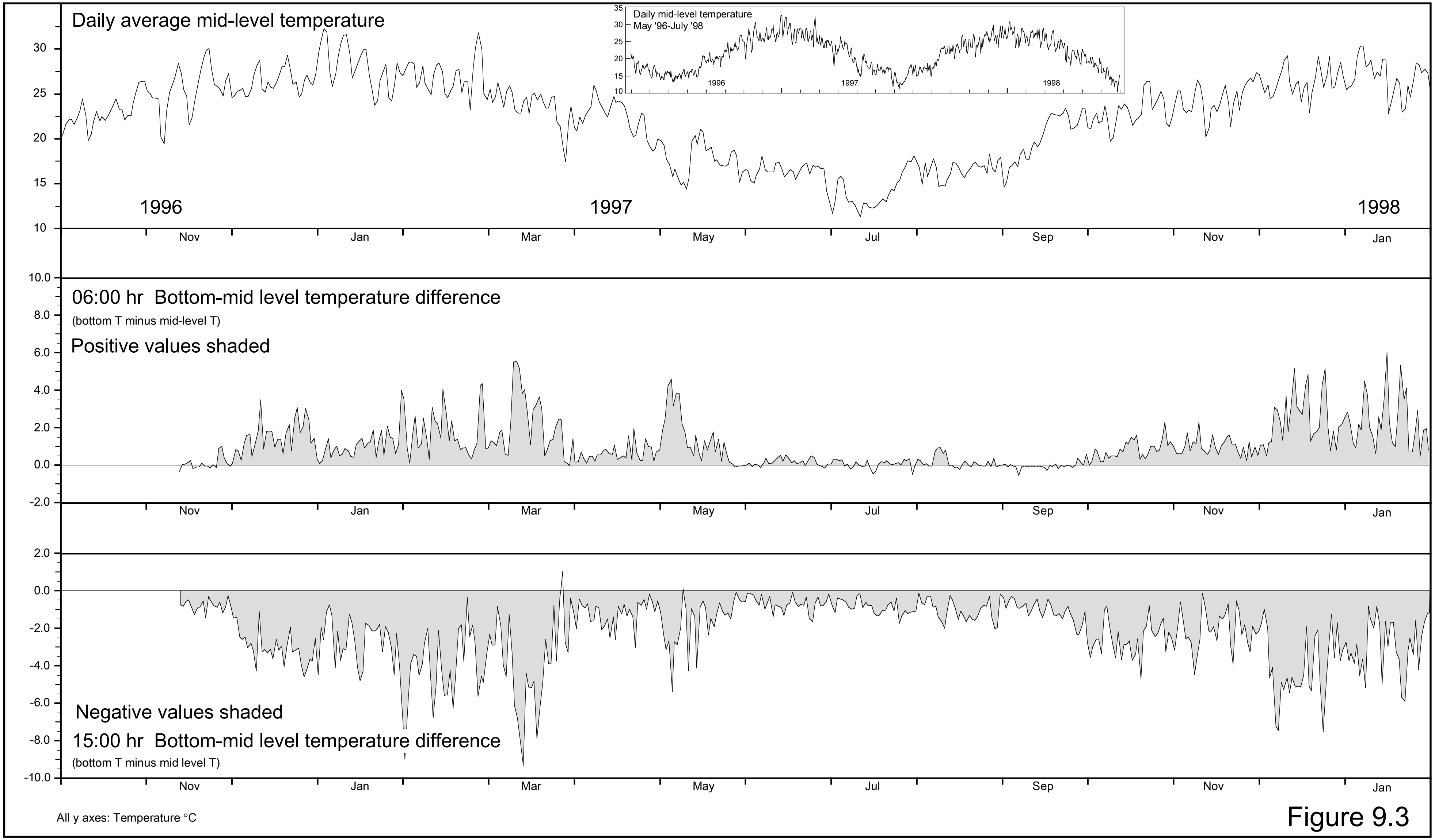

Daily average mid-level temperature
30
25
20
15
10
1996
1997
1998
Daily mid-level temperature
May '96-July '98
35
30
25
20
15
10
1996
1997
1998
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
06:00 hr Bottom-mid level temperature difference
(bottom T minus mid-level T)
Positive values shaded
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
Negative values shaded
15:00 hr Bottom-mid level temperature difference
(bottom T minus mid level T)
All y axes: Temperature °C

Figure 9.3

Sediments below temperate lakes typically display a sinusoidal temperature cycle, characterised by a decrease in amplitude and phase lag with increasing depth below the water-sediment interface. Simple harmonic functions can be used to describe this oscillation (Likens & Johnson, 1969). At Williams Lake, Sturrock *et al* (1992) were able to measure the sediment term directly using an equation described by Pearce and Gold (1959) where the heat flux at time *t* and depth *x* is defined by

$$Qse = akT_s e^{-ax} \, sin\left(\omega t + \phi + \frac{\pi}{4} - xa \right) \tag{9.7}$$

where

$a = \sqrt{\dfrac{\pi C_v}{Pk}}$

C_v volumetric heat capacity

k thermal conductivity

P period of temperature variation

$\omega = \dfrac{2\pi}{P}$

T_s amplitude of temperature variation at the surface

ϕ phase lag in time of temperature variation at the surface

Hughes (1967) used a similar technique to measure heat flux through the bottom of the Salton Sea, California. Tsay *et al* (1992) used a harmonic analysis of temperature oscillations at the water-sediment interface to model sediment heat flux in small lakes in New York state. Walker (1973) used a similar approach to estimate sediment heat storage for Lake Werowrap (Victoria) using an expression derived by Neumann (1953, cited Walker 1973). The expression describes the sediment term at time *t*

$$Qse = \frac{c_m}{\sqrt{2b}} a \sin(A + \omega t - \pi / 4) \tag{9.8}$$

where

a and A are respectively amplitude and phase angle of the sin wave

c_m is the thermal capacity

$\omega = 2\pi / T$, T being the wave period (1 year)

$b = \sqrt{\omega / 2K}$

K is the sediment diffusivity

The expression defines the case where the bottom water temperature differs from the sediment temperature by a negative phase angle of π/4 radians (*i.e*. the sediment temperature lags behind the bottom water temperature by three months).

Temperature oscillations can also be used to estimate other parameters. Stallman (1965) demonstrated that in homogeneous sediments, rates of vertical non isothermal recharge from surface water bodies can be estimated using the attenuation of sinusoidal fluctuations of temperature with depth. This concept was extended by Bredehoeft & Papadopulos (1965) who used vertical groundwater temperature profiles to determine vertical groundwater velocity and hydraulic conductivity. Lapham (1989) applied this to streams in the eastern United States, to estimate recharge rates, discharge rates and vertical hydraulic conductivity. Similarly Hunt *et al* (1996) used sediment temperature profile modelling to estimate groundwater discharge and recharge in a wetland complex in Wisconsin.

9.2.2 Approach adopted at Perry Lakes

In Chapter 8 we noted that shallow lakes are not generally considered to be good candidates for thermal balance studies. In such lakes large proportions of the incoming day time radiation are conducted to both the water and underlying sediments. At night much of this energy may be lost as long wave radiation. Shallow lakes are incredibly dynamic systems when considered from a thermal perspective.

At Perry Lakes these problems were compounded by large area/volume changes which occur on both daily and seasonal time scales. East Lake volume and area may double or triple within a few hours in response to storm water and top up. Throughout the day shade from fringing trees can affect large areas of the lake. This is particularly so in winter with low sun angles. In short, such lakes present gross spatial and temporal complexities.

Ten thermistor strings were installed over winter 1996 (Figure 5.1a). As noted previously, we anticipated being able to use these ten point data sets to extrapolate over the entire lake on a daily basis using one or more of the approaches outlined in Section 9.2.1. Trial manipulation of the initial thermistor data augmented by manual measurements at other points in the lake indicated that a more holistic approach would be necessary. In particular, daily observations of large changes in lake area over small changes in lake stage (Figure 9.2b) and extensive shading (particularly at low winter sun angles) were identified as problems which would be difficult to resolve using a few fixed data collection points and led directly to the thermal balance approach. Any balance in which one component is derived as a residual is a compromise because the cumulative errors in measuring all the other components are reflected in the residual (Winter 1981). In this case the shear magnitude of the sediment flux term suggested that the seasonal patterns of sediment heat flux would still be defined even if their quantification contained some error.

9.3 SEDIMENT HEAT FLUX IN LAKES AND WETLANDS

9.3.1 Literature review

Thermal balances on water table dominated rivers in Britain (Table 9.1) showed that conduction into the river bed was the dominant form of non advective heat loss, while groundwater discharge was a significant contributor of advected heat gain to the system. Shallow rivers are similar in many respects to very shallow lakes. Depth ranges for the river reaches are similar to those at Perry Lakes and just as at Perry Lakes, heat budgets in rivers are dominated by radiative fluxes. Sediment conduction accounted for 2.8% of net non advective heat gain and 10.4% of heat loss in the 18 surveys in Table 9.1 completed in 1992 and 1993. These sediment heat flux data display ranges similar to those observed at Perry Lakes (Table 8.3 and Appendix 8.1).

Table 9.1 Mean Daily Bed Conduction (*Qse*) UK Rivers (all values in W m^{-2})

River & Season*	Depth (m)	Gains	Losses	Net
River Piddle Trib (W) 1994	0.50	4.21	-12.94	-8.73
River Piddle Trib (S) 1994		3.10	-51.05	-47.95
River Bere (W) 1994	0.80	4.25	-12.14	-7.89
River Bere (S) 1994		0.47	-0.21	0.26
River Barle Trib 1 (S) 1992	0.12	0.37	-6.06	-5.69
River Barle Trib 2 (S) 1992	0.11	1.20	-15.56	-14.36
River Barle Trib 2 (Sp) 1993	0.12	0.94	-8.41	-7.47
Black Ball Stream (S) 1992	0.10	0.66	-27.25	-26.59
Black Ball Stream (Sp) 1993	0.17	0.44	-7.44	-6.99
Jackmoor Brook (S) 1992	0.19	2.76	-1.33	1.43
Jackmoor Brook (W) 1993	0.17	1.06	-4.66	-3.59
River Creedy Trib (A) 1993	0.15	0.55	-1.59	-1.04
River Pulham (W) 1993	0.51	1.62	-0.17	1.45
River Haddeo (A) 1992	0.16	0.05	-0.84	-0.79
River Haddeo (S) 1993	0.25	1.10	-2.70	-1.60
Iron Mill Stream (S) 1992	0.22	0.10	-1.98	-1.89
Iron Mill Stream (S) 1993	0.26	1.18	-1.32	-0.14
River Haddeo 2 (A) 1992	0.24	2.52	-0.09	2.43
River Haddeo 2 (S) 1993	0.15	0.98	-5.03	-4.05
River Culm (A) 1993	0.48	0.58	-7.96	-7.38
River Culm 2 (S) 1992	0.41	1.52	-12.48	-10.96
River Culm 2 (A) 1993	0.41	0.01	-15.66	-15.65

* S summer, W winter A autumn, Sp spring. Data from Webb & Zhang (1997 & 1999)

In deeper lakes radiative fluxes become less important. Likens & Johnson (1969) obtained thermistor readings to 8m depth in sediments below two small (<1 ha) lakes in Wisconsin. In both the transition from water to sediment was via a gelatinous ooze false bottom. Their purpose was to measure the distribution of sediment heat in small temperate lakes. Tub Lake is of similar size to Perry Lakes (area 0.84 ha) but much deeper (mean 3.6m, maximum 8.0m). Beyond depths of 6m, light levels are extremely low. Stewart's Dark Lake (area 0.69 ha) is similar (mean depth 4.3m, maximum 8.8m). In shallow water, there was a negative steady state gradient indicating a net heat flow into the sediments. In the deeper portions however diurnal variations were completely damped and there was a linear increase of temperature with depth. In Stewart's Dark Lake there was a net positive annual heat flux out of the deep sediments of approximately 0.09 W m^{-2} of which approximately half was solar heat and half geothermal heat.

Long term studies which report only net annual sediment heat flux are deceptive. A lake where annual positive and negative sediment fluxes are equal has a net annual flux of zero. When compared to other studies world wide (Table 9.2), Perry East appears to have an abnormally high negative net sediment flux. This is interpreted to reflect the influence of a large annual net negative advected flux (the lake is predominantly in recharge through storm water and summer top up inputs). In their natural state Perry Lakes probably had net annual sediment heat fluxes closer to the examples in Table 9.2.

Table 9.2 Annual sediment heat flux (*Qse*) for various lakes

Lake	Mean Depth (m)	Sediment Heat Flux (W m^{-2})	Reference
Beloye (USSR)	4.2	-3.32	1
Hula (Israel)	1.7	-1.86	2
Mendota (Wisconsin)	12.1	-2.66	3
Tub (Wisconsin)	3.6	-1.29	4
Stewart's Dark (Wisconsin)	4.3	-0.97	4
Cranberry Pond (New York)	2.9	-2.15	5
Woods(New York)	3.6	-1.49	5
Dart's (New York)	7.1	-0.78	5
Little Simon (New York)	10.0	-0.70	5
Perry East	<1.0	-7.55	This work

References: 1 Rossolimo (1932), 2 Neumann (1953), Birge *et al* (1927) 1,2 & 3 all cited Likens & Johnson (1969), 4 Likens & Johnson (1969), 5 Tsay *et al* (1992). Perry East flux calculated for balance periods 21-50 (January 3 1997 to January 3 1998)

9.3.2 Seasonal Feedback

Likens & Johnson (1969) used a simple model assuming a sinusoidal annual temperature variation in the lake sediments. They found that for these small temperate lakes, maximum feedback of heat from the deepest bottom sediments occurred about 140 days after the seasonal temperature maximum. We also observed a lag at Perry East where the peak occurred around mid August. Ficke (1972) estimated that the negative sediment heat flux in early summer and positive heat flux in early winter for Pretty Lake, Indiana was -8.2 and 14.5 W m^{-2} respectively.

Perry East displays a pronounced seasonal feedback (Figure 9.4). At first sight it might be tempting to equate this with the period of flow through (shown as a shaded bar graph), however it is more likely that this has always occurred even when the lake was flow-through all year. This interpretation is based on the fact that the phenomenon is well documented for temperate Northern Hemisphere lakes most of which are water table lakes in which both groundwater discharge and lake seepage are described. For example at Williams Lake (Minnesota), Sturrock *et al* (1992) describe 'inseeping groundwater' and 'lake water seeping out'. In their thermal balances completed for five summer seasons the daily average sediment term was found always to be negative (*i.e.* a net heat flux from the water column to the sediments). It varied from about -0.05 to -1.03 W m^{-2} over the period April to October. Inclusion of the sediment term in the thermal balance decreased evaporation by up to 7%. It is likely that during winter, after freeze up, Williams Lake probably displays a positive sediment flux but winter data was not collected.

Thermal conditions in shallow lakes and rivers which freeze over winter are highly dependent on heat exchange between the water and sediments. Theoretical calculations (Pivovarov 1973) predict an almost equal balance between heat lost into the sediments over summer and heat returned to the water column from the sediments over winter. Table 9.3 summarises positive winter sediment fluxes for some cold temperate North American lakes.

Table 9.3 Average winter heat flux in temperate lakes

Lake	+ve Flux (W m^{-2})	Reference
Mendota (Wisconsin)	2.9	1
Mendota	3.8	2
Misc Wisconsin Lakes	1.5-1.9	2
Tub (Wisconsin)	1.1	3
Stewart's Dark (Wisconsin)	0.8	3
Pretty (Indiana), November	14.5	4

References: 1 Birge *et al* (1927), Scott (1964), (all cited Likens & Johnson (1969), 3 Likens & Johnson (1969), 4 Ficke (1972).

This also appears to be the case in temperate lakes which don't freeze. Lake Werowrap in the western districts of Victoria (Walker 1973) is a saline lake similar in size and depth to Perry Lakes (mean depth 1.35m, mean surface area 21 ha). Descriptions of lake hydrology suggest that it cycles seasonally between flow through and recharge regimes. In summer groundwater seepage springs around the up gradient shore dry up and the lake probably reverts to recharge status. Monthly sediment heat flux over two years displays a similar pattern to that observed in Perry East (Figure 9.4).

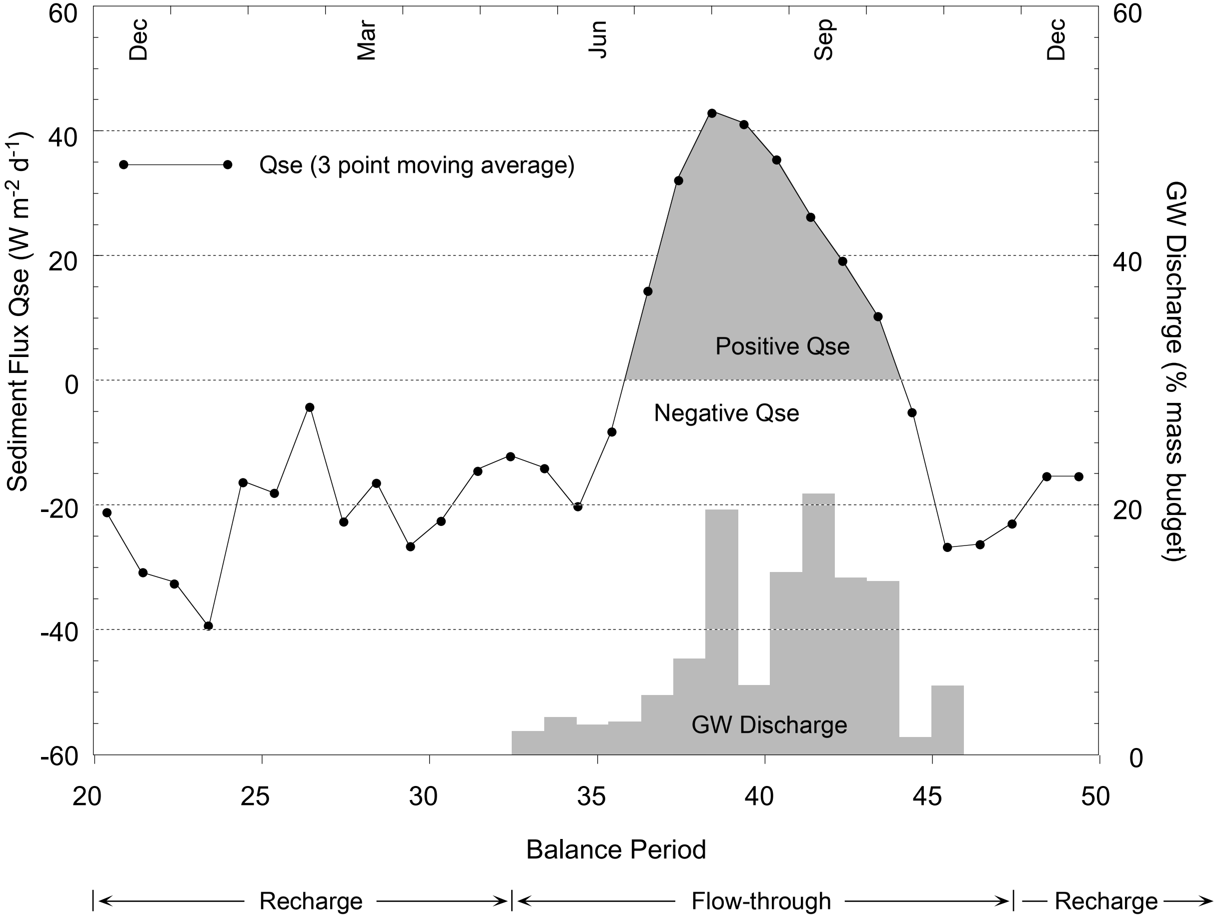
9.3.2 Perry East

Perry East was originally instrumented with the intention that one or a combination of the methods described earlier in this chapter would be employed to measure the sediment heat flux term. The thermal regime in Perry East however is very complex. The water-sediment interface is difficult to define and at any given time this interface displays large areal variations in temperature due to shading from trees and emergent vegetation.

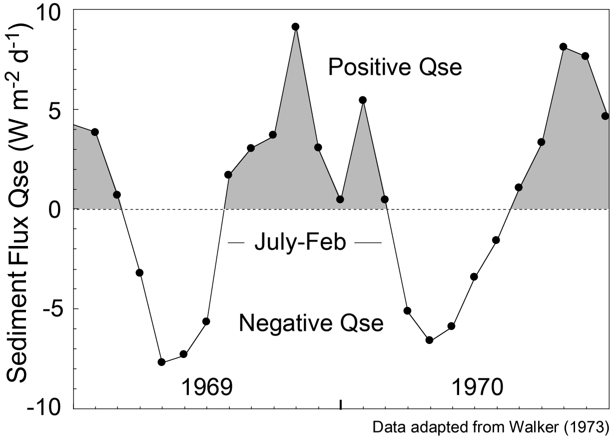
Sediment Heat Flux Qse

Figure 9.4

Perry Lake East Qse by Balance Period



Lake Werowrap Monthly Qse



Data adapted from Walker (1973)

Positive Qse occurs where there is a net heat flux from the sediment into the water column. Negative Qse occurs where there is a net heat flux from the water column into the sediments

Qse is largely a conductive process driven by the seasonal temperature differential between the water column and the sediments, heat moving from warmer to cooler areas. Qse is influenced by heat advected in groundwater discharge and recharge. Under flow through regimes these advected fluxes occur close to the up and down gradient shores, under recharge regimes water (and heat) is advected over the entire basin.

Perry Lake East, Qse is daily average per balance period,
Lake Werowrap, Qse is daily average per month

This difficulty is illustrated by data from small (<1 ha) temperate lakes in Wisconsin (Table 9.4) where the areal variation of sediment heat flux is defined by water depth. The area of East Lake is also extremely variable and may expand or contract over 100% in less than a day. In shallow lakes anywhere there is a pronounced solar heating of water and sediments. East Lake's shallow depth (mean 0.2 to 0.5m) results in extreme diurnal and seasonal temperature cycles.

As the complexity of the thermal regime became evident it became clear that a holistic method was required rather than the more usual empirical methods where measurements at a single (or several) points are assumed to be representative of the whole. The methodology employed at Perry East was a simple extension of the traditional thermal budget determination of evaporation. If all heat flux terms can be measured, then the residual must be the heat used to evaporate water. In this study, all heat flux terms except the sediment term but including evaporation were measured. The residual is the net sediment heat flux term.

Table 9.4 Spatial distribution of heat flux

Depth (m)	Tub Lake	Stewart's Lake
0-1	-4.05	-3.33
1-2	-2.52	-1.39
2-3	-1.27	-0.76
3-4	-0.53	-0.44
4-5	-0.23	-0.30
5-6	-0.15	-0.19
6-7	-0.11	-0.07
7-8	-0.10	0
8-9	n/a	0

all values in W m^{-2} data from Likens & Johnson, 1969

In their Wisconsin lakes studies Likens & Johnson (1969) estimated that the stored heat contribution from sediments represented approximately 10-12% of the total heat budgets for these lakes. In Chapter 8 we noted that had the sediment flux term been ignored at East Lake and the thermal balance simply used to determine evaporation this would have resulted in a 6.5% over estimate for 1997, equivalent to 89.6mm of evaporation.

Having used the thermal balance to determine sediment heat flux we were left with a huge amount of data from the thermistor strings. While not used for its intended purpose this data allowed the spatial and temporal complexities of the sediment thermal regime to be examined and integrated with the seasonal patterns of lake-aquifer interaction. Section 9.4 examines in detail the instrumentation used to collect the lake and sediment thermal data which is presented in Sections 9.5 and 9.6.

9.4 INSTRUMENTATION

9.4.1 Water temperature loggers

An array of three temperature sensors was constructed to measure surface, mid-level and bottom temperature of the water column (Figure 9.5). Bottom was taken to be clear water immediately above the false bottom. The temperature array was sited in the deepest section of the South Basin (Figure 5.1a). Over the survey period the height of the water column varied from 0.136m (lake stage 2.836m, December 19, 1997) to 0.875m (lake stage 3.575m, September 10, 1997). LM35 temperature sensors were employed. These are completely linear, to better than ±0.25°C (National Semiconductors 1989). Each sensor was calibrated in the laboratory over 0-50°C against a standard laboratory thermometer. Sensors were mounted on a floating frame hinged at the water-sediment interface. Data was captured using three Dataflow 392 single channel loggers mounted in ventilated 40mm PVC enclosures. Point readings were recorded every 10 minutes.

Lake surface temperatures are required for thermal balance (Chapter 8) and some empirical evaporation techniques (Chapter 10). Thermal profiles allowed heat storage (*Qx*) within the lake to be calculated and provide data on stratification and degree of wind mixing. In larger water bodies a number of such profiles are used. This was considered unnecessary due to the small size of East Lake. In such lakes surface temperature is usually measured only in one central location (Anderson 1954 a&b, Harbeck *et al* 1958, Sturrock *et al* 1992).

9.4.2 Thermistor strings

Three profiles of thermistor strings were installed across East Lake (Figures 5.1a and 9.8a). Construction and installation represent modifications of field techniques described by Lapham (1989) and Hunt *et al* (1996). Construction and installation details are summarised in Figure 9.6. The total number of thermistors in a string was limited by the cable (9 conductors plus screened common) connecting the strings to the shore based reading stations. The measured cable resistance was 12 ohms/100m which was considered insignificant in comparison to the operating resistance of the RS 151-243 thermistors (200,000-52,000 ohms between 10-40 °C). Thermistor spacing was varied between different profiles as shown in Table 9.5.

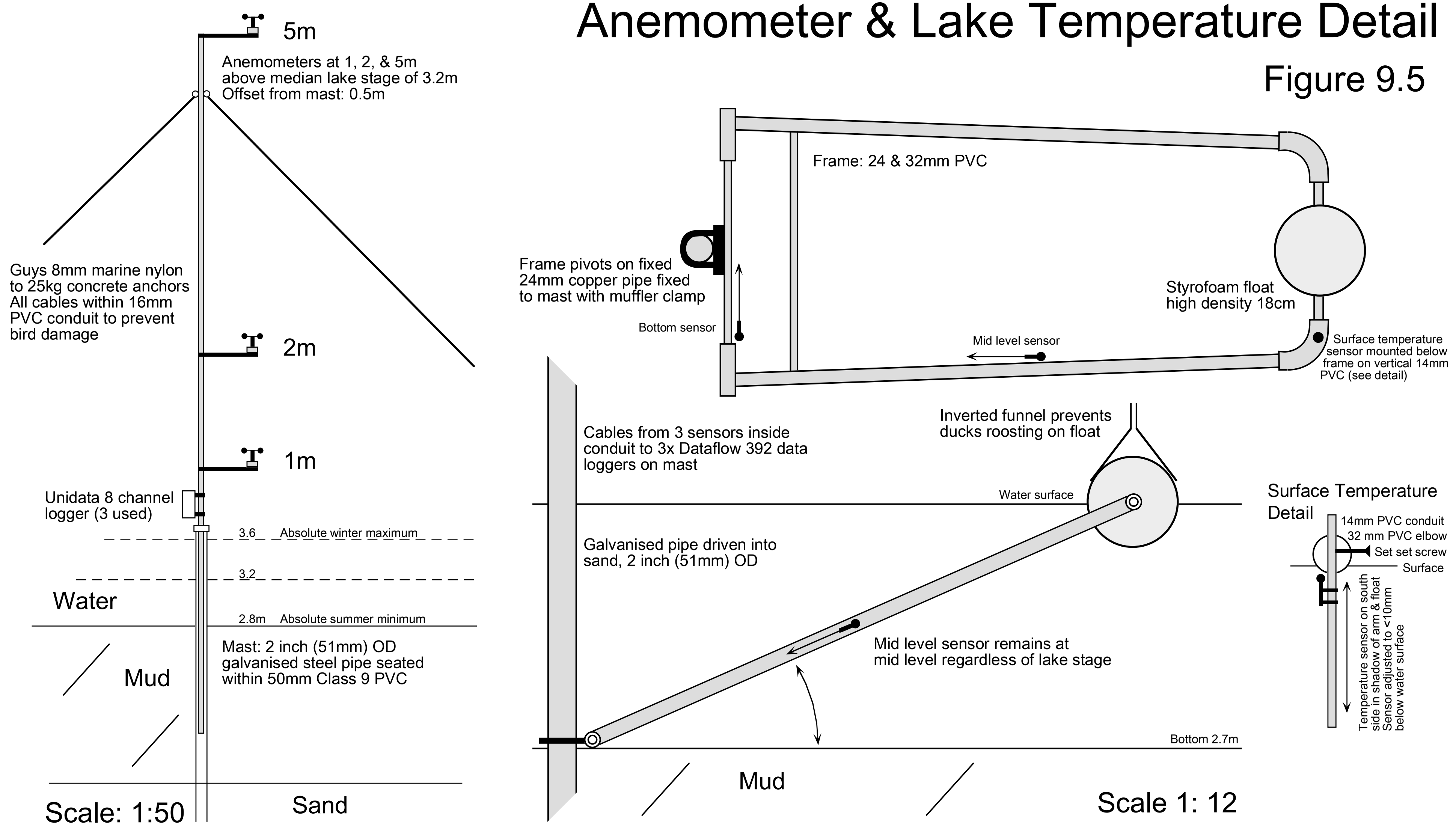
Table 9.5 Thermistor depth below water-sediment interface

Depth (m) refer note	0.0	0.1	0.2	0.3	0.5	1.0	2.0	3.0	4.0	6.0
Ts 2-5 inclusive	X	X	X	X	X	X	X		X	X
Ts 1, TS 6-10 inclusive	X	X	X		X	X	X	X	X	X

Note: Depth is distance below soil surface or water-sediment interface (top of false bottom)

Anemometer & Lake Temperature Detail

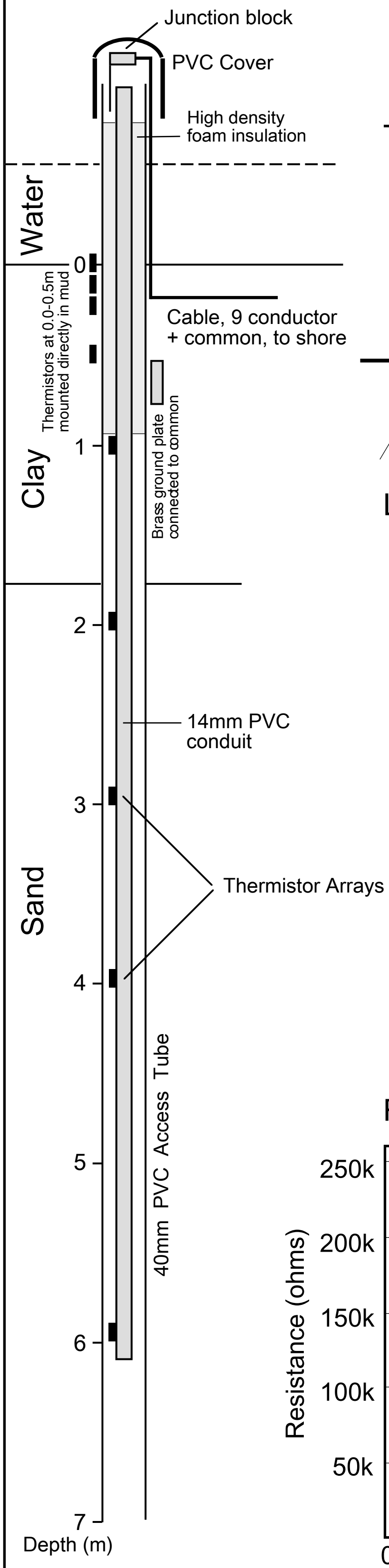
Figure 9.5



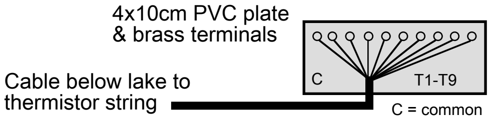
Thermistor String Details

Figure 9.6

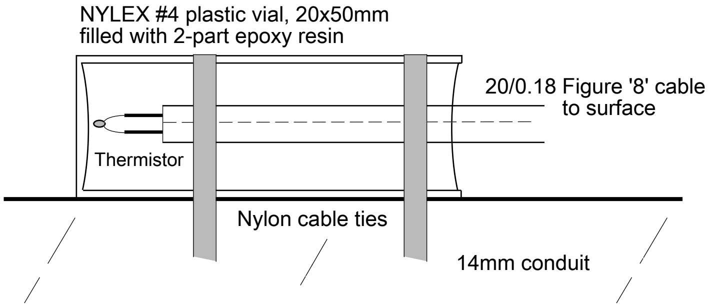
Typical Installation



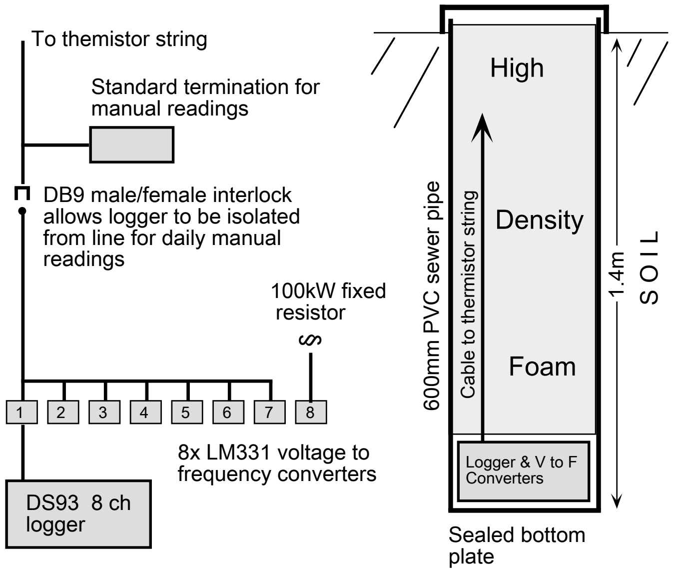
Shore based termination for manual reading



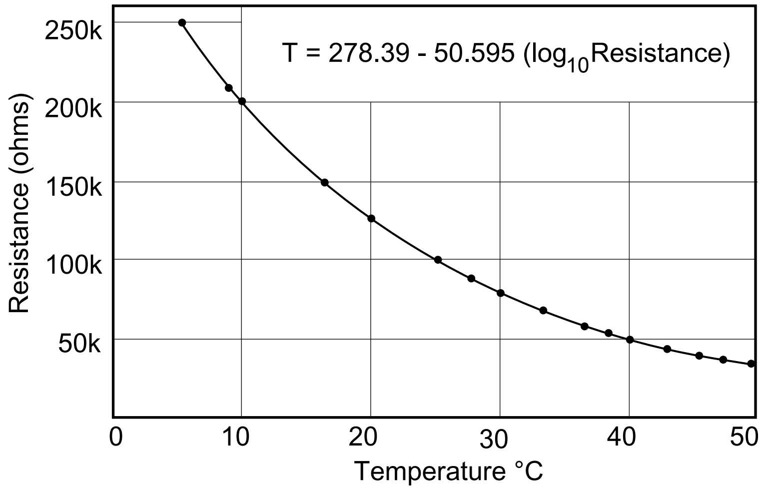
Thermistor Assembly Detail



Logger Detail TS 3 & 7



RS 151-243 Thermistor Response Curve



The additional thermistor at 0.3m in Ts 2-Ts 5 was to provide additional detail on diurnal fluctuations and diurnal extinction depths. The additional thermistor at 3.0m in the remainder provided additional long term (seasonal) data.

The thermistor strings were installed within 40mm PVC access tubes installed by sludge pump to 7m depth below the land surface (Ts 1) or water-sediment interface (Ts 2-10). The top of each access tube was 0.5m above anticipated winter maximum lake level. The method is similar to that of Hunt *et al* (1996) with the exception that the access tubes were not sealed at the base. They are essentially piezometers with the water level in each reflecting potentiometric head at 7m depth. Because there is no direct hydraulic connection with the lake however, the water column in the access tube is essentially static and the temperature at any height in the tube is in equilibrium with the aquifer material outside the tube. The alternative was to insert the thermistor string and then withdraw the access tube. Initial experiments suggested this would be near impossible for the 9 lake based sites as the belled and glued access tube joints precluded easy recovery of the tube. The system adopted also allowed any thermistors suffering water leakage to be replaced and ultimate removal of the thermistor strings at the completion of the project.

Initially all thermistors were mounted inside the 40mm access tube. Thermistors in the upper 1m suffered spurious diurnal cycling from changes in lake water temperature. Experiments with thermistors mounted directly in the lake bed mud confirmed that this cycling exhibited different phase and amplitude to that occurring in the mud and was present to about 0.7m depth. An experimental solution was found whereby all thermistors above 1m were inserted directly in the mud approximately 0.4m away from the access tube. Within the access tube, high density foam water pipe insulation was installed from the 1m thermistor to a height exceeding winter maximum lake stage (Figure 9.6). Induced currents were present on the cables from Ts 6 and 7 which manifest themselves as erratically fluctuating resistance readings for all thermistors. These currents originated with high voltage overhead and underground power cables at the sewage pumping station (Figure 5.1a). The currents were damped by grounding the common signal return with a brass plate buried in the mud at the thermistor end of each array (Figure 9.6).

Data from the thermistors (90 in total, 9x10 strings) was collected manually and electronically. Daily manual readings were taken at nominal 08:00hr using a digital multimeter (Altronics DT830B). These readings (individual thermistor resistance in ohms) were entered in spreadsheets and converted to temperature in °C. Data was rounded to 0.1°. Typically one hour was required daily to read all 10 strings. Readings were always completed in the same station order determined by the locations of the cable terminations on shore (Figure 5.1a). These in turn were determined by the locations of suitable hiding places (typically beneath low bushes) to preclude vandalism. The daily manual readings provide high resolution seasonal information useful below the diurnal extinction depth.

Continuous readings were collected from strings 3 and 7 in the Central and South Basins (refer location map Figure 9.8a). Two 8 channel data loggers (Dataflow Systems DS93) were modified to log data from the RS 151-243 thermistors. Principal modification involved the construction of 16 custom voltage to frequency (V to F) converters, built around a precision V to F chip (National Semiconductor LM331). Circuit details (Appendix 9.1) are modified from a typical application design provided by National Semiconductor (National Semiconductors 1989). Each V to F converter was individually calibrated using 37 1% precision resistors varying from 10k to 430k ohms. Each resistor represents a known equivalent thermistor temperature between 76.0° (10k ohm) and -6.6° (430k ohm) and resulted in a unique frequency output for each V to F converter. The frequency data was curve matched to produce a polynomial expression allowing frequency to be converted directly to temperature at better than 0.1° precision. Typically a 5th degree polynomial resulted in a coefficient of determination of R>0.9999. Loggers scanned each thermistor string every 2 minutes, recording a mean value every 20 minutes. Seven of the ten thermistors in each string were logged (Table 9.6).

The channel '8' V to F converters on both loggers were hard wired with 100k ohm 1% precision resistors across their inputs. These allowed diurnal temperature induced variations in V to F output frequency to be monitored. During the initial set up of Ts 3 in December 1996, with the logger at ground level, it became evident that diurnal temperature changes in the electronics were producing unacceptably high changes in apparent temperature. The logger was run with 100k ohm fixed loads across all 8 V to F inputs. Thermally induced diurnal signals were evident on all channels, equivalent to 1.4°C drift over 24 hours.

Table 9.6 Logger set up Ts 3 and Ts 7

Thermistor depth (m)	0.0	0.1	0.2	0.3	0.5	1.0	2.0	3.0	4.0	6.0
Ts 3 (Logger S/N 8101)	X	X	X	X		X	X		X	
Ts 7 (Logger S/N 20001)	X	X	X		X	X	X		X	

The thermal drift problem was solved by mounting the loggers in 1.2m deep insulated pits (Figure 9.6). CSIRO tests in Gnangara sand showed that summer diurnal temperature fluctuations are damped to better than 0.1°C at 1.5m depth (J. Smith pers com). Subsequent tests (again with fixed 100k ohm inputs) indicated electronic thermal drift was reduced to better than 0.1°C over 24 hours. Long term absolute drift is not important in this application since we were interested only in the pattern of diurnal variations. The daily manual readings provided long term absolute data.

The RS 151-243 thermistors are negative temperature coefficient types. They are precision curve matched to better than ±0.2°C over 0°-70° range precluding the need for individual calibration. They have a resistance of 100k ohms at 25°C. Calibration data is included in Figure 9.6.

Profile sedimentology is summarised in Table 9.7:

Table 9.7 Thermistor string sedimentology

Thermistor string	Ts 1	Ts 2	Ts 3	Ts 4	Ts 5	Ts 6	Ts 7	Ts 8	Ts 9	Ts 10
Peat	0.0-0.3									
Lake lining clays	0.3-0.4	0.0-0.9	0.0-1.2	0.0-1.2	0.0-0.3	0.0-0.8	0.0-2.4	0.0-0.2	0.0-0.8	0.0-0.4
Sand	0.4-6.0	0.9-6.0	1.2-6.0	1.2-6.0	0.3-6.0	0.8-6.0	2.4-6.0	0.2-6.0	0.8-6.0	0.4-6.0

9.4.3 Regional Data

Temperature profiles were measured monthly in the five deep piezometers N1c to N5c. Limited data was also collected for comparative purposes from PL3 and regionally from wells in the UWA Field Station, Bold Park and Jubilee Park (refer location maps within Figure 9.8). An epoxy encapsulated RS 151-243 thermistor was lowered slowly (to prevent vertical mixing) into each well. Temperature was measured at one metre intervals. Each reading took about 1 to 2 minutes, this being the time required for the thermistor to equilibrate.

9.5 THE WATER-SEDIMENT INTERFACE

9.5.1 Diurnal extinction depth

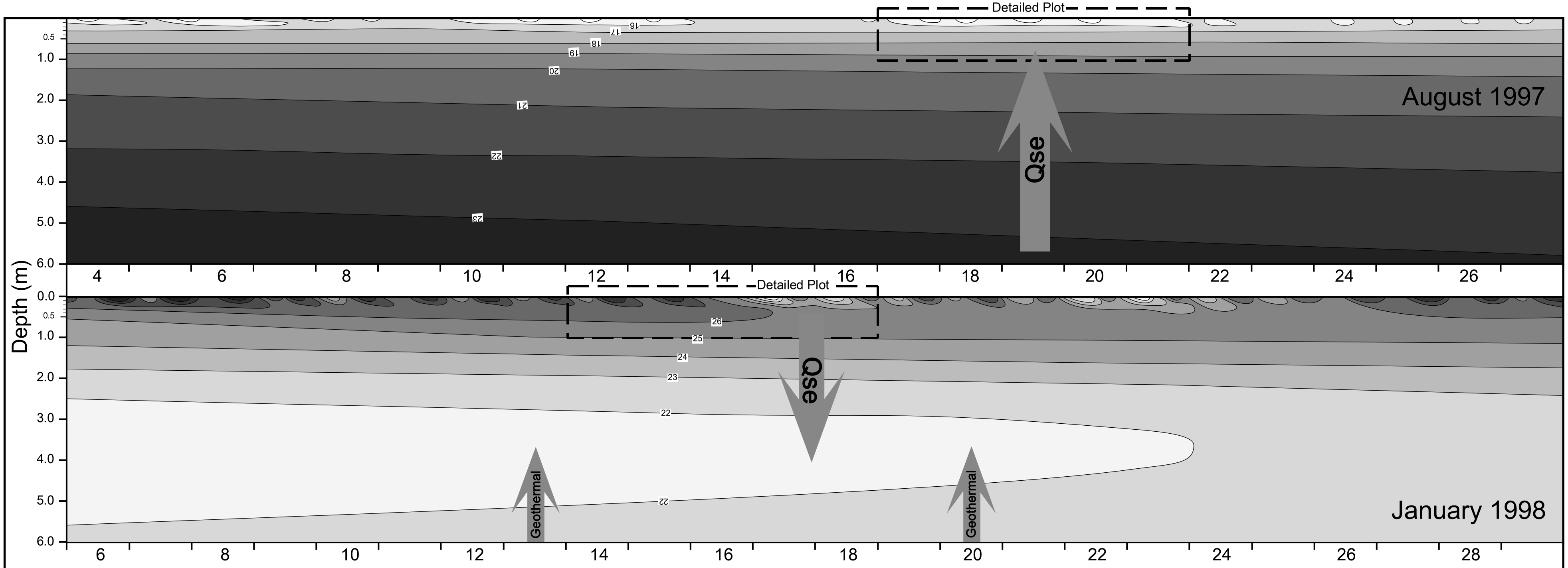
At Perry Lakes there is a continuum between the water column, water saturated unconsolidated gel like 'false bottom' sediments and compact clays. The water column displays strong diurnal temperature cycles of a sin wave nature. This diurnal signal extends into the false bottom where with increasing depth its amplitude decreases and the phase is shifted. The extinction depth is the point where the diurnal signal is completely damped and varies spatially and temporally within the lake basin. Continuous twenty minute thermal data was collected from Ts 3 and Ts 7 (Section 9.5). The data are similar and only Ts 7 data is presented.

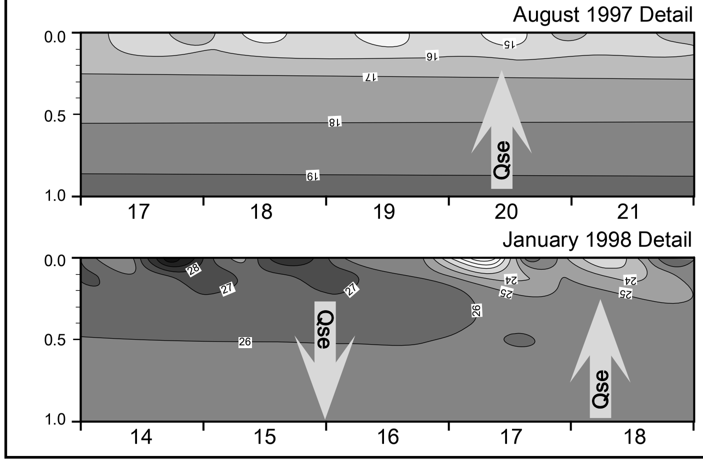
Ts 7 Profile Detail

Figure 9.7

Each 24 day plot developed from 2625 data points
Daily 08:00 hr manual readings at 9 depths 0 to 6m
Hourly data logger readings at 0.0, 0.1, 0.2 and 0.5m

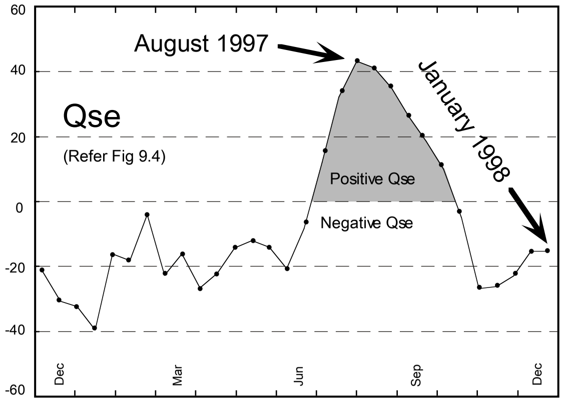
Contours developed by kriging
Ts 100x100 cells



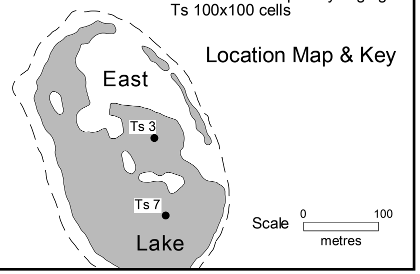


In winter the signal from cold night lake water temperatures are extinguished at about 0.1m

In summer predominant signal is from warm day time water. Extinction depth is now 0.3m. The predominating negative sediment heat flux is temporarily reversed during lake level top up pumping (January 17 & 18)



Location Map & Key



During winter, under a positive sediment heat flux, the signal from cold August night time lake water is extinguished at about 0.1m sediment depth (Figure 9.7). During summer a negative sediment heat flux prevails. Hot day time air temperatures heat the lake water and the underlying sediments. This hot diurnal signal is extinguished at about 0.3m. The local flux is reversed during lake level maintenance when large quantities of groundwater at an average temperature of 20.7˚ C are introduced (Figure 9.7 January detail).

Concepts of conductive and advective heat flows are expanded in Section 9.6.

9.6 REGIONAL EFFECTS

Below the extinction depth seasonal patterns predominate. In East Lake these patterns vary spatially across the lake basin reflecting seasonal changes in flow regime. Vertical profiles of groundwater temperature within and close to a flow-through lake reflect heat transported by advection (via groundwater flow) and conduction (Suzuki 1960, Stallman 1965). Hunt *et al* (1996) provide a practical field demonstration of how the groundwater component within a wetland water balance can be estimated from the seasonal depth of heat penetration from the land surface. In their study, the one-dimensional numerical model of Lapham (1989) was used to solve the partial differential equation governing heat flow derived by Stallman (1965). In East Lake this methodology was expanded to include profiles beneath zones of seasonal and permanent inundation however the data were used only to generate temperature profiles for comparison with the flow regimes defined by the water balances.

9.6.1 The regional aquifer

N5 (Figure 9.8d) is an example of a section of the aquifer almost completely insulated from solar effects. Mean soil thickness is about 8.5m. A 'cold front' is conducted down the soil profile over winter, reaching the aquifer by about November. This results in a cold 'tongue' of water (0.1˚C cooler than the surrounding water) which persists until about the following July. The summer 'warm front' also moves down, reaching the aquifer about August the following winter. This warming effect (of up to 0.2˚C) persists until November when the cycle repeats. Data collected regionally from UWA Field Station, Bold Park and Jubilee Park (Figure 9.8f) show similar surface effects superimposed on the regional geothermal gradient which is expressed as a slow warming trend with depth (Davidson 1995).

9.6.2 The aquifer adjacent to wetlands

N1c and N3c are piezometers very close to the original up gradient lake edges. West Lake is now dry much of the year while East Lake has shrunk and is now effectively centred south of N3c (the 'South Basin'). We know that within Perry Lakes Reserve water in the upper part of the unconfined aquifer is of the order of 21˚C. When a flow-through regime is established in either lake over winter warmer water moves upwards from depth and enters the lakes close to the up gradient shores. We observe a hint of this in N3c (Figure 9.8b) in May-June (defined by the field between 20.0 and 20.2˚C) and more weakly in N1c (Figure 9.8f) during June in the field between 20.2 and 20.4˚C.

Both piezometers however display a clear thermal boundary separating surface and possible wetland interaction effects with the deeper regional thermal gradient. In N1c this is defined by the 20.4˚C isotherm which is flat over time at about 13m depth with temperature slowly increasing below that level. Similarly in N3c, the 20.2˚C isotherm is essentially horizontal at about 16m depth. The thermal data corroborates the argument put forward in Chapter 7 that both piezometers were largely outside the zone of surface water-groundwater interaction. The observed seasonal patterns appear to be primarily the effects of conduction from the land surface which is in both N1c and N3c only about 2.5m above the water table. In N1c the thermal patterns over summer can only be surface conduction effects as the adjacent section of West Lake was dry.

Piezometers N2c and N4c on the down gradient shores display patterns which are a combination of surface conduction and flow regime advection effects. Groundwater recharge exceeds groundwater discharge in both lakes. This is particularly so in East Lake where top up maintains persistent summer recharge regimes. In N4c a tongue of warm discharge water (defined by the 22.0˚C isotherm) descends to about 16-17m below the water table (Figure 9.8d). This along with limited data from PL3 provide estimates of the depth of surface water-groundwater interaction. Aquifer thickness is about 36-37m suggesting interaction to about half the aquifer thickness (0.5B). This plume of warm discharge water extends for an unknown distance down gradient. The distance between N4c and PL3 is 64m. There is no evidence of the plume in N5c, 420m distant (Figure 9.8d).

9.6.3 The aquifer beneath the lake basin

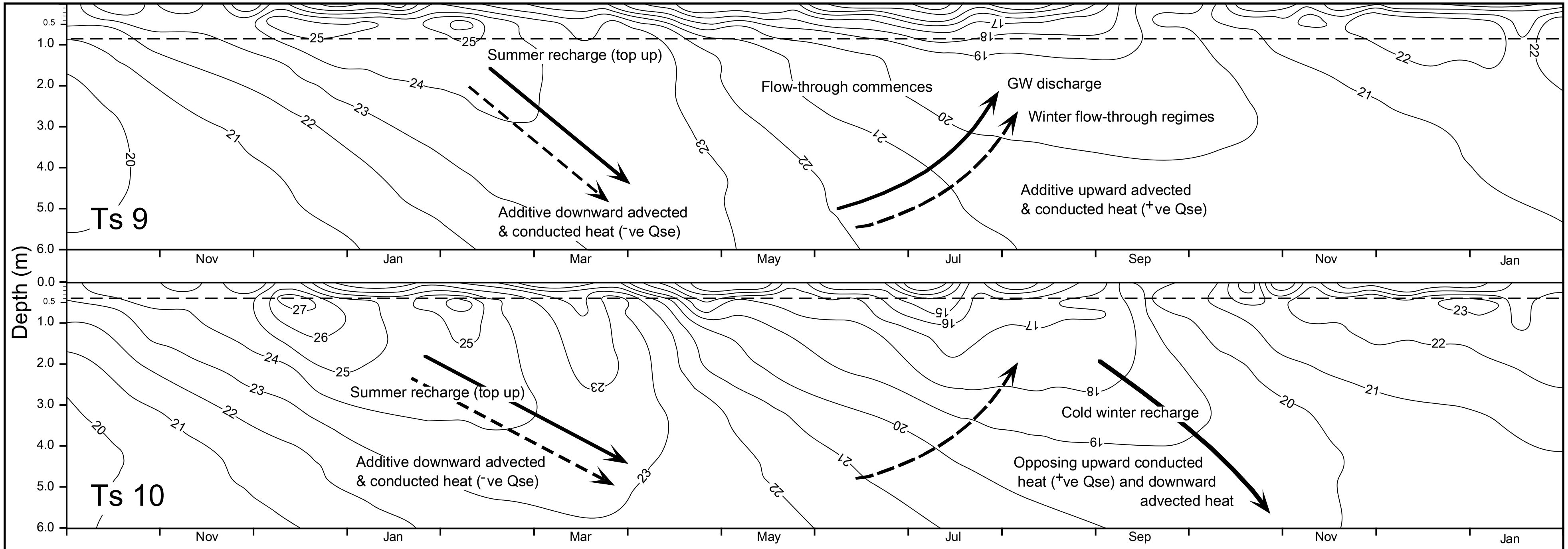
Ten thermistor strings comprising three profiles were installed across the northern, central and southern sections of East Lake (location map, Figure 9.8a). The profiles were aligned parallel to the regional groundwater flow. Each profile displays a similar pattern from east (up gradient) to west (down gradient). The only exception is Ts 1 (Figure 9.8b) which was located close to N3c and also appears to be uninfluenced by surface water-groundwater interaction. In summer the area is dry. Dense *Typha* shades the ground resulting in little heat being conducted into the soil. In winter the area is flooded to about 10cm depth. Winter cold is conducted well below 6m depth.

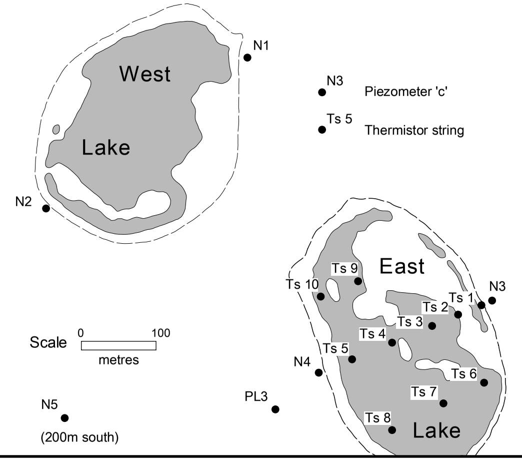
Ts 9, Ts 2 and Ts 6 are located close to the up gradient shore. Their thermal time-depth patterns reflect this in that they are influenced seasonally by both flow-through and recharge regimes. In summer under recharge regimes induced by lake top up, heat is both advected and conducted downwards. In winter under flow-through regimes the process reverses with heat now advected and conducted upwards. This is the positive sediment flux (positive *Qse*) discussed in Section 9.2. The result are annual patterns with much smaller ranges of seasonal change than the equivalent stations (Ts 10, Ts 5 and Ts 8) on the opposite side of the lake.

Ts 10, Ts 5 and Ts 8 are located close to the down gradient shore. In summer heat is again advected and conducted downwards. Compared to holes on the up gradient side, the recharge flux here is much greater. This is particularly evident in Ts 8 (Figure 9.8e) which was adjacent to the South Basin which was almost continually flooded over summer. In comparison Ts 5 and Ts 10 suffered periodic drying out on a weekly basis. In winter the downward advection of lake water continues as the lake reverts to flow-through regimes. Now however there are the opposing forces of upward conduction from sediments warmed the previous summer (positive *Qse*) and the downward advection of cold winter lake water.

Profiles in the centre of the lake Ts 4 and Ts 7 were on or close to the dividing stream line. Heat was advected only in the summer under top up induced recharge regimes. In winter heat transfer was by conduction only, this again being an upward (positive) flux from the sediments.

The thermal profiles also demonstrate the effects of differing management regimes. In early summer 1996, top up commenced October 19. Early top up forced the lake from flow-through to recharge. Warmer summer water advected heat downward. In contrast, in 1997, top up was withheld until December 20 resulting in an entirely different thermal pattern. This is particularly evident in Ts 2 and Ts 5. In Ts 6, a distinct change in slope of the 21° isotherm marks the commencement of top up and transition from a flow-through to recharge regime in December 1997. This effect is demonstrated in Table 9.8 which tabulates the daily rate of temperature rise at fixed depth.





Location Maps & Notes

—→ Advected heat flux

- - → Conducted heat flux

All thermistor strings measure from 0 (sediment-water interface) to 6m depth, thermistor spacing varies, as follows:

Depth	Ts
0.0, 0.1, 0.2, 0.3, 0.5, 1.0, 2.0, 4.0, 6.0	2, 3, 4, 5
0.0, 0.1, 0.2, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0	1, 6, 7, 8, 9, 10

Each thermistor plot developed from 4212 data points (9 daily 08:00 hr readings over 468 days), each piezometer plot developed from about 357 data points (20-21 monthly readings)

Piezometer surveys measure temperature of aquifer from water table to depth of 20-21m (depending on season) measured monthly at metre intervals

All temperatures accurate to better than 0.1°C

Contours develped by kriging: Ts 10x100 cells
Piezometers 20x15 cells

Thermal Profiles in Sediments

Within & Adjacent to East and West Lakes

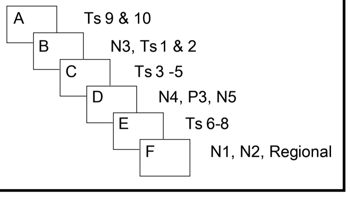
Lake lining (mud) thickness (m)

Ts	Mud
1	0.2
2	0.9
3	1.2
4	1.2
5	0.2
6	0.8
7	2.4
8	0.2
9	0.8
10	0.4

Mud-sand contact: — — — — —

Figure 9.8 A-F

Note: Figure covers 6 sheets



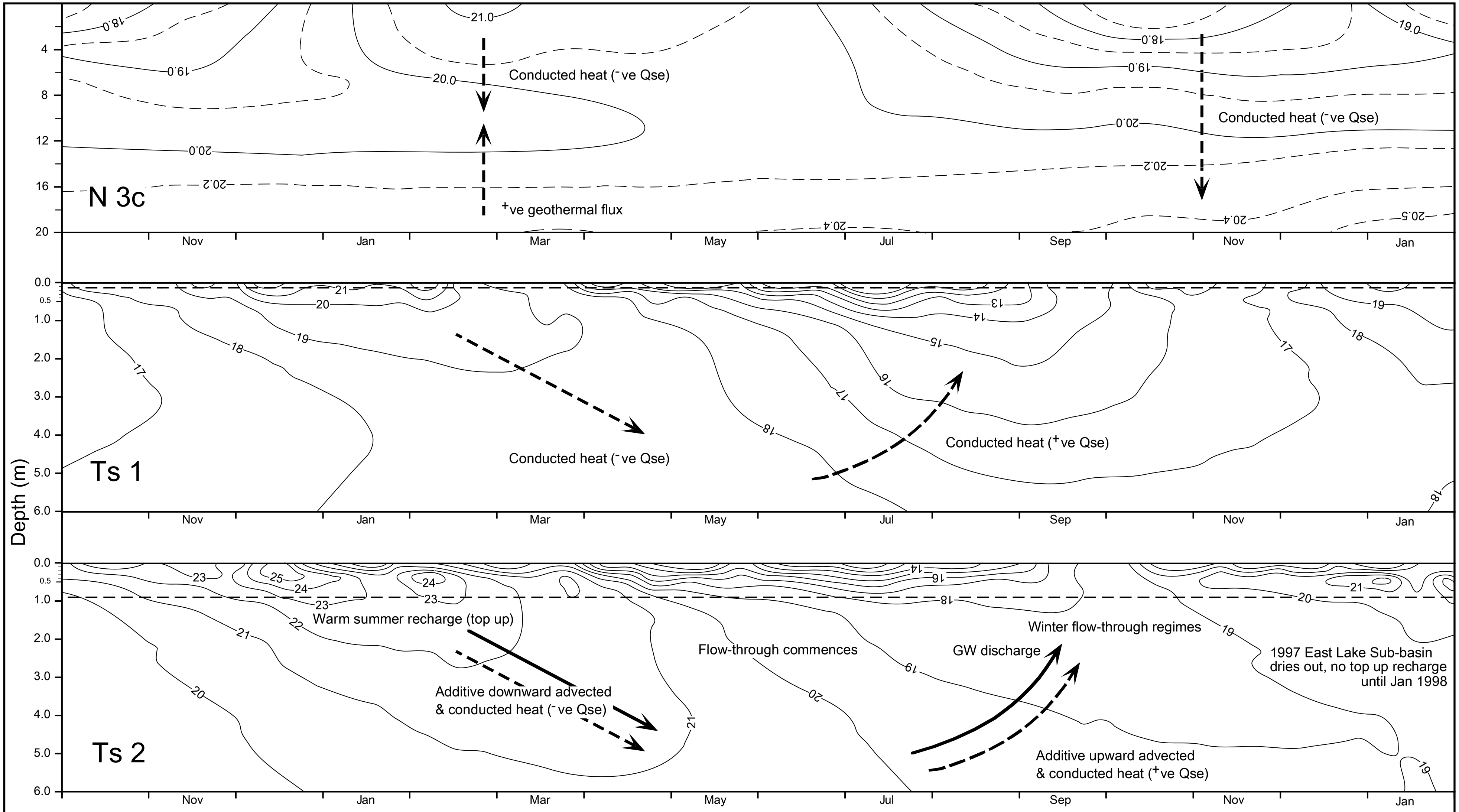

N 3c
Ts 1
Ts 2
Depth (m)
4
8
12
16
20
0.0
0.5
1.0
2.0
3.0
4.0
5.0
6.0
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
18.0
19.0
20.0
20.2
20.4
20.5
21.0
Conducted heat (⁻ve Qse)
⁺ve geothermal flux
Conducted heat (⁻ve Qse)
13
14
15
16
17
18
19
20
21
Conducted heat (⁻ve Qse)
Conducted heat (⁺ve Qse)
22
23
24
25
Warm summer recharge (top up)
Additive downward advected & conducted heat (⁻ve Qse)
Flow-through commences
Winter flow-through regimes
GW discharge
Additive upward advected & conducted heat (⁺ve Qse)
1997 East Lake Sub-basin dries out, no top up recharge until Jan 1998

Figure 9.8B

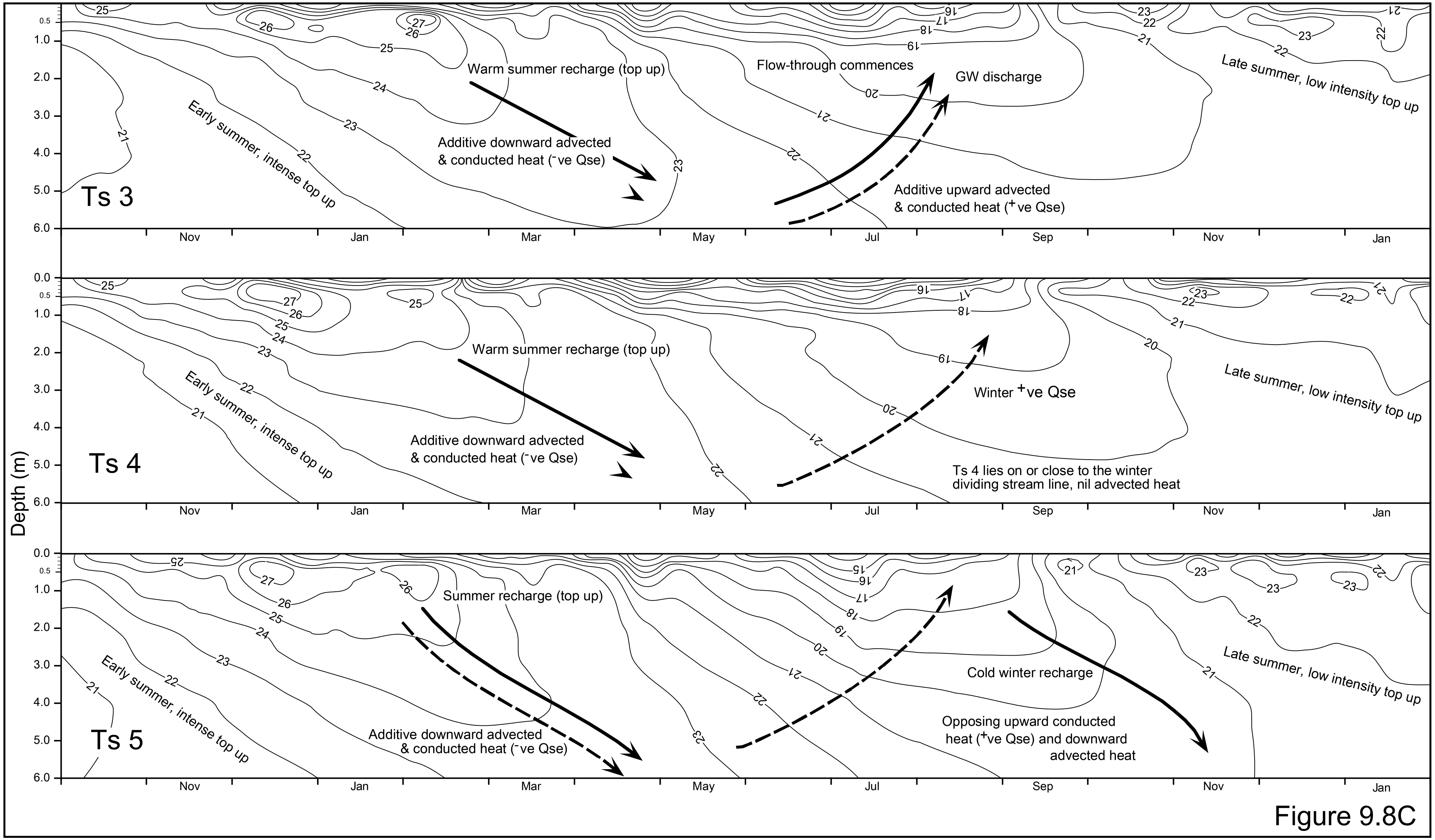

Ts 3
Ts 4
Ts 5
Depth (m)
0.0
0.5
1.0
2.0
3.0
4.0
5.0
6.0
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Early summer, intense top up
Warm summer recharge (top up)
Additive downward advected & conducted heat (⁻ve Qse)
Flow-through commences
GW discharge
Additive upward advected & conducted heat (⁺ve Qse)
Late summer, low intensity top up
Winter ⁺ve Qse
Ts 4 lies on or close to the winter dividing stream line, nil advected heat
Summer recharge (top up)
Cold winter recharge
Opposing upward conducted heat (⁺ve Qse) and downward advected heat
15
16
17
18
19
20
21
22
23
24
25
26
27

Figure 9.8C

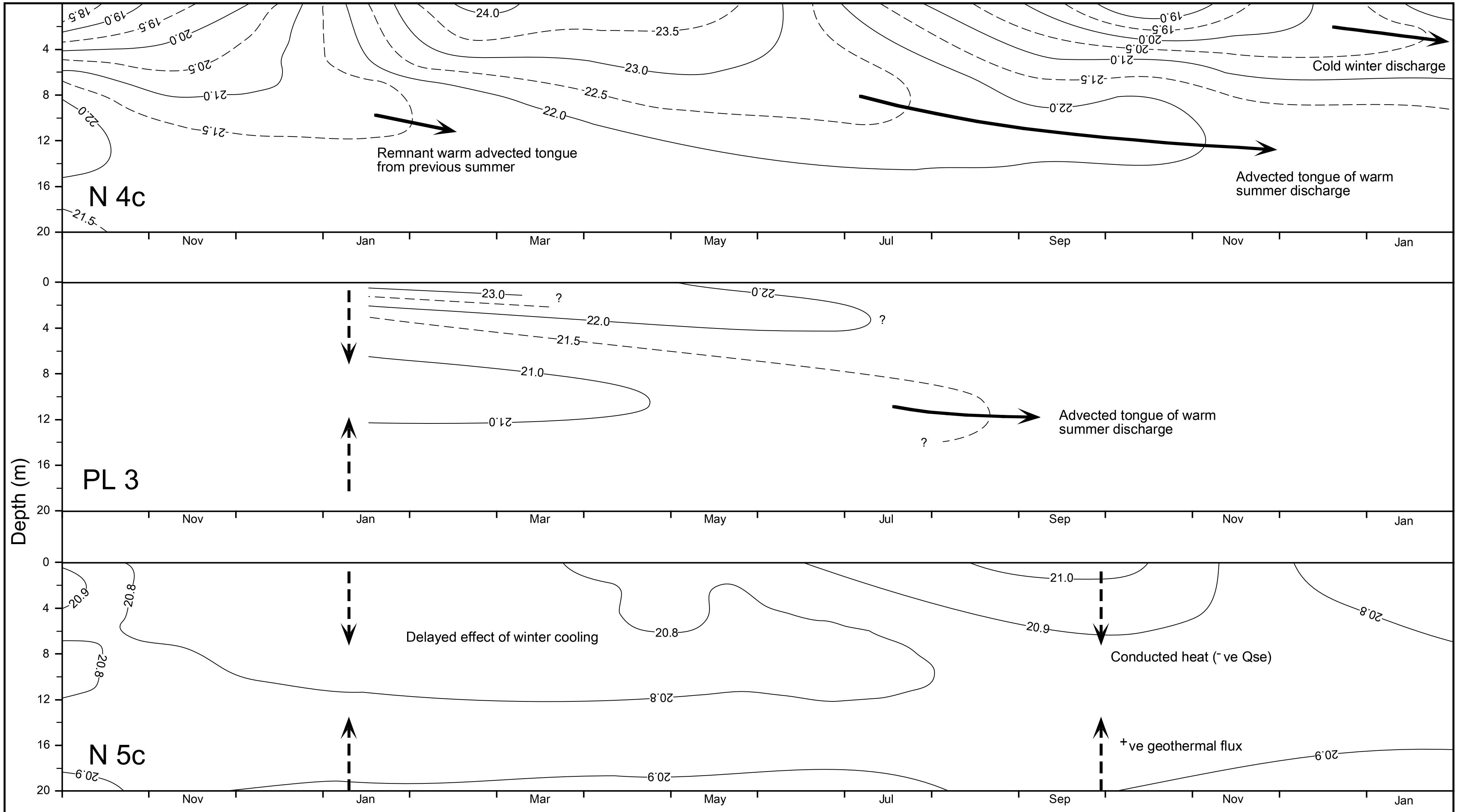

N 4c
PL 3
N 5c
Depth (m)
0
4
8
12
16
20
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
18.5
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
23.0
23.5
24.0
Remnant warm advected tongue from previous summer
Advected tongue of warm summer discharge
Cold winter discharge
?
20.8
20.9
Delayed effect of winter cooling
Conducted heat (⁻ve Qse)
⁺ve geothermal flux

Figure 9.8D

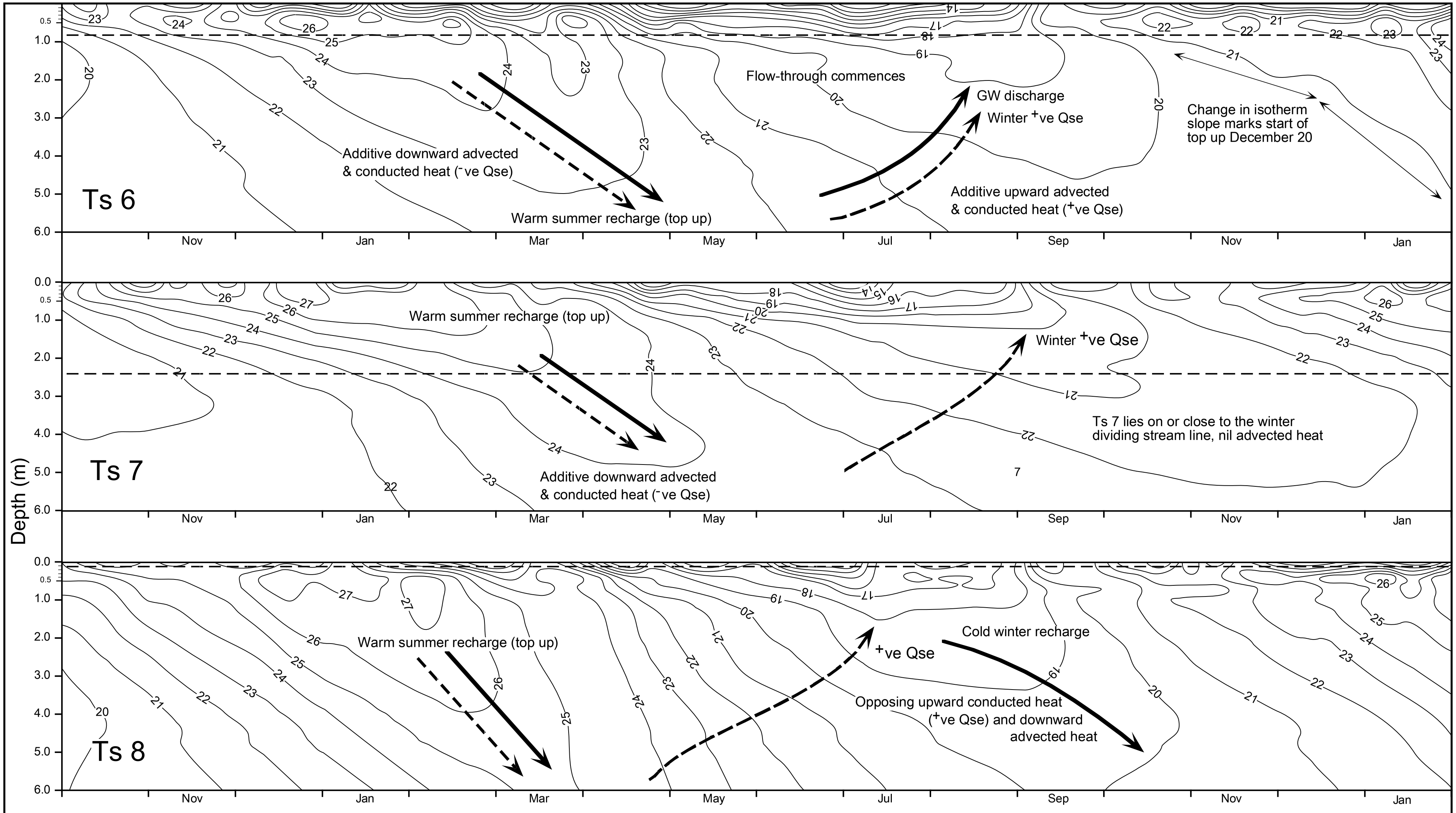
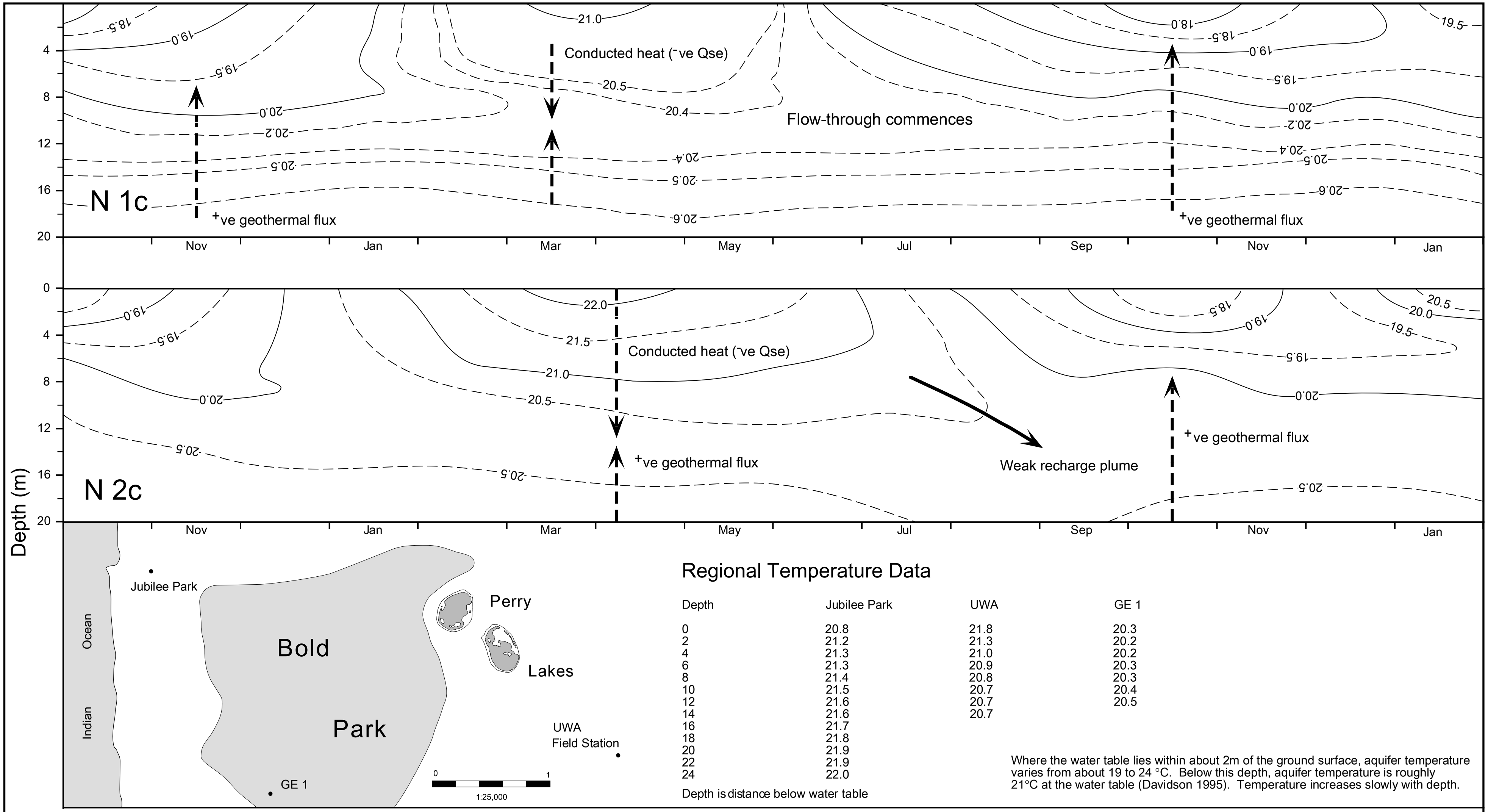

Ts 6
Flow-through commences
GW discharge
Winter $^{+}$ve Qse
Change in isotherm slope marks start of top up December 20
Additive downward advected & conducted heat ($^{-}$ve Qse)
Warm summer recharge (top up)
Additive upward advected & conducted heat ($^{+}$ve Qse)
Ts 7
Warm summer recharge (top up)
Winter $^{+}$ve Qse
Ts 7 lies on or close to the winter dividing stream line, nil advected heat
Additive downward advected & conducted heat ($^{-}$ve Qse)
Ts 8
Warm summer recharge (top up)
Cold winter recharge
$^{+}$ve Qse
Opposing upward conducted heat ($^{+}$ve Qse) and downward advected heat
Depth (m)
0.0
0.5
1.0
2.0
3.0
4.0
5.0
6.0
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
14
15
16
17
18
19
20
21
22
23
24
25
26
27

Figure 9.8E



Regional Temperature Data

Depth	Jubilee Park	UWA	GE 1
0	20.8	21.8	20.3
2	21.2	21.3	20.2
4	21.3	21.0	20.2
6	21.3	20.9	20.3
8	21.4	20.8	20.3
10	21.5	20.7	20.4
12	21.6	20.7	20.5
14	21.6	20.7	
16	21.7		
18	21.8		
20	21.9		
22	21.9		
24	22.0		

Depth is distance below water table

Where the water table lies within about 2m of the ground surface, aquifer temperature varies from about 19 to 24 °C. Below this depth, aquifer temperature is roughly 21°C at the water table (Davidson 1995). Temperature increases slowly with depth.

Figure 9.8F

Table 9.8 Sediment temperature rise, early summer

Station	Profile	Daily Rate of Temperature Rise (°C) at Depth of 3m Nov 02-Dec 31 1996	Oct 15-Nov 30 1997*
Ts 9	North	0.032	0.019
Ts 10	"	0.046	0.035
Ts 1	Central	0.015	0.015
Ts 2	"	0.028	0.016
Ts 3	"	0.034	0.021
Ts 4	"	0.042	0.028
Ts 5	"	0.044	0.039
Ts 6	South	0.028	0.017
Ts 7	"	0.011	0.008
Ts 8	"	0.056	0.038

* Ts 9&10 October 15 to November 15

Early top up in 1996 increased the rate of rise at all stations except Ts 1 which further confirmed that it lay outside the influence of surface water-groundwater interaction.

Plotting the ratio of temperature rise in profile end member pairs illustrates the effects of both surface water-groundwater interaction and management regime (Table 9.9). The rate of summer temperature rise is always greater on the down gradient margin of the lake (ratios <1). This is because in summer under flow-through or recharge regimes, there is an additive effect of conducted and advected heat. Early top up and persistent artificially induced summer recharge accentuates this effect. The 1996 ratios are therefore greater than those in 1997 when the natural flow-through regime was allowed to persist into summer.

Table 9.9 Temperature rise ratios, Up & Down gradient pairs

Ratio	Profile	Ratio of Daily Temperature Rise (°C) at Depth of 3m Nov 02-Dec 31 1996	Oct 15-Nov 30 1997
Ts 9:10	North	0.698	0.533
Ts 2:5	Central	0.627	0.401
Ts 6:8	South	0.499	0.455

9.6.4 Long Term Trends

Thermistor string Ts 7 was left in place and was read occasionally up to June 1999. Table 9.10 shows comparisons with temperatures on the same dates in 1996-1998. The time frame of this data is simply too restricted to confirm definite trends. The data suggests however that with persistent low summer levels (augmented by top up), there is a slow increase in thermal input to the aquifer. Very shallow lakes may be effective as heat sources for the aquifer. They heat up quickly in summer and there is direct absorption of thermal energy by the dark mud bottom.

Over this period 1996 to 1999 there continued to be a net decline in the size (and mean depth) of Perry East.

Table 9.10 Thermal trends in sediments at 6m depth, Ts 7, 1996-1999

Day	1996	1997	1998	1999	Trend
January 22		21.73	22.07	21.88	warmer (?)
May 11		23.67	24.10	24.24	"
June 25		23.73	23.91	23.83	"
December 02	21.71	22.12	21.99		"

The data suggests a probable slow warming trend.

CHAPTER

10

EVAPORATION STUDIES

10.1 INTRODUCTION

In hydrology, evaporation (E) is the phenomenon by which water is converted from the liquid into vapour. Transpiration (T) is a special case where vaporisation occurs through the stomata of living plants. Frequently these two phenomena are combined in the term evapotranspiration (ET) since direct evaporation from the soil and small water bodies and transpiration from vegetation are difficult to separate (Brutsaert 1982). Under arid conditions evaporation is often reported as potential evaporation (PE), a concept introduced by Thornthwaite (1948) in relation to climate classification. It is now generally understood to define the maximum rate of ET that could occur over an area of soil and actively growing vegetation supplied with adequate water at all times (Granger 1989). A more agriculturally specific definition defines it simply as the 'maximum rate of ET from a large area covered completely and uniformly by an actively growing vegetation with adequate moisture at all times' (Brutsaert 1982 p214). This reflects the widespread use of the concept in agriculture where transpiration dominates over soil evaporation as the principal mechanism of transferring water to the atmosphere. Where used here, PE is the maximum transfer of water to the atmosphere that could occur over a given area under given micro-climatic conditions through evaporation from open water and soil, and through transpiration. Actual evapotranspiration is the amount of evapotranspiration actually occurring. This should never exceed PE if they have been correctly calculated. Where plants or soils cannot meet the atmospheric demand on their evaporating surfaces, actual evaporation may be much less than PE (Fleming 1997).

Evapotranspiration and precipitation are the two principal phases of the hydrological cycle. Some indication of their magnitude and importance can be gained from global and regional water balance estimates (Table 10.1). On the Swan Coastal Plain open water evaporation is the largest single factor contributing to wetland water loss and may exceed precipitation by three times in drought years.

The general water balance (equation 6.1) expresses the conservation of mass in anything from a small wetland to a large lake. Regardless of scale, many of these components are seemingly easier to estimate or accurately measure than evaporation. Despite its importance, evaporation is therefore frequently estimated as the residual in the balance despite the potentially large cumulative errors and uncertainties (Chapter 4). Frequently this is the only avenue available to researchers when budgets, available data or instrumentation are limited.

Table 10.1 Estimates of world water balance (m y^{-1})

Land (1.49×10^8 km^2) P	 Et	Oceans (3.61×10^8 km^2) P	 Et	Global P = Et	Reference*
0.73	0.42	1.14	1.26	1.02	Budyko (1970, 1974)
0.73	0.47	1.14	1.24	1.02	Lvovitch (1970)
0.83	0.54				Lvovitch (1973)
0.75	0.48	1.07	1.18	0.97	Baumgartner & Reichel (1975)
0.80	0.49	1.27	1.40	1.13	Korzun *et al* (1978)

*Table adapted from Brutsaert (1982) and references therein, P (precipitation), Et (evapotranspiration)

Evaporation is an important component of lake hydrology. At Perry Lakes it can comprise up to 40% of the water budget (Chapter 6). Viewed at a regional scale, all components of the hydrological cycle present formidable problems in both estimation and sampling (Brutsaert 1982). Often when the scale is reduced to something like a small wetland, many of these problems are likewise reduced. A simple rain gauge for example provides a reasonable event by event estimate of rainfall. Evaporation however, remains notoriously difficult to determine either at a point location or regionally. This difficulty frequently results in gross inaccuracies in water balance estimates (Winter 1981).

It is generally accepted that a thermal balance represents the most accurate method of estimating evaporation (Anderson 1954a, Harbeck *et al* 1958, Rosenberry *et al* 1993). However any thermal balance is extremely complex, time consuming, logistically difficult and expensive. These drawbacks have therefore generally precluded such studies being sustained for more than several years at any one site. The five year study by Sturrock *et al* (1992) being an admirable exception. Such difficulties have also resulted in many attempts to design much easier to implement empirical field methods. These frequently claim ease of implementation and high accuracy (for example Webb 1966, Keijman 1974, de Bruin 1978, Stewart & Rouse 1976). Based largely on Northern Hemisphere studies their unquestioned adoption under Australian conditions is fraught with uncertainty.

The general approach adopted in many large studies therefore has been to complete short term thermal balance estimates (often for one full year) concurrent with a variety of empirical techniques and evaporation pan studies. The thermal balance data is taken as 'true' and used to calibrate the empirical techniques which generally rely on much easier to measure meteorological and other parameters and can usually be run over much longer periods. In the end the choice of a method for measuring or calculating evaporation depends on the problem under consideration and is governed by the available data, instrumentation and, all too often, financial resources.

On the Swan Coastal Plain research is frequently centred on urban wetlands either because they are conveniently located in relation to universities or other research institutions or because increasingly such wetlands are being recognised as valuable assets within urban environments and their proper management is of increasing concern to wetland managers. The Perry Lakes thermal balance therefore represented an opportunity to calibrate both evaporation pans and a number of empirical techniques under local conditions. Those presented in this chapter can now be applied to nearby wetlands with much greater confidence than would otherwise be the case.

10.2 EVAPORATION PANS AS SIMPLE PHYSICAL MODELS

Evaporation pans are probably the simplest physical model for evaporation from a lake. As Brutsaert (1982) notes, their intuitive appeal is easy to understand because they model evaporation from a free water surface in a visible way. Depending on their construction and whether they are situated above or below ground, evaporation from a pan and a nearby wetland can differ significantly. These differences result from the basic factors affecting evaporation from water bodies such as surface water temperature, heat storage, wind, turbulence, wave action, soluble salts and nature and shape of the evaporating surface (WMO 1966). Wind effects and heat advection not typical of the natural environment (Winter 1981) and air turbulence created by the pan rim are their principal source of error. Jacobs *et al* (1998) showed that the physical analogy between a pan and reference evaporation is predominantly dependent on the weather and that a unique constant pan co-efficient cannot exist. As the predominating character of the weather changes seasonally, so too does the average pan co-efficient. Generally pans tend to over estimate evaporation from lakes. These errors can be decreased by sinking the pan below ground level and increasing its thermal mass (*i.e.* increasing both diameter and depth) thereby more closely approximating a small natural water body.

Pan coefficients, defined as the ratio of lake evaporation to pan evaporation represent the simplest method of relating pan evaporation to lake evaporation. In practice this coefficient varies seasonally and is highly site specific. In southern coastal areas of Australia the coefficient may approach 1.0 while in the arid interior it may be as low as 0.6 (AWRC 1970). Pan coefficients can be reasonably accurate for some areas when applied over long time frames (Hoy & Stevens 1979, Knapp 1985) however they cannot be used with any accuracy over the short term. The seasonal range in coefficients may be as low as 0.2 in the tropics to 0.5 in southern Australia (AWRC 1970). In general however coefficient values for Class A pans vary from about 0.5 to 0.9 with 0.7 being a generally assumed global average for an unguarded pan (WMO 1966). This figure appears to derive originally from the Lake Hefner (Oklahoma) studies (Kohler 1954) where a mean annual figure of 0.69 was determined for 1950-51.

Pan data is most valuable where evaporation has been determined independently for a lake and a nearby evaporation pan. Pan data can then be used to make further estimates of lake evaporation. Data for fourteen Australian lakes is compiled as Table 10.2.

Table 10.2 Measured Class A pan and sunken pan coefficients for Australian lakes

Lake	Location	Pan 1	Pan 2	Sunken
Lake Menindee	SE Broken Hill - Darling River area NSW	0.71	0.76	0.79
Lake Pamamaroo	SE Broken Hill - Darling River area NSW	0.66	0.71	0.73
Lake Cawndilla	SE Broken Hill - Darling River area NSW	0.71	0.76	0.79
Stephens Creek Reservoir	Broken Hill NSW	0.69	0.74	0.77
Lake Albacutya	Western NSW	0.79	0.85	0.88
Lake Hindmarsh	Western NSW	0.74	0.79	0.82
Lake Eucumbene	Snowy Mountains, NSW	0.81	0.87	
Cataract Reservoir	West of Sydney NSW	0.92	0.98	
Manton Reservoir	South of Darwin NT	0.87	0.93	
Mundaring Reservoir	East of Perth, WA	0.93	1.00	
Blue Lagoon	Gippsland, eastern Victoria	0.88	0.94	
Lake Wyangan South	Griffith, central NSW	0.77	0.82	
Rifle Creek Reservoir	Mount Isa, Queensland	0.64	0.68	
Lake Albert	SE South Australia	0.81	0.87	
MEAN		0.78	0.83	

Class A data is for unguarded pans (1) and pans equipped with standard bird guard (2), sunken pan coefficients for standard Australian sunken pan. Data from Hoy & Stephens (1979) and Australian Water Resources Council (AWRC 1970). Lake evaporation measured by thermal balance.

The data demonstrate the potential for error in applying an average coefficient to a specific location. Lakes have large heat storage capacity and mean temperatures which vary little on a diurnal basis. In comparison, evaporation pans contain very small quantities of water, hence their heat storage capacity is small and mean temperatures show wide diurnal variation. Therefore pan evaporation depends predominantly on present weather while lake evaporation is more strongly influenced by antecedent weather (Edgeloe *et al* 1987). For this reason even a well calibrated above ground pan cannot be used with any confidence to measure lake evaporation over short periods. Monthly coefficients are the shortest period routinely reported (for example WMO 1966, Kohler 1954).

Class A pans are mounted above ground. This configuration accentuates the effects of radiation from the pan walls and heat transfer from the air. Sunken pans eliminate many of these problems with aerodynamic and radiation properties which approximate those of a lake. They have therefore been widely used to estimate open water evaporation (Kohler 1954, WMO 1966, AWRC 1970, Brutsaert 1982) and evapotranspiration

(Rijtema 1965). There are numerous sunken pan configurations with little standardisation country to country (WMO 1966). The Australian sunken tank was designed to reduce soil to tank conduction and was widely used before Class A pans became the Bureau of Meteorology standard. It comprised an inner circular metal tank three feet in diameter and three feet deep within an outer tank, the annulus width being six inches. The entire assembly was sunk in the ground approximately flush with the soil surface. Sunken pan to lake coefficients are included in Table 10.2.

Russian sunken pans of 5m diameter (surface area $20m^2$) and 2m depth have pan to lake coefficients which exceed unity when operated under Australian conditions. These pans have no annular water jacket, the tank walls being in direct contact with the soil. Coefficients for Lake Wyangan for a pan operated at Griffith NSW varied from 1.11 to 1.16 (Hoy & Stephens 1979). They found that this tank estimated lake evaporation with similar accuracy to a neighbouring Class A pan. Comparative Russian studies (Gangopadhyaya *et al* in WMO 1966) showed that evaporation from a sunken $20m^2$ tank was 11% to 29% less than a Class A pan over an 11 year monitoring period.

Floating pans represent the ultimate physical model of wetland evaporation. They float within the lake under study. Therefore they are subject to identical average conditions of wind and water temperature. Their obvious disadvantages are difficulty of use and potential error from wave slop. Neuwirth (1973 cited Winter 1981) showed that a floating pan maintained at a similar thermal regime to a lake evaporated 22% less water (over 0.5 yr) than a Class A pan operated under similar (mid lake) meteorological conditions. Published studies of floating pans typically describe large triangular rafts whose orientation changes with the wind and which employ elaborate wave damping construction (WMO 1966). In large ($>3\text{-}4km^2$) lakes WMO (1966) recommended that floating pans be located greater than 200m from any shore. There appears to be little literature on the use of these pans in small lakes. Clearly a central position is best, but empirical methods employing wind run can provide excellent estimates of evaporation for small lakes using shore based instruments (Winter *et al* 1995). This suggests that over longer integration periods, the position of a floating pan within a small lake may not be critical.

The floating pan described in Chapter 5 was designed to be as aerodynamically simple as possible. Due to the large water fowl population the pan had to be operated with a bird guard however this was of custom design with large (100 by 100 mm) mesh. For the purposes of the water balance in East Lake, the floating pan coefficient was assumed to be unity, the assumption being that any over estimate from pan heating would be balanced by the effect of the bird guard. If anything the floating Class A pan probably slightly under estimates East Lake evaporation; however, these errors were assumed to be small given that the lake is small, irregularly shaped, with large sections frequently in shade or protected from the wind. Certainly floating pans are most likely to nearly approximate lake evaporation (McKay & Stichling 1961). In Finland where floating GGI-3000 pans were operated in four lakes, floating pan evaporation was taken as the standard (Järvinen 1978).

All Bureau of Meteorology pans operated in Australia have standard bird screens. A 'Bureau Standard' screen was fitted to the pan operated at the UWA Field Station. Under various Australian conditions these screens have been found to reduce monthly evaporation by about 4 to 8%, mean 6.6% (van Dijk 1985). The standard screen consists of a 300mm high cylindrical frame covered with chicken wire with a mesh aperture of about 18mm. The floating pan used in East Lake had a conical guard with a mesh aperture of 100mm (Figure 5.2). Compared to a standard guard, this was assumed to have minimal attenuation of evaporation. The total error introduced by setting the floating pan to lake coefficient as unity is probably a few percent. This is of similar magnitude to the accepted error in other mass components measured directly such as rain gauge catch and artificial maintenance flow meter data.

In addition to bird guards, other nearby obstructions and even small physical barriers can strongly influence evaporation from any pan flush with a land or water surface. The resulting small changes in surface roughness can have a large influence on the flow of air over a small pan. With sunken pans Bonython (1950) cited Rijtema (1965) reported that a drop of 50mm water height in the pan reduced measured evaporation by 15%. Raft mounted Class A pans were used at three locations on Lake Mead (forming the Nevada - Arizona border) over the period 1937 to 1953. The rafts were large structures with extensive anti wave and splash baffles. These baffles can be an additional source of error in that they impede circulation resulting in warmer water between the baffle and the pan (Winter 1981). Mean annual floating pan to lake coefficients calculated from data reported by Harbeck *et al* (1958) vary from 0.79 to 0.98 over the period 1941-1953. In Saskatchewan McKay & Stichling (1961) computed an average summer coefficient of 0.93 over four months using a 'two chamber' floating pan, mounted on a large raft similar to those used at Lake Mead. In both these cases the influence of large rafts and associated structures resulted in coefficients less than unity.

10.3 PAN to LAKE VARIATION ON THE SWAN COASTAL PLAIN

As part of this study, a Class A pan was operated close to Perry Lakes at the UWA Agricultural Field Station. This pan was calibrated against the floating Class A pan in

East Lake. Monthly pan coefficients were calculated for Perry Lakes using both the Field Station pan and the Bureau of Meteorology pan at Perth Airport. Water temperature and wind run were also measured at both locations. Table 10.3 shows the differences in mean monthly maximum and minimum temperatures for Perry Lake East and a nearby Class A pan. Maximum day time temperatures in the field station pan are very similar to those in the lake suggesting that pan temperature may be attenuated by the proportionately greater cooling effect of evaporation itself. At night evaporation plays a diminished role. The data show that night time radiative cooling has a much greater effect on the pan than the lake.

Table 10.3 Mean monthly maximum and minimum temperatures 1997

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ag pan min	18.8	19.5	16.3	16.7	12.7	11.9	7.6	9.6	12.0	13.4	15.1	17.4
Floating pan min	20.7	21.1	18.2	18.4	14.5	13.7	10.6	13.0	15.8	17.9	18.5	19.3
Ag pan max	32.8	31.6	28.0	25.8	20.1	18.6	16.6	19.2	22.7	26.2	27.7	30.1
Floating pan max	32.2	31.4	28.6	25.4	20.7	18.1	16.4	18.7	22.3	25.8	28.5	32.5

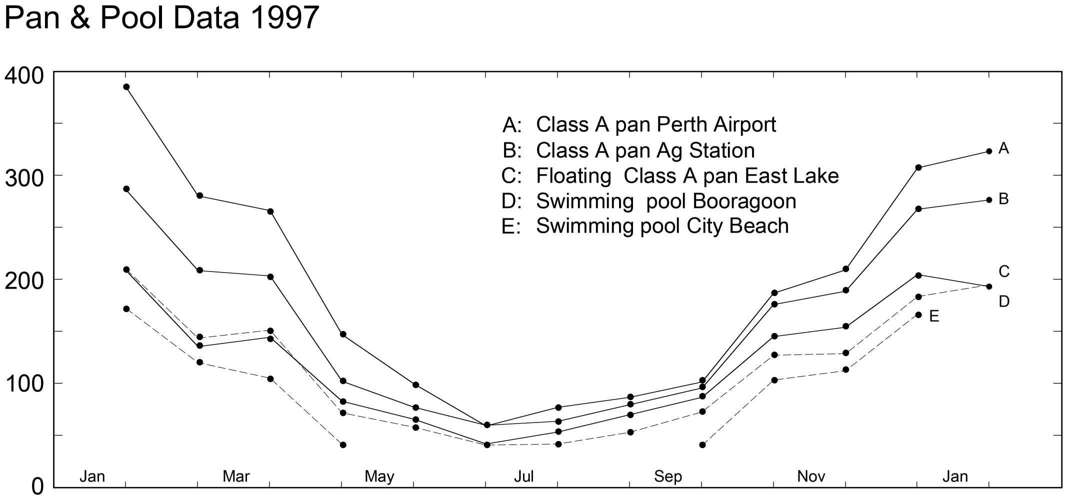
Data from 'Sixes' max-min thermometers in Ag Station Class-A pan and Perry Lakes floating pan

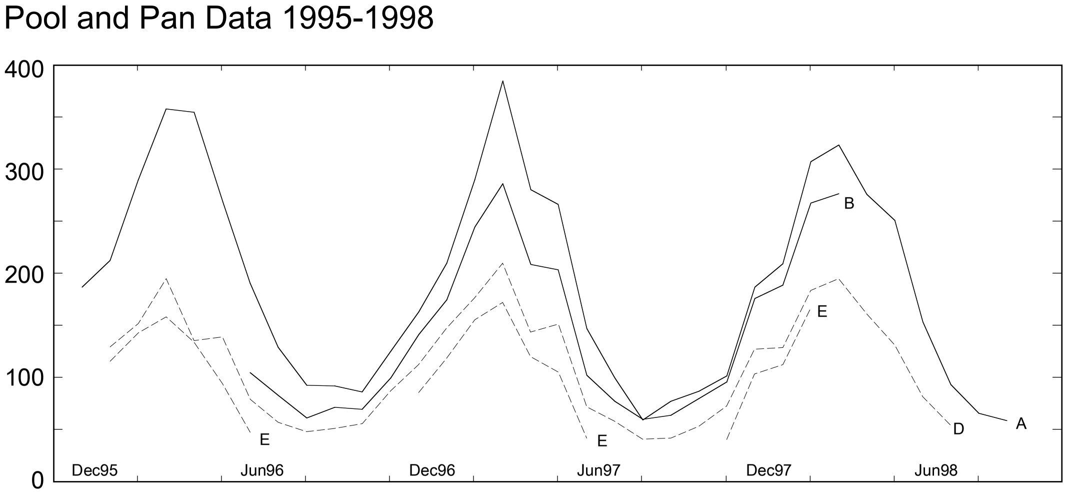
Small wetlands like East Lake tend to be somewhat sheltered, occurring within topographic depressions and usually surrounded by trees. Class A pans on the other hand are recommended to be operated in open areas with no nearby obstructions. The UWA Agricultural Field Station site is less sheltered than Perry Lakes where the floating pan was operated in East Lake. The pan site at Perth airport is completely open with fetches of several kilometres. Table 10.4 shows monthly mean daily wind run for these three pan sites plus the Swanbourne automatic weather station (AWS) located on the coast 2km southwest of Perry Lakes.

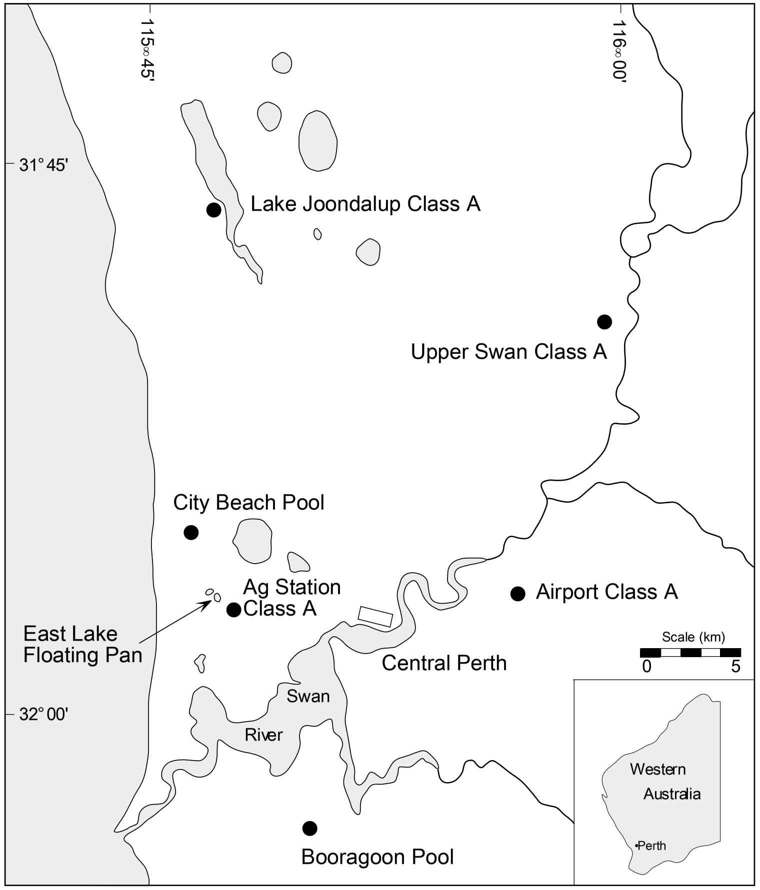
Table 10.4 Mean daily wind run (km) at 2m 1997

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East Lake	141	136	136	92	105	94	86	109	101	143	139	146
Field Station	170	159	157	85	94	76	72	91	86	135	132	168
Airport	333	316	323	218	233	154	172	198	185	268	205	249
Swanbourne	471	457	458	345	401	397	359	405	350	441	433	466

During winter when the predominant wind is from frontal systems approaching from the west, the fetch on East Lake is such that average daily wind run exceeds that at the agricultural station. In summer when east winds predominate, the situation is reversed. The Swanbourne AWS is located atop coastal dunes and receives significantly greater wind run than the other sites. It is obvious from wind data alone that pans operated in different nearby locations will have significantly differing annual evaporation.


Pan & Pool Data 1997


Pool and Pan Data 1995-1998



Evaporation Pans & Pools

Figure 10.1

10.4 SWIMMING POOLS AS SIMPLE MODELS OF SMALL WETLANDS

Evaporation pans are often difficult to operate in urban areas due to vandalism and other problems. In cities like Perth however there are abundant below ground domestic swimming pools which mimic sunken evaporation pans. Given that the typical 'back yard' pool suffers from varying degrees of shading and wind obstruction it still seemed possible that if properly calibrated, such pools could function as long term secure analogues of small wetlands.

Two back yard pools were monitored in City Beach and Booragoon (Figure 10.1). Both were of a generally northerly aspect such that the pools were as far as possible not in house shade. In both cases there was a certain amount of shading from vegetation which varied seasonally. The wind flow in a typical suburban back yard is attenuated by buildings, fences and vegetation. No meaningful wind run data was collected from either site[1]. A standard 4 inch (100mm) funnel rain gauge was mounted at 0.5m height immediately adjacent to each pool.

Evaporation was calculated using two methods. At both pools a calibrated flow meter installed in a dedicated garden hose recorded all water used to top up the pool levels to a reference depth. Evaporation was also measured directly on a daily basis. Stilling wells were mounted on both swimming pool steps. Depth was measured with a mm rule. The Booragoon pool had a 450mm concrete surround. Rain falling on the surround was included in the calculations. The City Beach pool was not useable in winter due to run off from an adjacent patio during high rain events. In both cases the pools were rarely used for swimming. Data gaps on swimming days were estimated using coefficients developed for the Ag Station and Perth Airport pans.

The data (Table 10.5) suggests that swimming pools do work as surrogates for large sunken evaporation pans. In both cases the pools had a maximum depth of about 1.8m and surface to volume ratios much smaller than East Lake. As with many sunken pans and tanks, the correlation coefficient with natural wetlands (in this case East Lake) approach or exceed unity. Given the limitations imposed by disrupted aerodynamics and measurement difficulties, we were surprised at how well the pools worked. Certainly a pool in a large open yard with minimal shading and wind flow disruption could be calibrated to act as a long term secure measuring device for a nearby urban wetland. A Class A pan located close to the wetland of interest however is much easier to use and if well calibrated will probably provide equally accurate estimates of open water evaporation for periods of a month or longer.

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[1] An anemometer left at the Booragoon site to collect annual wind run became the victim of an over enthusiastic creeping vine

Class A Pan & Pool Statistics

Table 10.5

Month	East Lake Floating Class A		Ag Station Class A		Perth Airport Class A		Booragoon Pool		City Beach Pool			Pan:Lake Coefficients		
1997	Total (mm)	Daily (mm)	Total (mm)	Daily (mm)	Total (mm)	Daily (mm)	Total (mm)	Daily (mm)	Total (mm)	Daily (mm)	Ag Station	Airport	Booragoon	City Beach
January	208.5	6.7	286.2	9.2	385.0	12.4	209.6	6.8	171.8	5.5	0.73	0.54	0.99	1.21
February	135.1	4.8	208.4	7.4	280.6	10.0	143.2	5.1	119.8	4.3	0.65	0.48	0.94	1.13
March	144.2	4.7	203.1	6.6	266.2	8.6	150.9	4.9	104.8	3.4	0.71	0.54	0.96	1.38
April	82.4	2.7	101.6	3.4	147.0	4.9	71.5	2.4	41.1	1.4	0.81	0.56	1.15	2.00
May	65.2	2.1	76.7	2.5	99.2	3.2	57.5	1.9			0.85	0.66	1.13	
June	41.5	1.4	59.3	2.0	58.8	2.0	40.4	1.3			0.70	0.71	1.03	
July	53.3	1.7	63.5	2.0	77.0	2.5	41.4	1.3			0.84	0.69	1.29	
August	69.6	2.2	79.7	2.6	86.4	2.8	52.6	1.7			0.87	0.81	1.32	
September	86.9	2.9	95.8	3.2	101.2	3.4	72.1	2.4	39.8	1.3	0.91	0.86	1.21	2.18
October	144.9	4.7	175.8	5.7	186.4	6.0	127.0	4.1	102.9	3.3	0.82	0.78	1.14	1.41
November	154.1	5.1	188.4	6.3	209.2	7.0	128.4	4.3	112.0	3.7	0.82	0.74	1.20	1.38
December	204.5	6.6	267.8	8.6	307.4	9.9	183.2	5.9	166.5	5.4	0.76	0.67	1.12	1.23
Total	1390.2		1806.3		2204.4		1277.8		Annual Mean Coefficient		0.79	0.67	1.12	1.49
1998														
January	192.9	6.2	276.7	8.9	323.4	10.4	194.7	6.3						

Notes

All land based pans fitted with standard Bureau of Meteorology bird guards

Floating pan fitted with wide aperture custom guard (refer text)

10.5 EVAPORATION ON THE SWAN COASTAL PLAIN

Evaporation records for Perth are limited. Unfortunately due to differing measurement locations and methods, data sets over extended time frames are impossible. Evaporation was measured adjacent to Kings Park from 1953 to 1966 using a below ground tank evaporimeter. In 1967 observations were shifted to Perth Airport and instrumentation changed to a World Meteorological Organisation standard above ground Class A pan. As noted above, heat transfer from soil to sunken pans and air to Class A pans results in vastly different mean and seasonal correlation coefficients with evaporation from nearby open water.

McFarlane (1984) compared evaporation data over twelve months during 1981-1982 between Class A pans operated in central Perth, Upper Swan and Perth Airport (refer map Figure 10.1). On an annual basis evaporation at Perth Airport was 18% greater than in central Perth. In late summer this difference rose to about 30%. Annual data from the Upper Swan Research Station for 1974, 1975 and 1978 indicated that evaporation there was about 12.5% greater than in central Perth. Congdon (1985) obtained weekly Class A measurements over the period August 1979 to December 1980 from central Perth and a site in Edgewater on the west side of Lake Joondalup. Annual data for 1980 showed no statistical difference between the two sites with 1705mm of evaporation recorded at Edgewater and 1702mm at Perth. McFarlane (1984) examined the climatic factors influencing evaporation in the Perth area. He found that there were significant differences in temperature, relative humidity and wind run. Evaporation in coastal areas including Perry Lakes have a strong maritime influence in the form of strong summer afternoon sea breezes. Often these are restricted to within a few kilometres of the coast and frequently do not penetrate as far inland as the airport.

Evaporation data from the current study collected over three years is displayed graphically in Figure 10.1. Data for 1997-1998 (the period in which the floating pan operated) is tabulated as Table 10.5. It corroborates the earlier data. For 1997, evaporation from the Perth Airport pan (2204.4mm) exceeded the Field Station pan evaporation (1806.3mm) by 22.0% and East Lake (1390.2mm) by 58.6%.

The data also shows clearly why annual average wetland evaporation calculated from 'rule of thumb' pan coefficients are prone to error. The annual mean coefficient for East Lake varies by 12% between the Field Station and Airport pans. Calculated coefficients for individual pans also exhibit even larger seasonal variations . Applying an annual coefficient on a monthly basis incurs potential errors of up to about 15%. Such errors are implicit in a number of earlier water balance studies of Swan Coastal Plain wetlands

(Table 10.6). Lake evaporation in these studies would have been highly prone to error. The Perry Lakes data show that evaporation from coastal plain wetlands can vary significantly from that at Perth airport.

Table 10.6 Pan coefficients in Swan Coastal Plain water balances

Lake	Determination of Lake E	Reference
Lake Mariginiup	Annual E taken as 0.8 Perth Class A pan	Hall (1985)
Lake Jandabup	Annual E taken as 0.8 Perth Class A pan	Allen (1979)
North & Bibra Lakes	Annual E based on Perth Class A pan & coefficient from Mundaring Reservoir	Congdon (1985)
Mason Gardens & Shenton Park Lake	Annual E based on Perth Class A pan & coefficient from Mundaring Reservoir	McFarlane (1984)

Perth Class A pan refers to the Perth airport pan

Mundaring Reservoir is a deep fresh water body on the Darling Plateau with a climate significantly different to that on the Swan Coastal Plain. Peel Inlet is a large coastal estuary subject to further error as evaporation from saline waters is approximately 8% less than for fresh water (Walker 1973). Both would have vastly greater heat storage abilities compared to small shallow coastal lakes. They also have widely differing rainfall. Congdon (1985) found a strong inverse relationship between rainfall and evaporation on the Swan Coastal Plain. At the time however these represented the only published pan to water body coefficients for the Perth area (Table 10.7).

Table 10.7 Published lake to pan factors prior to Perry Lakes

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mundaring	1.02	1.06	1.12	1.18	1.15	1.18	1.01	0.91	0.81	0.78	0.79	0.94	1.00
Peel Inlet	0.6	0.6	0.7	0.8	0.9	1.0	1.0	1.0	0.8	0.8	0.7	0.7	0.8

Mundaring Reservoir data: Hoy & Stevens (1979)
Peel Inlet data: Black & Rosher (1980) cited Congdon (1985)

Attempting to apply these to a balance at Lake Joondalup, Congdon (1985) estimated that annual groundwater flux (calculated as a net input residual) might be anywhere from 8% to 16% of the total annual flux.

The Perry Lakes data presented here represents one year for one wetland. Truly useful data can only be obtained from many years of consistent monitoring. Despite this, they are the only accurate lake-pan coefficients ever developed for Swan Coastal Plain wetlands. Due to their shallow depth, coastal wetlands have a low heat storage. Therefore the lake to pan phase lag should be much less pronounced than with deep water bodies and the errors from applying pan coefficients on a monthly basis should be reduced. This study represents the first attempt to accurately measure evaporation from a Swan Coastal wetland and provide accurate coefficients tied to the Bureau of Meteorology pan at Perth Airport.

10.6 REVIEW OF EMPIRICAL METHODS FOR MEASURING EVAPORATION

Despite the general difficulty in measuring evaporation, there are more (and varied) methods of estimating evaporation than any other component in the hydrologic cycle. This is largely because evaporation is directly controlled by many more easily measured parameters, almost always working in combination. Empirical methods are derived from experience and experiment. As such they are site specific. Many were derived for northern hemisphere sites. Many include empirically derived constants which may be modified for use at other sites. Empirical methods are attractive primarily because measuring evaporation or evapotranspiration directly is extremely difficult. Empirical methods allow E or ET or PE to be estimated by utilising other, more easily measured parameters. In many cases these parameters can be measured in the general vicinity and where they are routinely measured by meteorological stations, permit historical estimates to be constructed. These parameters include air and water temperature, humidity, wind, turbulence and solar radiation.

Turbulent Diffusion

Best known is the direct or eddy correlation method. Turbulent fluxes of water vapour, momentum and sensible heat are determined from co-variances. In practice at any given time or location the velocity field and vapour content cannot be quantified. Instead dependent variables are decomposed into mean and turbulent components.

Under steady conditions over a uniform surface the Reynolds or eddy flux is:

$$E = \overline{\rho w' q'} \qquad \text{(Brutsaert 1982, eqn 3.74)} \qquad (10.1)$$

where

E evaporation flux at the surface (kg m^{-2} sec^{-1})

ρ density, comprising density of water vapour plus density of air (kg m^{-3})

w' turbulent component of the vertical velocity (m sec^{-1})

q' turbulent component of the specific humidity (kg water per kg air)

In practice, methods based on turbulent fluxes have very stringent instrumentation requirements (Brutsaert 1982 p191), which until recently, precluded their use in routine field studies. In practice such studies have relied instead on empirical or mean profile methods (W. Scott pers com). Now robust krypton hygrometers and sonic anemometers facilitate direct measurement of evaporation using eddy covariance (D. Rosenberry pers com).

Mean Profiles Methods

These relate the exchange of water vapour between a water surface and the atmosphere using measurements of related parameters. The best known implementation is the mass transfer method. Extensive theoretical treatments are contained in Brutsaert (1982). Marciano & Harbeck (1954) and Harbeck *et al* (1958) provide the theoretical basis for the derivation of the basic formula used in the Lake Hefner and many subsequent studies, which can be applied using simple instrumentation. Mean profile methods are all based on boundary layer theory. A boundary layer is a general term for the layer of air adjacent to a surface (Oke 1987 p400). Where a fluid is moving close to a solid the boundary layer is a region of concentrated velocity and shear stress close to the solid (Middleton 1965 cited Gary *et al* 1974). It is both time and scale dependent (Oke 1987 p6), therefore in real world situations the extent of a boundary layer is determined by the extent to which the properties of the main flow are affected by the surface or object. A boundary layer can be divided into a roughness or turbulent layer extending above the tops of the surface roughness features and a laminar layer which is in direct contact with the surface (Oke 1987 p6).

During flow over a lake surface and while transfers are occurring, momentum, heat and moisture change with different boundary layers. Evaporation itself is a boundary layer phenomenon. The turbulent transport of momentum and water vapour are identical and are considered to have similar coefficients of eddy transport (Marciano & Harbeck 1954).

On this basis a workable field equation was derived from Sverdrup (1937)

$$E = \frac{0.623 \rho k_0 u_f \left(e_0 - e_z \right)}{P \left[\ln \left(\frac{z + z_0}{\delta_l + z_0} \right) + \frac{k_0 \delta_l u_f}{D} \right]} \tag{10.2}$$

where

D	molecular vapour diffusivity (m^2 sec^{-1})
E	evaporative flux (kg m^{-2} sec^{-1})
P	atmospheric pressure (pascals)
e_0	vapour pressure of air at the temperature of the water surface (pascals)
e_z	vapour pressure of air at height z (pascals)
k_0	Von Kármán's constant (dimensionless, relates the mixing scale to height)
u_f	friction velocity (m sec^{-1})
z, z_0	height above water surface, roughness parameter (m)
δ_l	thickness of the laminar film (m)
ρ	density of the air (kg m^{-3})

Marciano & Harbeck (1954) reduced this to a simple form which continues to be used as a basic mass transfer equation of general form

$$E = Nu_z\left(e_0 - e_z\right) \tag{10.3}$$

where

N	empirically derived coefficient of proportionality (dimensionless)
u_z	average wind speed at height z (m sec^{-1})
e_o	saturation vapour pressure, usually at temperature of the water surface (mb)
e_a	vapour pressure of the air (mb)

Equation 10.3 relates evaporation to easily measured parameters which reflect the movement of air over a water surface and the capacity of the air to take up moisture from that surface. The coefficient N represents the combined effect of all other factors influencing evaporation (Hughes 1967). It is site specific and empirically derived.

Empirical Methods

Empirical methods rely on easily measured meteorological parameters to estimate potential evaporation (PE) or potential evapotranspiration (PET). Brutsaert (1982) defines potential evapotranspiration as the 'maximum rate of evapotranspiration from a large area covered completely and uniformly by an actively growing vegetation with adequate moisture at all times'. As Brutsaert points out however this botanically biased concept is difficult to apply because of numerous biological effects such as stomatal impedance and stage in the growth cycle. The concept is further complicated by meteorological effects. After rain or heavy dew fall, air over a vegetated area will be completely saturated, leading to Brutsaert's suggestion that potential evaporation is a preferable term. Clearly there is little difference between thoroughly wetted soil and vegetation and an open body of water. It is on this basis that many equations originally developed for measuring potential evapotranspiration can be adapted directly for measuring open water evaporation.

10.7 FIELD COMPARISON OF MEAN PROFILE & EMPIRICAL EQUATIONS

Monthly evaporation was computed for 1997 using ten mean profile and empirical equations (Table 10.8). The methods chosen were identical to those evaluated by Winter *et al* (1995) for Williams Lake, Minnesota. The results allow a direct comparison with this Northern Hemisphere study, and more importantly provide a basis for evaluating their applicability to Swan Coastal Plain wetlands. This study and the Williams Lake study follow in the tradition of pioneering American work in the 1950's at Lake Hefner and Lake Mead (Harbeck 1954, Harbeck *et al* 1958) where empirical techniques were tested against free water evaporation determined by thermal balance. More recent similar studies such as Warnaka & Pochop (1988) are compromised by using only pan coefficients to estimate wetland evaporation.

Many empirical equations have been developed over many years. Those tested here are representative of the principal approaches taken but are by no means a complete suite. New approaches or modifications of older techniques appear regularly in the literature. For example equations recently presented by de Bruin & Lablans (1998) and Xu & Singh (2000) may prove of interest to Swan Coastal Plain researchers.

Putting aside for one moment the inherent inaccuracies in empirical techniques, a principal practical problem has always been the cost and logistics of gathering information requiring somewhat sophisticated instrumentation. This includes such parameters as air temperature, wind run, vapour pressure or relative humidity and solar radiation. Ideally these should be measured in the central portion of the lake using rafts or other installations. Commonly however, data is collected from a land station adjacent to the lake, or (more frequently) from a government weather station many kilometres from the study lake. Winter *et al* (1995) showed that substitute data from adjacent and distant stations can in some cases be used to provide acceptable evaporation estimates. Clearly the substitute data and techniques will to a certain extent be site specific.

At Perry East wind and lake surface temperature were collected in the centre of the lake, wet and dry bulb temperatures were collected at the isotope experiment site adjacent to the lake, and solar data was collected at the Swanbourne AWS site 3km to the southwest. Normally wet and dry bulb data are collected over the water surface at typically 1-2m height (Winter *et al* 1995). Shore based data was collected here due to the requirement for daily maintenance of the wet-wick wet bulb thermistor. Equations requiring air temperature (T_a) or parameters adjusted to mean daily air temperature saturated vapour pressure (e_o) and saturated vapour density (SVD), were calculated using the shore based dry bulb data and the lake surface temperature (T_o), taken to represent air temperature just above the water surface.

Empirical methods can be assessed on their ability to accurately estimate evaporation over an extended period , say annually or their ability to estimate evaporation over shorter periods (seasonally, monthly, daily). Apart from the mass transfer method, empirical equations are generally applied without calibration against other techniques. At Perry East equations were ranked on the basis of best 'annual' estimate over 377 days (December 22 1996-January 3 1998, being balance periods 20-50) and best estimate over the individual balance periods (average period 12 days) after equations were calibrated against the floating pan evaporation for the same period.

Table 10.8 Equations Tested for Estimating Potential Evapotranspiration (PET) and Evaporation, Perry Lake East

Method	Equation	Application	Ref
Makkink	$PET = 10[(0.61(s/(s+\gamma))(Q_s/L)) - 0.012]$	Monthly PET (Netherlands)	1
Stephens-Stewart	$PET = 10[(((0.0082T_a) - 0.19)(Q_s/1500))2.54]$	Monthly PET (Florida)	1
Jensen-Haise	$PET = 10[((((0.014T_a) - 0.50)(Q_s))0.000673)2.54]$	PET (Nebraska) >5 days	1
Hamon	$PET = 10[(0.55(D/12)^2(SVD/100))2.54]$	Daily PET	2
DeBruin	$PET = 10[((\alpha/\alpha - 1))1.141(\gamma/(s+\gamma))((3.6 + 2.5(U_3))(e_0 - e_a)))/L]$	PET 10+ days	3
Mass Transfer	$E = 10[NU_2(e_0 - e_a)]$	Evaporation	4
Penman	$PET = 10[[(s/s+\gamma))(Q_n - Q_x) + (\gamma/(s+\gamma))((15.36(0.5 + 0.01U_2))(e_0 - e_a))]/L]$	PET 10+ days	5
DeBruin-Keijman	$PET = 10[((s/(0.95s + 0.63\gamma))(Q_n - Q_x))/L]$	Daily PET	6
Priestley-Taylor	$PET = 10\alpha(s/(s+\gamma))[(Q_n - Q_x)/L]$	PET 10+ days	7
Brutsaert-Stricker	$PET = 10[(2\alpha - 1)(s/(s+\gamma))(Q_n - Q_x) - (\gamma/(s+\gamma))[0.26(1 + 0.86U_2)(e_0 - e_a)]]/L$	Daily PET	8

Where: $s + (s + \gamma)$ and $\gamma / (s + \gamma)$ are parameters derived from *s* (slope of the saturated vapour-pressure curve) and γ (the psychrometric contant); α is the Priestley-Taylor constant (dimensionless); Q_n is net radiation (cal cm^{-2} d^{-1}); Q_s is solar radiation (cal cm^{-2} d^{-1}); Q_x is change in stored heat within the lake (cal cm^{-2} d^{-1}); U_x wind speed (m sec^{-1}) at height x(m) above the water surface; e_0 is saturated vapour pressure (mb); e_a is vapour pressure at temperature and relative humidity of the air (mb); *SVD* is saturated vapour density at mean air temperature (g m^{-3}); T_a is air temperature °C (except for Jensen-Haise & Stephens-Stewart equations which require degrees Fahrenheit); *L* is latent heat of evaporation (cal g^{-1}); *N* is the mass transfer coefficient (dimensionless); *D* is hours of daylight at latitude of the lake.

Notes

General format modified from Table 1 of Winter *et al* (1995).
Equations listed from best to worst fit (refer Table 10.10), All equations return *E* as mm/day
DeBruin, Penman, DeBruin-Keijman and Brutsaert-Stricker in their original form return calories mm^{-2} d^{-1}, division by *L* returns mm d^{-1}

References: (1) McGuinness & Bordne 1972; (2) Hamon 1961; (3) DeBruin 1978; (4) Harbeck *et al* 1958; (5) Jensen *et al* 1974; (6) DeBruin & Keijman 1979; (7) Stewart & Rouse 1976; Brutsaert & Stricker 1979

Table 10.9 shows evaporation over 377 days using uncalibrated equations. Exact form of each equation is that which produced the best calibrated fit (shown with an asterisk in Table 10.10 and plotted in Figure 10.2). On this long term basis, the Penman and DeBruin-Keijman methods were within 1.1% of the floating pan total with the Penman under estimating by only 1.1mm.

Table 10.9 Annual Evaporation Estimates Using Uncalibrated Equations

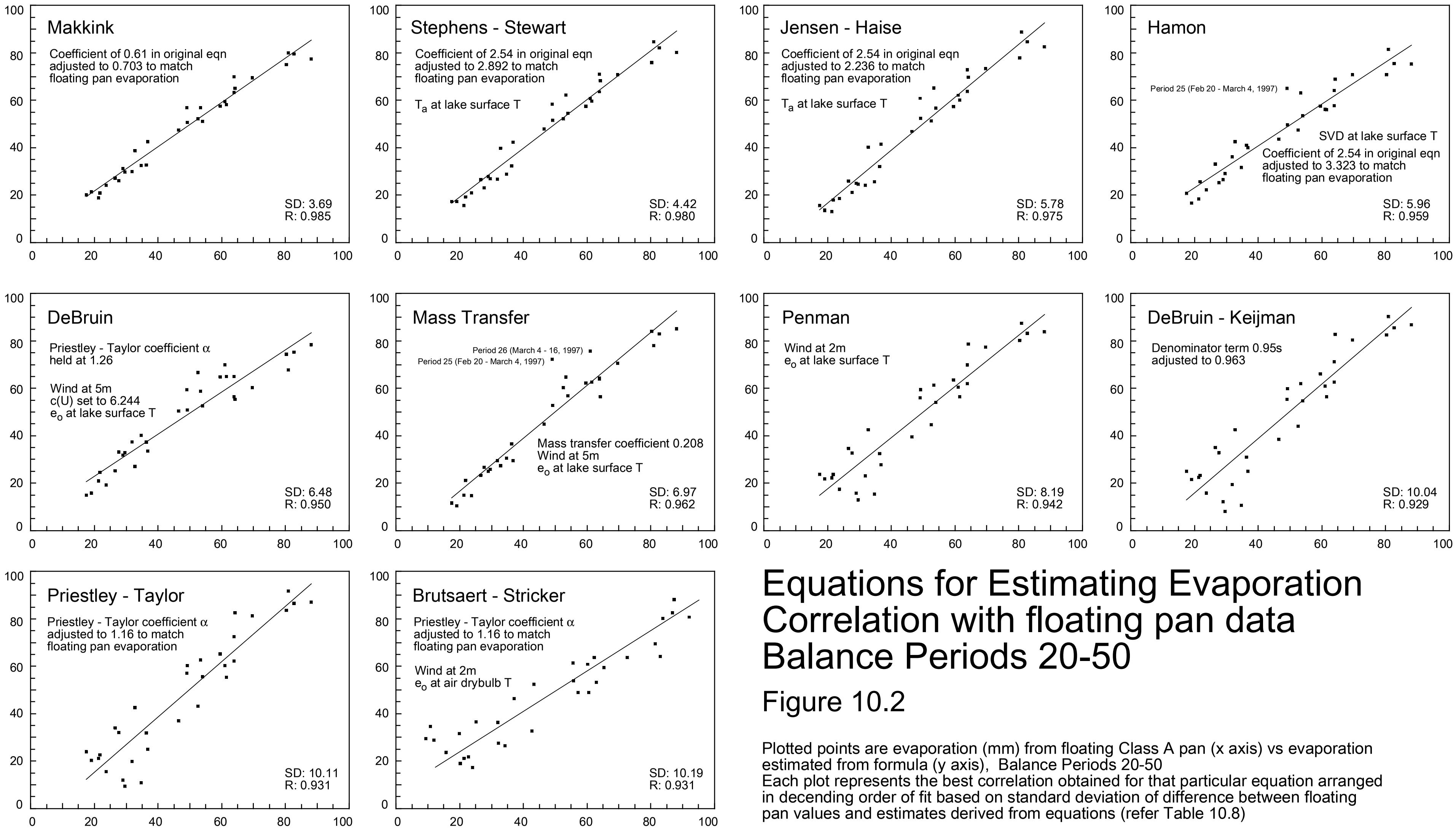
Method	Makkink	Stephens-Stewart	Jensen-Haise	Hamon	DeBruin
Total E (mm)	1267.1	1288.8	1667.5	1121.7	613.1
Floating Pan	86.3%	87.8%	113.6%	76.4%	41.8%
Method	**Mass Transfer***	**Penman**	**DeBruin-Keijman**	**Priestley-Taylor**	**Brutsaert-Stricker**
Total E (mm)	1467.6	1466.5	1483.2	1590.4	1908.1
Floating Pan	100.0%	99.9%	101.1%	108.4%	130.0%

Total evaporation December 22 1996-January 3 1998 (Balance Periods 20-50) compared to floating pan total for this period of 1467.6mm. * Mass Transfer method cannot be compared because it requires calibration of the Mass Transfer coefficient N against an independent calculation of evaporation. The Mass Transfer method thus calibrated can only be compared on a balance period basis.

Comparing methods on a balance period basis essentially shows how well the method copes with seasonal variations. All equations are essentially linear in form and can be adjusted against evaporation measured independently either by adjusting an existing coefficient or introducing a local coefficient of proportionality. Each equation was adjusted to produce a total evaporation of 1467.6mm. Balance period totals were plotted against the corresponding floating pan data (Figure 10.2).

Seasonal fit was measured in two ways. For each method, the difference between the floating pan total and the equation total was computed for each balance period. Methods are ranked in Table 10.10 on the basis of the standard deviation of these differences, the lower the standard deviation, the better the fit. Equations can also be ranked on the basis of the linear regression coefficient of determination which produces a similar (but not identical) ranking. It is evident from Table 10.10 that much better estimates were obtained where T_a or e_o were adjusted to lake surface temperature. Within individual equations the height at which wind data was recorded however was of little practical consequence. Figure 10.2 is a graphical representation of the best fit for each of the ten equations tested.

The extent to which seasonal or other variations contribute to overall correlation was examined by calibrating equations against corresponding floating pan data on a monthly basis (Figure 10.3). It is evident from the graphs and the standard deviations of the monthly coefficients that those equations which displayed the best correlation on a balance period basis also display the smallest seasonal variations. The Mass Transfer method



Equations for Estimating Evaporation Correlation with floating pan data Balance Periods 20-50

Figure 10.2

Plotted points are evaporation (mm) from floating Class A pan (x axis) vs evaporation estimated from formula (y axis), Balance Periods 20-50
Each plot represents the best correlation obtained for that particular equation arranged in decending order of fit based on standard deviation of difference between floating pan values and estimates derived from equations (refer Table 10.8)

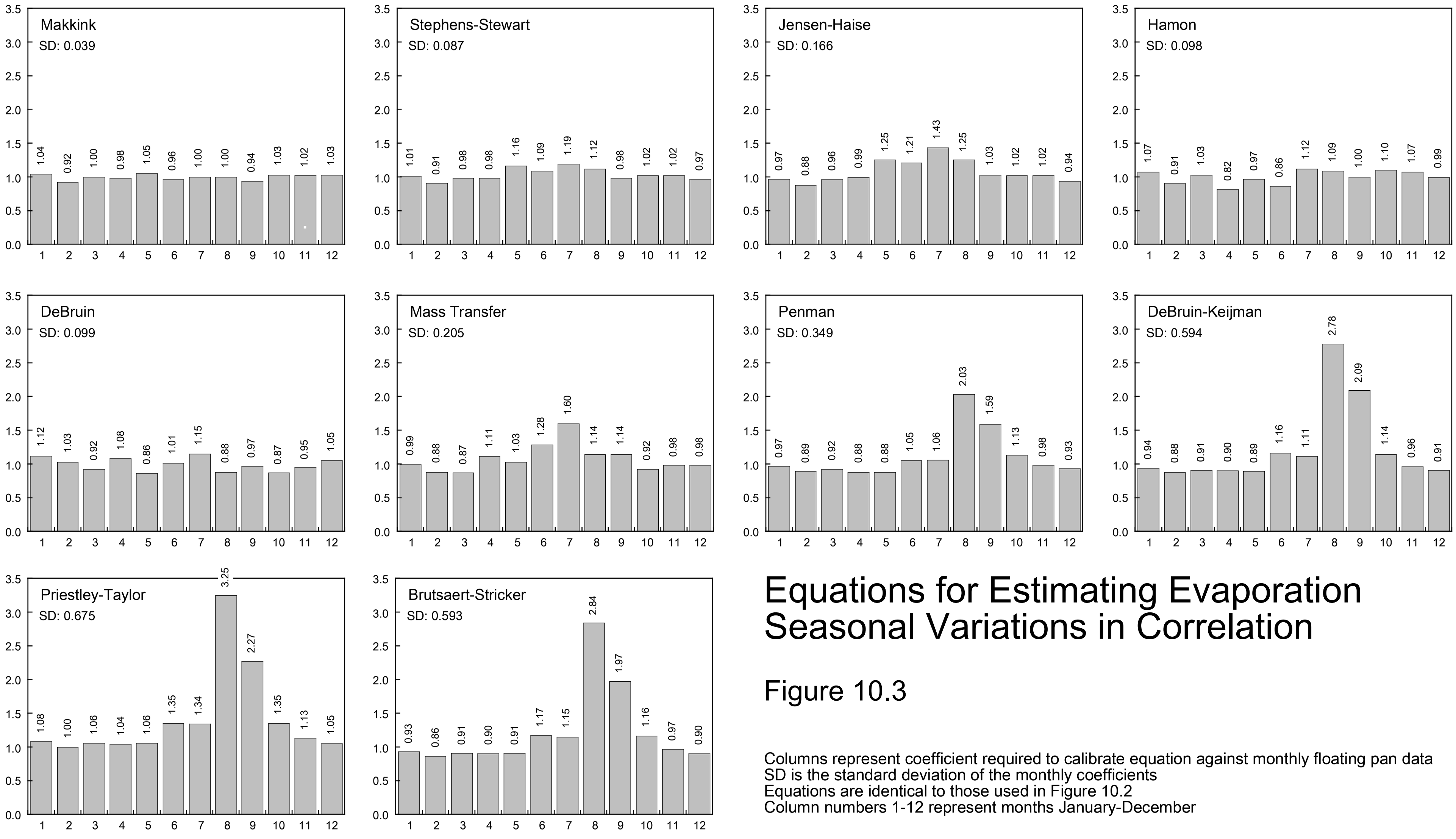
(Table 10.8) displays diminished correlation during June and July, while the Penman, Debruin-Keijman, Priestley-Taylor and Brutsaert-Stricker all display diminished correlation during July and August where they grossly under estimate evaporation. These last four equations have an underlying common form (Table 10.8) based on net radiation and changes in stored heat (Q_n-Q_x) which at Perry East, provide poor estimates of evaporation during late winter.

Table 10.10 Analysis of Empirical Equations for Estimating Evaporation

Method	Modification	Wind	PT Coeff	N	Coeff 1	Coeff 2	SD	R
Makkink*	none				0.610	0.703	3.69	0.985
Stephens-Stewart*	Ta at lake surface T				2.540	2.892	4.42	0.980
Stephens-Stewart	Ta at air dry bulb T				2.540	3.249	5.19	0.976
Jensen-Haise*	Ta at lake surface T				2.540	2.236	5.78	0.975
Hamon*	SVD at lake surface T				2.540	3.323	5.96	0.959
DeBruin*	eo at lake surface T	5m	1.260		2.5(U)	6.244(U)	6.48	0.950
DeBruin	eo at lake surface T	2m	1.260		2.5(U)	6.971(U)	6.60	0.949
DeBruin	eo at lake surface T	5m	1.094		2.5(U)		6.75	0.948
DeBruin	eo at lake surface T	2m	1.084		2.5(U)		6.96	0.946
Mass Transfer*	eo at lake surface T	2m		0.208			6.97	0.962
Mass Transfer	eo at lake surface T	1m		0.221			6.98	0.962
Mass Transfer	eo at lake surface T	5m		0.018			7.07	0.963
Hamon	SVD at air dry bulb T				2.540	3.851	7.32	0.936
Jensen-Haise	Ta at air dry bulb T				2.540	2.618	7.60	0.965
Penman*	eo at lake surface T	2m				unity	8.19	0.942
Penman	eo at air dry bulb T	2m				1.047	8.99	0.936
DeBruin	eo at air dry bulb T	5m	1.066		2.5(U)		9.44	0.892
DeBruin	eo at air dry bulb T	2m	1.060		2.5(U)		9.50	0.890
DeBruin-Keijman*	none				0.95s	0.963s	10.04	0.929
Priestley-Taylor*	none		1.160				10.11	0.931
Brutsaert-Stricker*	eo at air dry bulb T	2m	1.0855				10.19	0.931
Brutsaert-Stricker	eo at lake surface T	2m	1.0873				10.25	0.931
Mass Transfer	eo at air dry bulb T	2m		0.289			12.13	0.897
Mass Transfer	eo at air dry bulb T	5m		0.258			12.21	0.897
Mass Transfer	eo at air dry bulb T	1m		0.307			12.55	0.889

Notes: PT is the Priestley-Taylor coefficient, N is the Mass Transfer coefficient, Coefficient 1 is original coefficient of proportionality (refer Table 10.8), coefficient 2 is modified form to achieve calibration against floating pan evaporation. SD is standard deviation (difference against floating pan evaporation), R is the linear regression correlation coefficient, U is wind speed. DeBruin-Keijman coefficient requires *s* (slope of the saturated vapour-pressure curve). Equations marked * are plotted in Figure 10.2

Lake top up pumping appears to detract from equation accuracy. The poor mass transfer correlation for balance periods 25 and 26 and Hamon correlation for period 25 (Figure 10.2) are interpreted to be the result of excessive lake top up pumping and measurement of e_a from shore based instruments. Analysis of day to day evaporation showed that mass-transfer values of approximately twice the floating pan values occurred on days when top up pumping occurred. Pumped water is uniformly about 20.7°C. Where pumping occurred over night, average daily lake surface temperatures were elevated, increasing the value of the term $(e_o - e_a)$. This error is further augmented by measuring e_a from the shore where night time values would be less than if measured over the lake. The correlation between pan and mass-transfer data always showed a slope of the regression line >1 indicating that the mass-transfer method on average tended to over



Equations for Estimating Evaporation Seasonal Variations in Correlation

Figure 10.3

Columns represent coefficient required to calibrate equation against monthly floating pan data
SD is the standard deviation of the monthly coefficients
Equations are identical to those used in Figure 10.2
Column numbers 1-12 represent months January-December

estimate evaporation. This may reflect the use of shore based e_a data which on a daily averaged basis is less than the equivalent data collected over the water.

Clearly where wetlands on the Swan Coastal Plain can be instrumented and independently calibrated, empirical methods such as presented by Makkink (McGuinness & Bordne 1972) which display minimal seasonal variation, can provide reasonable evaporation estimates over extended periods.

10.8 NOTES ON IMPLEMENTATION OF EMPIRICAL EQUATIONS

Hamon

A relatively simple method based on solar radiation (estimated from the theoretical maximum hours of daylight) and humidity expressed as saturated vapour density (*SVD*).

$$PET = [0.55\left(\frac{D}{12}\right)^2\left(\frac{SVD}{100}\right)]2.54 \qquad (10.4)$$

where

D maximum possible hours daylight is $(24/\pi)\omega s$ (10.5)

ωs sunset hour angle in radians, arcos(-tan (site latitude)tan δ) (10.6)

δ solar declination (radians), $0.4093\sin((2\pi/365)J-1.405)$ (10.7)

J is Julian day number

Site latitude is negative in the southern hemisphere. Saturated vapour density (*SVD*) at mean air or water surface temperature (g m^{-3}) was calculated using equation (6.5) of Fritschen & Gay (1979). Daylight hours were calculated from equations (4.4.1)-(4.4.3) of Maidment (1993). *SVD* was calculated from both mean daily air temperature and mean daily water surface temperature which for balance periods 20-50 returned:

SVD @ T_o	1121.7mm	Setting coefficient at 3.32 yields total pan evaporation
SVD @ T_a	968.1mm	Setting coefficient at 3.85 yields total pan evaporation
Floating pan	1467.6mm	

As with the Brutsaert-Stricker method, better results were obtained where air temperature is assumed to be water surface temperature. The Hamon coefficient of 2.54 was adjusted to match total pan evaporation, and yielded good correlation using both methods of calculating *SVD*. The exception again was Balance Period 25 where using *SVD* calculated from shore based air measurements during periods of excessive overnight top up pumping resulted in excessively high evaporation estimates. The Hamon method is extremely simple and when calibrated for a specific wetland appears to provide good estimates with a minimum of instrumentation.

DeBruin

Initial trials using the Priestley-Taylor constant set at 1.26 and wind at any height (1, 2 or 5m) resulted in total yearly values of 30-40% of pan values. This was the poorest correlation using an uncalibrated version of any equation for all methods tested. The original formula uses wind speed at 3m. No attempt was made to interpolate a value for U_3 as the wind profile above Perry East frequently deviates from the theoretical logarithmic wind profile equation (Monteith & Unsworth 1990) because of trees and other obstructions around its perimeter. This was most common in light breezes (wind speed less than about 0.4m sec^{-1}). Under these conditions hourly wind run at 1m and 2m was up to 40% greater than at 5m. The approach taken using the DeBruin equation was to adjust the wind speed coefficient since Perry Lakes is effectively a 'hole' in the tree canopy. Therefore the coefficient 2.5(U_3) in the original equation was felt to be too low. Taking e_o at lake surface T, values of 6.244(U5) and 6.971(U2) were required to achieve calibration (Table 10.10). Almost identical results were obtained adjusting the Priestley-Taylor coefficient α from 1.26 to 1.084 (U_2) and 1.094 (U_5).

The DeBruin plots produce better fits when modelled using polynomial expressions. Evaporation calculated by the DeBruin method during summer are low suggesting that over summer α is also too low. Certainly α does vary both on a daily basis (Katul & Parlange 1992, Parlange & Stricker 1996) and seasonally (DeBruin & Keijman 1979) who found that in Holland α varied from 1.20 to 1.50, with lowest values in mid summer and highest values in spring and autumn. This may contribute to the extreme under estimation of evaporation during August and September in methods such as the Priestley-Taylor and Brutsaert-Stricker.

Mass-Transfer

Detailed analysis of mass-transfer theory are contained in Marciano & Harbeck (1954), Harbeck *et al* (1958). Mass transfer equations relate easily measured meteorological parameters to the exchange of water vapour between a water surface and the atmosphere. The most common form relates evaporation to wind speed and vapour pressure difference. The equation tested at Perry East takes the general form of that developed for Lake Hefner (equation 10.3).

The mass-transfer coefficient N represents numerous difficult to quantify variables including wind variation with height, lake size, water surface roughness, atmospheric stability, barometric pressure and density and kinematic viscosity of the air (Harbeck 1962). The principal practical difficulty with the mass-transfer method is that N tends to be unique to each lake. Calibration requires evaporation to be determined over at least one year by an independent means (typically a thermal balance), *N* being obtained by dividing the independently determined value of evaporation by the product $u_x(e_o - e_a)$. At Perry East *N* was determined using the annual floating pan evaporation over the period December 22 1997-January 3 1998.

Winter *et al* (1995) experimented calculating e_o at air temperature and using air temperature and humidity collected from the centre of the lake and the shore. In that particular study (Williams Lake, Minnesota, area 36 ha) best results were obtained using e_o at lake surface temperature and air and humidity data collected from the centre of the lake. At Perry Lakes air temperature and humidity were collected only from the shore however Perry East is typically <0.1 the area of Williams Lake which suggested that the difference between raft and shore based data was likely to be minimal. Results for the Mass Transfer and other equations however show significantly improved correlation when e_o or T_a are calculated from lake surface temperature, more closely approximating the air temperature over the lake (Table 10.11).

Table 10.11 Comparative Mass-Transfer Results

	U_1, e_o Lake	U_1, e_o Air	U_2, e_o Lake	U_2, e_o Air	U_5, e_o Lake	U_5, e_o Air
Slope m	1.111	1.140	1.117	1.145	1.126	1.150
Pearson's R	0.962	0.889	0.963	0.897	0.963	0.897
M-T coeff N	0.22139	0.30685	0.20813	0.28873	0.18626	0.25784

Where wind is in m sec^{-1} and saturation and partial pressures in mb, these values of *N* provide evaporation in mm. Dividing *N* by 1000 yields evaporation in metres.

Mass transfer appears to be a simple method for long term evaporation measurement from Swan Coastal Plain wetlands, however the small size of these wetlands means that their local climatic influence is limited. Measurements must therefore be taken preferably from the centre of the open water and require independent measurement of evaporation for a minimum of one year (preferably more) to establish the correct mass-transfer coefficient.

Brutsaert-Stricker

This was the only method tested using the term (e_o-e_a) where calculating e_o from lake surface temperature had minimal effect. Using the standard equation with the Priestley-Taylor coefficient (α) set to 1.26, total evaporation (balance periods 20-50) is

$e_o@T_o$	1903.6mm
$e_o@T_a$	1908.1mm
Floating pan	1467.6mm

Total evaporation equals that of the floating pan when the Priestley-Taylor coefficient is set in the range 1.0855-1.0873. The Priestley-Taylor coefficient is generally interpreted as the ratio between the actual evaporation rate and the equilibrium evaporation rate. Field experiments confirm the applicability of the 1.26 value for evaporation from either wet (water bodies) or well watered surfaces (Eichinger *et al* 1996 and references therein). They note that this coefficient will approach unity where saturated air overlies water, a situation common during calm nights at Perry Lakes particularly in spring. It is likely that for small Swan Coastal Plain wetlands, α varies with time of day and season and that the generally accepted value of 1.26 is inappropriate. The method returns negative daily evaporation on some winter days when relative humidity is very high and/or rainfall relatively constant.

10.9 PICHE EVAPORIMETERS

Piche evaporimeters represent a simple, easy to use instrument for estimating evaporation. They consist of a glass tube 30cm in length with 0.1mm graduations, 1cm in diameter and closed at the top. Water within the tube evaporates via a circular disk of blotting paper, typically 8-13cm^2 in area held against the open bottom of the tube. The instrument is installed in a standard Stevenson screen and read daily. Brutsaert (1982) points out that the Piche evaporation rate is difficult to relate to natural evaporation. Being sheltered from solar radiation it responds primarily to humidity deficit and to a lesser extent, wind.

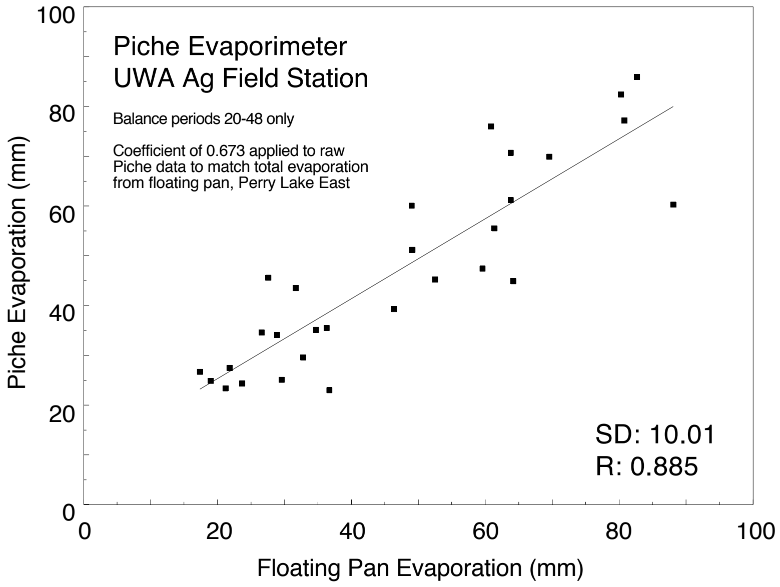


Figure 10.4 Piche evaporimeter vs floating pan evaporation, balance periods 20-48. SD is standard deviation of differences between Piche and pan period totals (compare to equivalent statistics for evaporation using empirical techniques Table 10.10).

Data from a Piche evaporimeter operated at the UWA Agricultural Field Station was compared to floating pan data for 1997, balance periods 20-48 (Figure 10.4). Total Piche evaporation was adjusted using a coefficient of 0.673 to match equivalent pan evaporation. The data indicates that the Piche provides a poor model of lake evaporation, and was inferior to any of the empirical methods tested.

10.10 THERMAL EXPANSION EFFECTS

The thermal expansion of water and measurement reference structures such as concrete dams can be significant in some water balance situations (Harbeck & Kennon 1954). The thermal expansion of water in a lake also works against observing evaporation and evapotranspiration effects. As the day proceeds evapotranspiration draws the level down while thermal expansion has the opposing effect. This is particularly the case in very shallow lakes where the entire body of water is well mixed and heats up more or less uniformly. Table 10.12 shows computed stage change from thermal expansion in East Lake.

Table 10.12 East Lake thermal expansion effects

Stage (m) at 15°C	Volume (m^3) at 15°C	Volume (m^3) at 35°C	Stage Increase (mm) at 35°C
2.800	179.6	180.5	0.24
2.900	913.5	918.2	0.42
3.000	2404.0	2416.3	0.58
3.100	5117.0	5143.1	0.79
3.200	8760.0	8804.7	1.12

The data suggests that in this case thermal expansion is insignificant and probably lies within the reading error of manual stage measurement.

CHAPTER
11

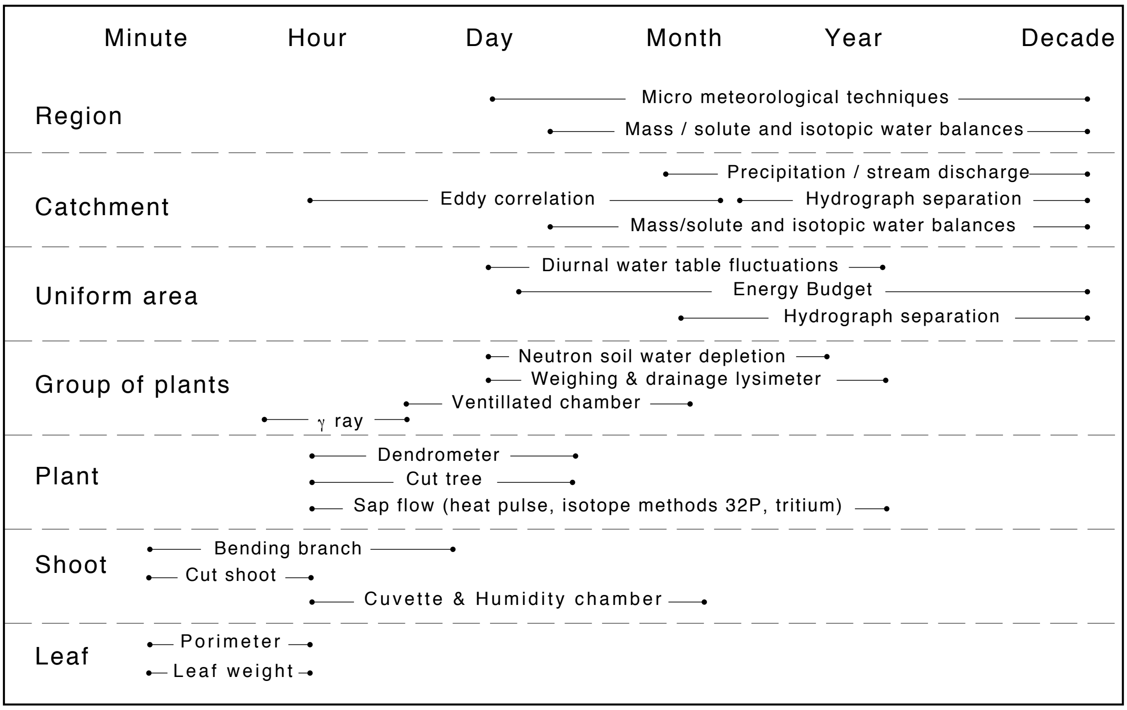
TRANSPIRATION

11.0 INTRODUCTION

In this chapter transpiration theory is reviewed along with available data from the Swan Coastal Plain. Results of experimental determination of transpiration from emergent vegetation at Perry Lakes is presented.

Greenwood (1979) noted the difficulties hydrologists have in coming to grips with transpiration. It is silent, invisible and not easily measured by any simple recording instrument. Like evaporation, its driving force is ultimately solar energy. Therefore transpiration varies diurnally and seasonally. Transpiration is ultimately the evaporation of soil water taken up by plant roots and vaporised within the leaf stomata. In wetland water balances it can represent a significant balance component (Winter 1981). Despite its both elusive and illusive nature, transpiration can be determined directly and indirectly using a wide array of techniques (Table 11.1).

Table 11.1 Transpiration measurement techniques classified by time and space



Modified from Stewart 1984

11.1 SWAN COASTAL PLAIN DATA

Recharge to the unconfined aquifer is derived primarily from rainfall (Davidson 1995). However most rainfall never reaches the aquifer as recharge but is returned to the atmosphere as transpiration from perennial vegetation and evaporation from soil (Allen 1981). Regional estimates of total rainfall lost to evapotranspiration are summarised in Table 11.2. At a local scale however these regional estimates cannot be applied. Sharma & Pionke (1984) cited Davidson (1995) noted that while average recharge over the Gnangara Mound was about 12%, nil recharge was occurring beneath mature pine plantations, while near the crest of the Gnangara Mound Thorpe (1989) estimated 21% recharge using tritium as a recharge indicator. In the same area Farrington & Bartle (1988) using water and chloride balances of *Banksia* woodland estimated 20-22% recharge. In native bushland within King's Park, McFarlane (1984) using a neutron probe found nil recharge at three sites during 1982.

Table 11.2 Recharge and Evapotranspiration Estimates, Swan Coastal Plain

Area & GW Mound	Method	Recharge[1]	ET[2]	Reference
Mirrabooka, (Gnangara)	Pump test, water balance	7.3	806	Bestow 1970 a&b
Western Gnangara	Water balance	8.5	804	Allen 1975
Gnangara Mound	Cl balance	11.5	769	Allen 1981
Jandakot Mound	Flow net analysis	11.9	766	Davidson 1984
Jandakot Mound	Water balance	5.5	821	Allen 1975
Lexia (Gnangara)	Flow net analysis	13.0	756	Davidson 1987

1: as percentage of annual rainfall, 2: assuming average rainfall of 869mm

It is evident that over much of the Gnangara Mound most rainfall never reaches the unconfined aquifer. It is lost either as direct evaporation from leaf capture, as evaporation from the soil or is transpired by plants from the vadose zone. Regionally these annual losses approach annual rainfall.

11.2 WETLANDS

Evaporation and transpiration contribute considerably to the difficulties in determining water budgets for wetlands. Typically such wetlands show wide seasonal variations in presence or absence of surface water or saturated soils and over periods of decades or less, large changes in the distribution of wetland vegetation. Shallow wetlands frequently include large zones of marshy emergent vegetation where water losses to the atmosphere include evaporation from the water surface and transpiration, both of which occur at different rates and both of which are difficult to quantify (Shih 1980). Hence they are typically dealt with in combination, the quantity known as evapotranspiration (Rijtema 1965). Evapotranspiration from wetlands may vary according to species, cover density, climate and phenology (Carter 1986).

Swan Coastal Plain damplands and sumplands represent special cases where the water table is at or close to the surface. Here vegetation tends to be exclusively phreatophytic, drawing water directly from the unconfined aquifer. Within the littoral zone of wetlands macrophytes are seasonally flooded. During winter inundation transpired water is drawn directly from the water column and from the underlying sediments and evaporation occurs directly from the inter plant water surface. In summer losses are directly from the aquifer as transpiration and surface evaporation via soil suction.

At Perry Lakes the two dominant emergent macrophytes are bulrush (*Typha orientalis*) and jointed twig-rush (*Baumea articulata*). These occur as virtual monocultures in large stands in both East and West Lake (Figures 3.1 & 3.2). In East Lake *Typha* mixed with scattered flooded gum (*Eucalyptus rudis*) form a near monoculture within sumpland forming the northeast quadrant of the lake basin. In West Lake vigorous stands of *Baumea* have colonised the eastern quadrant of the lake basin since 1995 in response to an altered hydrological regime (Chapter 3). The East Lake *Typha* meadows lie outside the flooded perimeter of the lake except during the most intense late winter storms. The West Lake *Baumea* meadows are similarly isolated over summer. These areas were therefore considered suitable for estimates of evapotranspiration using simple hydrograph techniques.

11.3 ESTIMATES OF *TYPHA* EVAPOTRANSPIRATION

The literature contains widely divergent conclusions on the question of total water loss (*i.e.* evapotranspiration) from wetlands containing helophyte meadows compared to simple open water evaporation. Kuznecov (1949) and Kiendl (1954), both cited Bernatowicz *et al* (1976), suggested ratios of 1.5-3.0 for northern hemisphere wetlands, concluding that transpiration by helophytes is much greater than evaporation from an identical area of open water. Other reviews such as Carter *et al* (1979) cited Carter (1986) indicate a range from 0.5 to 5.3 times pan evaporation for different wetland vegetation at various times during the growing season. Experimental error is believed to account for many of the more extreme results, in particular those obtained using lysimeters operated on dry ground where the 'oasis' effect artificially accelerates transpiration rates Koch & Rawlik (1993) and references therein.

Evidence from large temperate and tropical wetlands suggests that in general, vegetation decreases evaporation from open water surfaces (Idso 1981; Koch & Rawlik 1993). In North Dakota, Eisenlohr (1966) found that for small 'prairie potholes' with mixed emergent species including *Typha augustifolia, T. glauca* and *T. latifolia* evaporation rates were 0.7 to 0.8 that of open water over two seasons. In Australia, Linacre *et al* (1970) demonstrated that within a large *Typha orientalis T. domingensis* swamp in the Murrumbidgee, vegetated areas lost water at rates significantly lower than nearby open water. This trend was reversed only immediately after rain. Kadlec (1993) similarly reported dense emergents reduced water loss compared to open water in ten small marshes in Canada.

Such studies are difficult to compare. They are dominantly from the northern hemisphere encompassing widely varying climatic conditions and *Typha* species. Many measure only the transpirative component while others combine transpiration and open water losses. Brief studies typically employ tissue water content or vapour chamber methods which physically isolate plants or plant parts (possibly under unrealistic micro-climatic conditions). Longer studies use lysimeters, evaporation pans and micro meteorological methods. They fall into two principal categories:

- those where measurements occur within natural meadows of the macrophyte under study and include measurements of evaporation from adjacent open water
- those where measurements occur on dry land or under laboratory conditions and where 'open water' tended to be a pan evaporated under 'similar conditions' to the study area

Table 11.3 summarises these studies. Those of the first type typically involved micro meteorological methods but included pans and lysimeters operated within natural plant meadows ('Plants in situ' designation in Table 11.3). Studies of the latter type typically employed pans or lysimeters operating under what were clearly non wetland meteorological conditions. As a general rule studies operated under natural conditions typically display Novikova Indices <1 indicating that evapotranspiration in macrophyte meadows under flooded conditions is less than evaporation from open water under equivalent conditions. Conversely in experiments carried out on land the Novikova Index is typically >1. Anderson & Idso (1987) concluded that the large differences in Novikova Indices between natural sites and tanks is partially explained by canopy surface geometry. In very small tanks the peripheral surface comprises a significant percentage of the total vegetated surface area. As tank diameter increases, the Novikova Index decreases (refer footnote, Table 11.3). They note that the same principle applies to very small natural wetlands.

Studies of a few days duration are difficult to compare with continuous studies spanning months or years. Generally those carried out under 'in situ' conditions also tended to be of longer duration and are therefore considered more reliable. Finally, all studies assumed *Typha* to be growing under flooded conditions despite the fact that it can thrive for extended periods of up to many years under non flooded conditions (Froend *et al* 1993).

Transpiration and Evapotranspiration studies on *Typha* sp

Table 11.3

Location	*Typha* species	Methodology	Plants In situ	T flood (mm)	ET flood (mm)	e (mm)	ET dry (mm)	Open Water E (mm)	Novikova Index	Period	Reference	Comments
Kazakhstan	*augustifolia*	unknown	Yes	247				581	0.71-0.73	2 seasons	Novikova 1963 cited Bernatowicz *et al* 1976	Original in Russian
Poland	*latifolia*	phytometer	No	470	626	156		430	1.45	1972	Bernatowicz *et al* 1976	0.3m^2 phytometers submerged within natural *Typha* meadow
			No	460	712	252		430	1.65	1973		
Poland	*augustifolia*	phytometer	No	395	551	156		430	1.28	1972		Considered not to be in situ due to restricted size
			No	608	860	252		430	2.00	1973		
Poland	*latifolia*	phytometer	No				1305	430	3.03	1972	Bernatowicz *et al* 1976	0.3m^2 phytometers on land in open area
			No				1028	430	2.39	1973		Considered not to be in situ due to restriced size and location in clear ground
Poland	*augustifolia*	phytometer	No				1182	430	2.75	1972		
			No				822	430	1.91	1973		
Florida	*domingensis*	lysimeter	Yes		1423			1270	1.12	303 days	Abtew & Obeysekera 1995	9.8m^2 lysimeter installed within *Typha* marsh
N. Dakota	*augustifolia, glauca & latifolia*	mass transfer	Yes	213	548	335		792	0.69	1963	Eisenlohr 1966	Pothole #8 Data covers period May-October
			Yes	152	548	396		701	0.78	1964		Pothole #8
			Yes	335	609	274		701	0.87	1964		Pothole #5A
NSW	*orientalis & domingensis*	micro meteorology	Yes		15.8*			24.5*	0.65	4 days	Linacre *et al* 1970	* E expressed as heat flux (mW cm^2)
India	*augustifolia*	evaporation tanks	No	24	113	89		Not reported		15 days	Brezny *et al* 1973	Open water evaporation not measured
			No	315	781	466		Not reported		35 days		0.36m^2 concrete tanks on land
			No	332	864	532		Not reported		27 days		Comparison of ET/e suggests typical oasis effect
Alabama	*latifolia*	evaporation tanks	No	Not reported					1.62	6 months	Snyder & Boyd 1987	Open water evaporation not measured 5.8m^2 tanks on land, probable oasis effect T+e/E varied from 1.41 to 1.84 (average 1.62) depending on fertilizer treatment
Arizona	*latifolia*	evaporation tanks	No	Not reported					2.8-3.5	4 years	Anderson & Idso 1987	Open water evaporation not measured 4.15m^2 tanks on land, oasis effect operative

Novikova Index: (T+e)/E
where T is transpiration, e is evaporation from water surface among plants, E is evaporation from open water
(T+e) = ET

11.4 ET ESTIMATES FROM SUMPLANDS AT PERRY LAKES

11.4.1 Theory

Groundwater levels below phreatophytes typically fluctuate diurnally in a harmonic form. These fluctuations can provide estimates of daily water uptake by plants (White 1932, Troxell 1936, Todd 1959, Meyboom 1967, Farrington *et al* 1990). The method assumes constant lateral groundwater flow, in which inflow (as groundwater) and outflow (as evapotranspiration) is integrated, represented by the diurnal cycle. At sunrise evapotranspiration commences and the water table begins to fall (Figure 11.1b) as water loss exceeds inflow. The rate of fall peaks in early afternoon, then diminishes towards sunset as inflow eventually equals and then exceeds losses. Between sunset and dawn, inflow continues and the water table rises. Over night transpiration is essentially nil the only losses being minor evaporation from the soil surface. The rate of rise peaks, generally between midnight and about 04:00 hours. White (1932) assumed that during the period of maximum rise evapotranspiration can be considered nil. Taking this rate as the average for the day, then an approximation of total groundwater discharge becomes

$$Q_{ET} = S_y(24h \pm s) \qquad (11.1)$$

where

S_y specific yield within the zone of water table fluctuation

$24h$ maximum overnight rate of water table rise applied over 24 hours

s net fall or rise of the water table over 24 hours

Meyboom (1967) suggested that the S_y value should reflect 'readily available' specific yield, this being the yield available over the first 24 hours. The 'readily available' yield of 0.0069 used for the clay lining at Perry Lakes represents only 28% of true specific yield (measured over 59 days) of 0.024 (Chapter 3).

Figure 11.1b illustrates the relationship between diurnal fluctuation and water volume transpired. Dolan *et al* (1984) and Rushton (1996) utilised modified forms of this method to measure wetland evapotranspiration in Florida. Farrington *et al* (1990) working on the Swan Coastal Plain found that evapotranspiration calculated by water table fluctuations correlated well with data from ventilated chambers for six days between November and March (r = 0.90). The *Typha* and *Baumea* meadows at Perry Lakes are 'uniform areas' (Table 11.1) which were considered ideal for the application of diurnal water table techniques. The water table is consistently within about 0.8m of the surface, and the equipment required is simple and capable of continuous monitoring.

11.4.2 Field Set Up and Method

In East Lake three wells were constructed within non inundated *Typha orientalis* meadow. Wells were spaced approximately 1.2m apart and constructed by sludge pump from fully slotted 50mm PVC (Figure 11.1a). Here palaeolake silts and clays about 2.5m thick overly sands. Wells W26 and W26b were terminated within the lining sediments at 1.8m. W26a penetrated the lining sediments and was terminated at 3.0m depth within the sands.

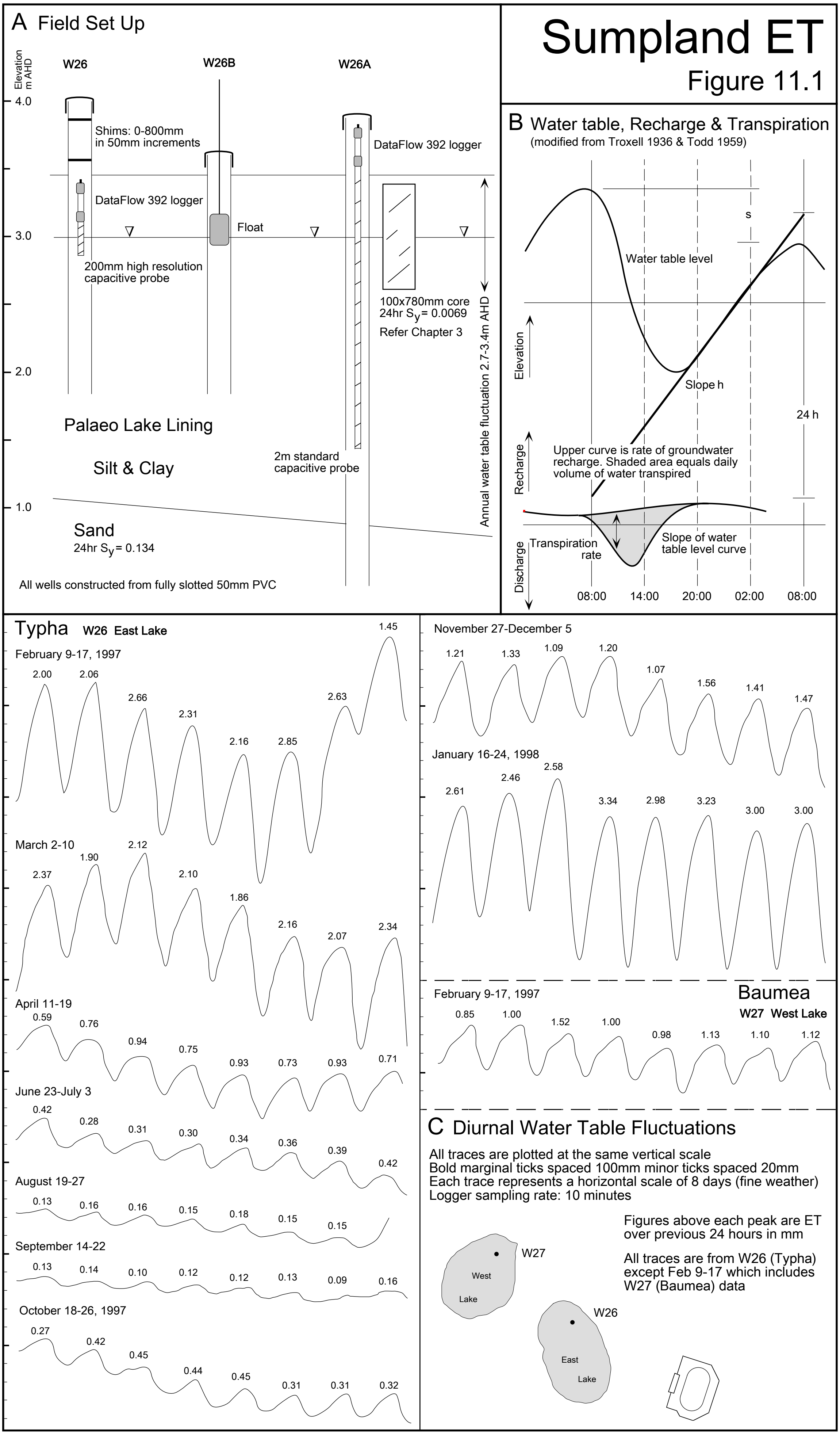
Over a year the water table fluctuated approximately 800mm within the upper portion of the lining sediments. W26 was fitted with a high resolution capacitive water level probe originally designed for detailed measurements in evaporation pans. This probe had an element length of 20cm and resolution of ±0.2mm. A set of 20 PVC shims cut in 50mm increments were inserted as needed to maintain diurnal variations in water level within the central portion of the probe. W26b was fitted with a float gauge which could be read daily to determine when W26 required shim adjustment. W26a was fitted with a standard 2m capacitive probe as part of the regional water table monitoring network.

Initial tests indicated that while similar ET estimates could be obtained from W26 and W26A, the deeper well was strongly affected by irrigation bore draw downs. The silt-clay lining appeared to buffer these fluctuations rendering hydrographs from W26 which were much easier to interpret. Data was collected from mid November 1996 to February 1998. The clays have a 'readily available' specific yield which is about 5.1% that of the adjacent aquifer sands (0.0069 vs 0.134). This low specific yield has the advantage of exaggerating the amplitude of the diurnal fluctuations facilitating easier interpretation. A vertical in situ core of sediment 780mm in length was extracted for specific yield measurements (Figure 11.1a). The core length was equivalent to the amplitude of annual water table fluctuation. Refer to Chapter 3 for details of the specific yield measurements.

In West Lake W27 was constructed within a dense, vigorous *Baumea articulata* meadow (*Baumea* height approximately 3.0-3.5m). This area is inundated over winter and damp over summer. Data was collected over February and March 1997. W27 was fitted with a high resolution probe and shims identical to W26. The geological section comprised 0.7m of silt-clay lake lining over sands. W27 was sludged to 2.2m, and terminated within the sands. This site was sufficiently distant from irrigation bores to preclude significant draw down effects.

Sumpland ET

Figure 11.1



C Diurnal Water Table Fluctuations

All traces are plotted at the same vertical scale
Bold marginal ticks spaced 100mm minor ticks spaced 20mm
Each trace represents a horizontal scale of 8 days (fine weather)
Logger sampling rate: 10 minutes

Figures above each peak are ET over previous 24 hours in mm

All traces are from W26 (Typha) except Feb 9-17 which includes W27 (Baumea) data

11.4.3 Hydrograph Interpretation

Hydrographs were plotted at a vertical scale of 1:1. In summer daily harmonic amplitude is typically 100-120mm within the clays. In late winter this is attenuated by an order of magnitude to 10-12mm. During and after rain no data was collected due to air entrapment effects from the downward moving wetting front (Wilson & Luthin 1963, Bianchi & Haskell 1966). The parameters *24h* and *s* were scaled off manually. Figure 11.1c shows the seasonal variation in typical hydrograph traces including comparison of *Typha* and *Baumea* meadows. Results are summarised in Table 11.4.

These figures for *Typha* were all carried out under non flooded conditions and are less than other studies where natural meadows were studied over a full growing season under flooded conditions such as Eisenlohr (1966) 548-609mm (North Dakota). The Perry Lakes data is not dissimilar to Swan Coastal Plain dampland data from Lake Pinjar (Farrington *et al* 1990) collected by ventilated chamber over mixed shrub species (Table 11.4). Wronski (1986) obtained similar results from dampland *Banksia* woodland in the same area (daily average 1.4mm) using capillary fringe solute balances over 108 days in summer.

Table 11.4 Open water E and macrophyte ET, Perry Lakes & Lake Pinjar

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Floating Pan	192.9	135.1	139.4	82.4	65.2	41.5	53.3	69.6	86.9	144.9	154.1	204.5
Daily average	6.2	4.8	4.5	2.8	2.1	1.4	1.7	2.3	2.9	4.7	5.1	6.6
Typha total	89.6	55.2	57.0	25.8	19.2	10.8	9.9	5.6	3.9	10.6	33.0	62.0
Daily average	2.9	2.0	1.8	0.9	0.6	0.4	0.3	0.2	0.1	0.3	1.1	2.0
Baumea total		28.3	25.1									
Daily average		1.0	0.8									
Lake Pinjar	60.4	40.3	30.4	33.0	31.0	40.2	40.9	38.7	65.7	76.6	139.2	92.1
Daily average	2.0	1.4	1.0	1.1	1.0	1.3	1.3	1.3	2.2	2.5	4.6	3.0

All values in mm, all data 1997 except January which is 1998. *Typha*: 262 days of data, *Baumea*: 53 days
Lake Pinjar data modified from Farrington *et al* 1990, data collected 1987-1988.

Annual ET from *Typha* sumpland, Perry East:	383mm	
Annual open water evaporation, Perry East:	1385mm	
Annual ET from Lake Pinjar dampland:	688mm	
Summer (Dec-Feb) ET East Lake *Typha*	207mm	(data 1997-1998)
Summer (Dec-Feb) ET Lake Pinjar dampland	193mm	(data 1987-1988)

11.4.4 *Typha* and *Baumea* Annual Cycle

On the Swan Coastal Plain *Typha orientalis* dies back over autumn and re-shoots in spring. Plants flower December-January, with green seeds set in February and shed as plants die back during March-June (Froend *et al* 1993, Chambers *et al* 1995). In the

Perry East meadows, new shoots were evident in early August, seed heads fully formed in early January, initial senescence (leaves browning) was evident by early February, and approximately 50% of leaves were dead by mid April with seed shedding under way. This pronounced annual cycle is evident in the data (Table 11.4 & Figure 11.1c) with minimum measured evapotranspiration during September being only 4.5% of that in January. In comparison Lake Pinjar native broadleaved perennials displayed much greater winter evapotranspiration. The summer data when *Typha* is growing most vigorously is very similar to that obtained for the Lake Pinjar damplands.

Baumea articulata remains green all year, flowering between September and November, green seeds are set December-January and seeds shed February-March (Froend *et al* 1993). The *Baumea* evapotranspiration rates determined here for February and March are considered less than the maximum which probably occurs during December and January.

11.5 CONCLUSIONS

All of the Perry Lakes transpiration estimates were from plants growing under non flooded conditions. While both *Typha* and *Baumea* spend considerable periods of each year under flooded and non flooded conditions it is naive to assume that transpiration under both regimes is the same. Experimental evidence (Table 11.4) clearly indicates that:

- for *Typha* spp (and most probably other dense tall macrophytes such as *Baumea*), total evaporative loss (ET) under flooded conditions is less than open water under similar conditions
- for the same plant species under non flooded conditions ET is most likely further attenuated due to reduced wind, shading and water availability

This is consistent with Woo & Rowsell (1993) who continuously monitored ET from non inundated wetland vegetation (bulrush *Scirpus acutus* & *S. paludosus*) fringing open water within Saskatchewan prairie sloughs. Over five months the non inundated ET was consistently less than that of the open water. Our measurements for both *Typha* and *Baumea* were under non inundated conditions. It is expected that the same meadows under flooded conditions would return somewhat greater ET values but these would still be less than open water evaporation as measured by the floating pan. Therefore the evaporation values used in the water balances are probably slight over-estimates.

The area of inundated *Baumea* within East Lake was approximately 10,000m^2 at 3.4m stage (Figure 3.1). Table 11.5 shows the change in water loss at typical open water (floating pan) evaporation rates at theoretical rates of evapotranspiration from inundated *Baumea* meadow.

Table 11.5 Theoretical effect of *Baumea* ET on East Lake water balances

E(mm)	Ratio ET:E 0.5	0.6	0.7	0.8	0.9	Unity
2.0	96.9	98.9	100.9	102.9	104.9	106.9
4.0	193.8	197.8	201.8	205.8	209.8	213.8
6.0	290.6	296.6	302.6	308.6	314.6	320.6
8.0	387.5	395.5	403.5	411.5	419.5	427.5
10.0	484.4	494.4	504.4	514.4	524.4	534.4

All ratio data (columns 2-7) are volumes (m^3)

In Table 11.5 volumes are evapotranspiration within a 10,000m^2 meadow of *Baumea* plus evaporation from the remaining 43,440m^2 of open water at different ratios of ET:E within the *Baumea*. Where ET=E (right hand column), volume is equivalent to open water evaporation from the entire lake surface. At 3.4m stage, lake volume is approximately 18140m^3. Where ET:E is 0.5, the *Baumea* reduces evaporated water volume by 9.3% representing 0.055% to 0.27% of total lake volume at open water evaporation rates of 2.0-10.0mm d^{-1}. Transpiration from native emergent vegetation is therefore an inconsequential component and has not been incorporated in the East Lake mass balances. It is possible however that greater (unmeasured) losses occur from European poplars and willows drawing directly from the lake.

CHAPTER

12

ISOTOPE EXPERIMENTS

12.0 INTRODUCTION

In this chapter the basic concepts of isotopic fractionation during evaporation are reviewed. Isotopic content of atmospheric water vapour δ_A and isotopic content of lake evaporate δ_E are introduced and their importance in isotopic balances of water bodies is discussed. Evaporation pan experiments are described to experimentally determine limiting steady state isotopic enrichment and location specific values of δ_A and δ_E . The application of pan derived exchange parameters to the water balance of an adjacent wetland is discussed. Field data directly measuring δ_A and δ_E is introduced. The time course of deuterium in East and West Lakes are constructed with accompanying δ_A and δ_E for integration with the mass balance.

Isotopic balances rely on knowing the isotopic composition of atmospheric water vapour δ_A and vapour evaporating from the lake surface δ_E. Generally these are estimated from published averages. At Perry Lakes a series of experiments were conducted to determine δ_E independently using data unique to the local area. These experiments build on earlier work by Craig *et al* 1963, Gat 1970, Welhan & Fritz 1977, Allison *et al* 1979 and Allison & Leaney (1982) but are more rigorous in terms of their duration and methodology. Experiments were also devised to measure δ_E directly. A routine air vapour sampling program was also conducted to directly measure δ_A. Due to the large number and complexity of the equations presented, separate notation is provided at the end of this chapter, page 12-56.

12.1 CONCEPTS OF ISOTOPIC FRACTIONATION

12.1.1 Natural Environmental Isotopes

Fractionation is any process (physical, chemical, biological) which separates isotopes of an element (Toran 1982, Clark & Fritz 1997). The Perry Lakes study deals almost solely with deuterium. Initial co-analysis of ^{18}O was abandoned due to cost considerations. Depletion or enrichment of deuterium (designated ^2H) relative to H is reflected by different 'delta' (designated δ) values (Gonfiantini 1981). Absolute measurement of isotopic values is analytically difficult. Therefore relative ratios are measured instead such that the δ value represents the relative difference in units of permil (‰) of ^{2}H:H relative to a standard ('VSMOW' - Vienna Standard Mean Ocean Water) maintained by the International Atomic Energy Agency (IAEA). Substituting ^{2}H in equation (6.10)

$$\delta^2 H_{sample} = \left(\frac{^2H:H_{sample}}{^2H:H_{VSMOW}} - 1 \right) \bullet 1000‰ \qquad (12.1)$$

In natural waters and evaporation pan experiments at Perry Lakes, deuterium values ranged from about -15.0‰ to +100.0‰ signifying waters with 15‰ (1.5%) less than the standard to waters with 100‰ (10%) more than the standard. The equivalent ^{18}O was about -3.4‰ to +21.1‰. All samples were analysed on CSIRO Floreat Laboratories mass spectrometer (VG Isogas Ltd SIRA 9). Measurement precision[1] is approximately 1‰ for δ^2H and 0.1‰ for δ^{18}O.

Molecules with different masses have different thermodynamic properties and thus different rates of diffusion, evaporation, condensation, freezing and melting. Different meteorological processes thus result in varying degrees of fractionation. Fractionation results from both chemical and physical reactions. It includes kinetic fractionation, essentially a unidirectional movement (controlled by the relative velocity and vibrational frequency of molecules) and equilibrium chemical reactions where isotopes are continuously exchanged (Gat 1981b, Toran 1982). At Perry Lakes, fractionation (represented by different δ values of ^{2}H and ^{18}O) is evident in all components of the water balance.

Rainfall, Stormwater, Groundwater

Rainfall originates in atmospheric vapour masses fractionated during evaporation and subsequently mixed prior to condensation. Rain drops are also subject to evaporation as they fall. Thus rain water in individual rain events will display widely differing degrees of fractionation. At Perry Lakes, rainfall collected between April 1996 and January 1998 ranged from -71.0‰ to +34.4‰ deuterium. As an air mass travels the loss of vapour as precipitation results in 'rainout', a process whereby condensation preferentially partitions ^{2}H and ^{18}O in the cloud droplets through Rayleigh distillation (Dansgaard 1953 & 1954, Epstein & Mayeda 1953). Rain drops subsequently formed from the droplets are

---

[1] Instrument precision (internal reproducibility) is 2x std deviation of 10 delta values derived from a series of 12 alternate sample-reference ratio measurements of one gas sample and is typically 0.3‰. The commonly cited precision of 1.0‰ represents the average spread obtained by simply analysing the same sample multiple times. Deviation from the true value is controlled by instrument precision, chemical purity, vacuum stability during gas transfer, leakage, time between water reduction and analysis and human error (V. Gailitis, mass spectrometer technician, CSIRO pers com).

isotopically enriched, but fall from a diminishing vapour mass which is continuously undergoing isotopic depletion (Clark & Fritz 1997).

The minimum -71.0‰ occurred April 10-11 1997 under conditions of bush fire smoke which possibly seeded precipitation from vapour already strongly isotopically depleted. A major frontal system September 5-6 1997 dropped 39.3mm which averaged -54.8‰. The maximum +34.4‰ occurred 6-7 March 1997 under conditions of low humidity, high evaporation and scattered thunder storms and virga. It reflects evaporation and isotopic enrichment of the rain as it fell. Stormwater channelled into storm drains will broadly reflect the isotopic content of the parent rainfall but is likely to undergo further isotopic enrichment through evaporation during surface flow on roads and gutters. Rain entering the soil profile and ultimately recharging the unconfined aquifer is subjected to little further evaporation. The groundwater derived from it therefore represents a volume weighted average of the isotopic content of rain over many (possibly thousands) of years.

Meteoric Water Line

The stable isotope composition of rainfall provides a baseline against which surface and groundwaters can be compared. At Perry Lakes monthly composites of rainwater have been collected since 1983. These monthly data, as amount weighted ^{2}H and ^{18}O, define the Perth Meteoric Water Line (MWL). Surface water in wetlands undergoing evaporation are subject to isotopic fractionation, becoming enriched in ^{2}H and ^{18}O. The extent depends on climate (rainfall, evaporation, temperature and humidity). Water in these wetlands or groundwater originating from them will plot in fields removed from the MWL in δ^{2}H - δ^{18}O space. This water represents evaporated lake and groundwater and defines a 'low slope' evaporation line below the MWL. The 'low slope' results from ^{18}O being proportionally more enriched than deuterium in residual lake water (Dinçer 1968). Figure 12.1a shows the Perth MWL plus a low slope evaporation line defined by water undergoing evaporation (Run 1 of pan experiments described later in this chapter). Atmospheric vapour and lake evaporate collected at Perry Lakes, as would be expected, also plot on the MWL. Water in adjacent East and West Lakes was evaporating under similar meteorological conditions and also falls on the same low slope evaporation line (Figure 12.1b). West Lake during late summer evaporates to a small pond and displays significant isotopic enrichment compared to East Lake which was being maintained with periodic groundwater 'top ups'.

Feed stock for the evaporation pans was groundwater collected from CSIRO irrigation bore #2 (Figure 1.1b). This is unevaporated groundwater derived directly from rainwater and plots in a unevaporated groundwater field ('UGF' in Figure 1.1) on or close to the MWL.

12.1.2 Application to Identifying Differing Wetland Water Balance Regimes

Dinçer (1968) and Townley *et al* (1993a) summarise the non-equilibrium evaporation processes which apply unique isotopic signatures to surface waters:

- proportionally greater enrichment of ^{18}O relative to ^{2}H
- general enrichment of surface waters relative to groundwater in the lake capture zone or unevaporated groundwater

This results in ^{2}H and ^{18}O becoming enriched along 'evaporation lines' which are displaced from the local meteoric water line through the differing effects of rainfall, evaporation, temperature and humidity. These waters thus acquire a distinguishable isotopic composition (Gat 1981c). Figure 12.1e demonstrates how pans evaporating at constant volume but different humidity define unique evaporation lines. It has been suggested (Turner pers com) that significant information on the hydrology of lakes on the Swan Coastal Plain may be determined from analysis of the range of seasonal isotopic variations and slope of the ^{2}H and ^{18}O relation for a given lake. Thus the data collected for Perry Lakes may provide clues on the water balances of similar nearby lakes. This concept remains to be developed.

12.1.3 Isotopic Water Balance of Lakes

The use of isotopic water balances was introduced in Chapter 4 and demonstrated in Chapter 6. Concepts and approaches applied in isotopic water balances are reviewed by Gat *et al* (1968) and Dinçer (1968). Townley *et al* (1993a p61) introduce general steady solutions for the isotopic water balance of a lake where

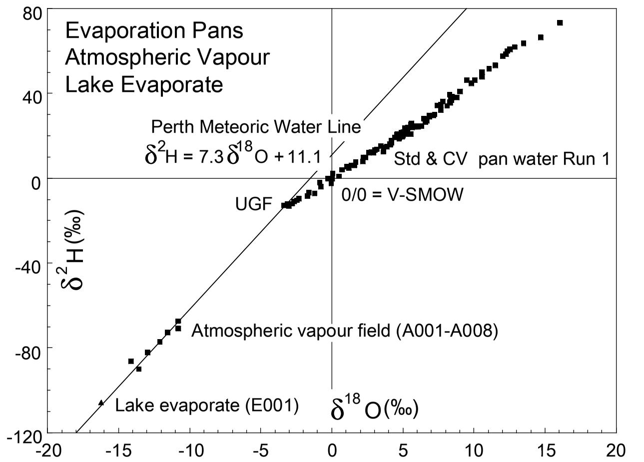
$$I(1+\delta_I)-O(1+\delta_L)+P(1+\delta_P)-E(1+\delta_E)=0 \qquad (12.2)$$

and where $(1+\delta_E)$ is unknown

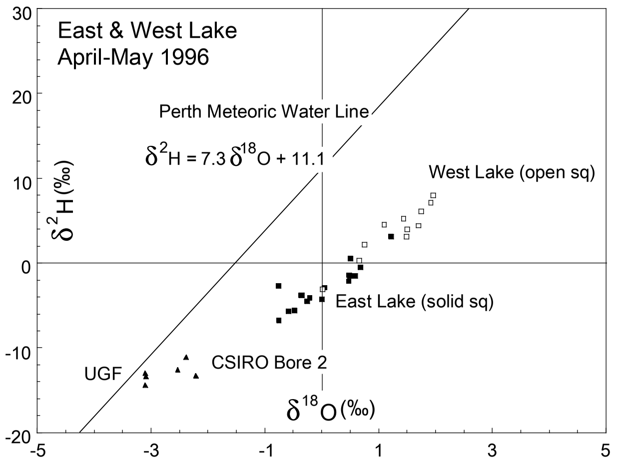
$$I(1+\delta_I)-O(1+\delta_L)+P(1+\delta_P)-E\frac{\alpha*(1-\delta_L)-h(1-\delta_A)}{1-h+\Delta\varepsilon}=0 \qquad (12.3)$$

The critical parameters are δ_E the isotopic composition of evaporating water from the lake surface and δ_A the isotopic composition of atmospheric water vapour. The substitution for δ_E in equation 12.2 derives from equation 23 of Craig & Gordon (1965), various forms of which appear elsewhere in this chapter (equations 12.6, 12.6a and 12.32).

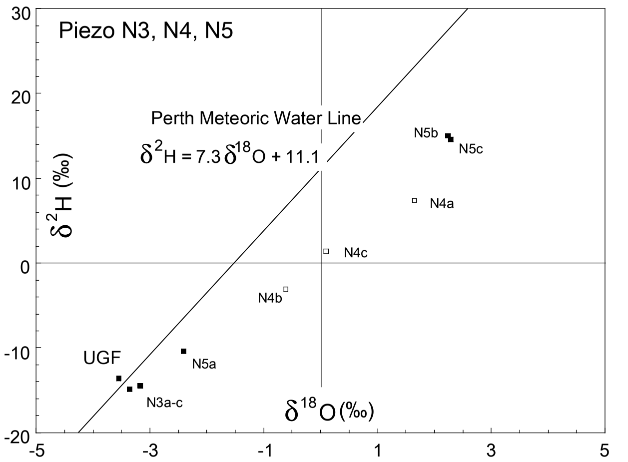
A Perth Meteoric Water Line (MWL) showing low slope evaporation line defined by evaporation pan waters. UGF is the unevaporated groundwater field



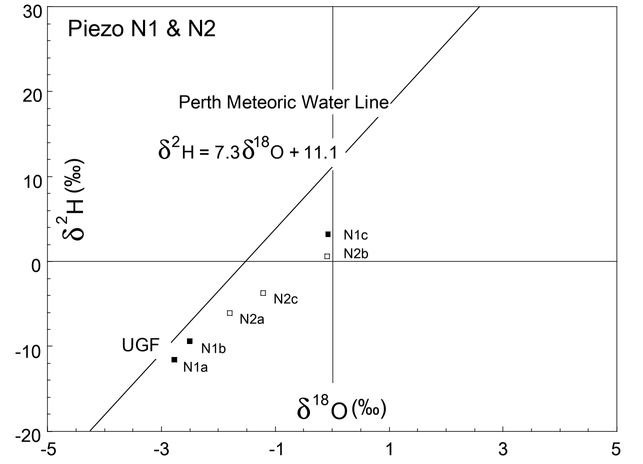
B East & West Lake waters collected during pan Run 1. Pans & lakes evaporated under identical meteorological conditions & define the same low slope evaporation line



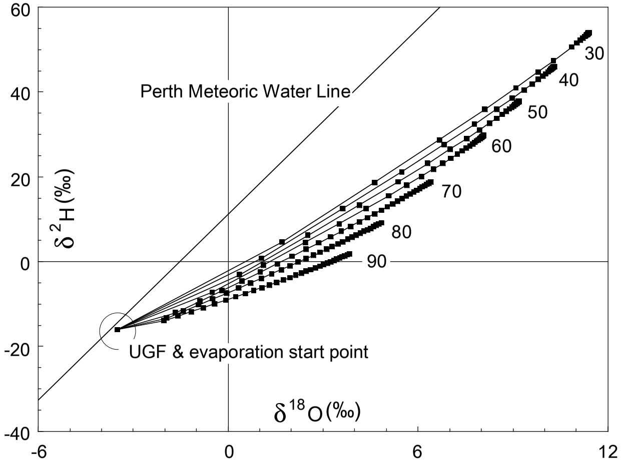
C East Lake nested piezometers, N3 up gradient, E shore N4 down gradient, W shore & N5 down gradient 400m N4 & N5 define an evaporated groundwater field



D West Lake nested piezometers, N1 up gradient E shore N2 down gradient, W shore. Refer text



E Time course and limiting values of GW evaporated at RH of 30% to 90%. This may have application in local lakes identifying differing water balance regimes



Perth Meteoric Water Line Concepts & Examples

Notes

UGF is the unevaporated groundwater field. Nest N3 clearly lies within this field confirming that groundwater discharging into East Lake is isotopically similar to pan feedstock derived from CSIRO irrigation bore 2.

Note widely differing δ^2H & $\delta^{18}O$ axis scales

Panel E is the time course of isotopic content of water in a constant volume pan under conditions of daily average relative humidity of 30-90%

All isotopic values are per mille (‰)

Figure 12.1

Atmospheric vapour δ_A is easily sampled and measured directly, however, doing so on a continuous basis is logistically impractical. In water balance studies, uncertainties of up to 50% can result from uncertainties in estimating δ_E (Zimmerman & Ehhalt 1970). Measuring δ_E directly is logistically very difficult since it requires selectively sampling evaporating moisture in the presence of ambient moisture (Zuber 1983). Techniques were developed at Perry Lakes for experimental direct sampling of δ_E under dead calm wind conditions and are described later in this chapter. Evaporation pans, (and also some lakes and ponds) can provide estimates of these crucial isotopic exchange parameters under the varying climatic and seasonal conditions unique to the wetland under study. This approach formed the basis of the 'pan experiments' conducted at East Lake from 1996 to 1998.

12.2 ISOTOPIC EXCHANGE PARAMETERS FROM EVAPORATION PANS

12.2.1 Historical Background

Lakes evaporating to dryness under high (>>50%) relative humidity approach a limiting or steady state isotopic enrichment (Craig & Gordon 1965, Fontes & Gonfiantini 1967, Gat & Levy 1978). Gat (1981d) noted that this limiting value which he designated δ^* is independent of the initial isotopic composition, being fixed solely by ambient parameters h and δ_A and approximated as

$$\delta^* \approx \delta_A + \frac{\varepsilon}{h} \qquad \text{(Gat 1981d Eqn 9.3)} \qquad (12.4)$$

Similarly Gat (1981) shows how in a 'terminal lake' where inflow is approximately matched by evaporation, steady state (designated δ_L^{ss}), can be defined as

$$\delta_L^{ss} \approx h\delta_A + (1-h)\delta_{in} + \varepsilon \qquad \text{(Gat 1981d Eqn 9.11a)} \qquad (12.5)$$

and drawing on the work of Craig & Gordon (1965) introduces the concept of defining δ_A in terms of δ_E where

$$\delta_E = \frac{\alpha^*\delta_L(1+E\rho_L) - h\delta_A - \varepsilon}{(1-h) + \Delta\varepsilon + \alpha^* E\rho_L^*} \qquad \text{(Gat 1981d Eqn 9.9)} \qquad (12.6)$$

which can be approximated by

$$\delta_E = \frac{\delta_L - h\delta_A - \varepsilon}{1-h} \qquad \text{(Gat 1981d Eqn 9.10)} \qquad (12.6a)$$

Working directly with natural systems to determine isotopic exchange parameters is extremely difficult. Large evaporation pans however are convenient analogues of natural systems:

Natural System	Analogue
Desiccating Lake	Pan evaporating to dryness
Terminal Lake	Pan evaporating at constant volume
Lake with inflow and outflow	Leaky pan evaporating at constant volume

Welhan & Fritz (1977) suggested using measurements of the isotopic time course of pans evaporating towards dryness as models of desiccating lakes and showed how they could be used as an indirect measure of the ambient parameters h and δ_A. Allison *et al* (1979) examined the extreme practical difficulties imposed on such measurements by natural variation in meteorological conditions. They were able to demonstrate however that where a pan evaporated to at least half its original volume, under stable humidity conditions, useable estimates of δ_E could be obtained and applied to an adjacent lake.

The ultimate goal of all these experimental techniques was to determine a value of δ_E which represented the sum effect of the varying exchange and evaporative processes occurring over time. Allison & Leaney (1982) showed how such 'flux weighted' exchange parameters, useable over weeks or months could be determined using pans evaporated at constant volume (analogues of terminal lakes) and how they could be applied to the water balance studies of adjacent lakes.

12.2.2 Pans Evaporated to Dryness

Early pan experiments using both ^{2}H and ^{18}O (Craig *et al* 1963, Gat 1970, Gonfiantini 1965 cited Welhan & Fritz 1977) confirmed that waters in pans evaporating to dryness reach different isotopic steady states under differing evaporation conditions. Welhan & Fritz (1977) present a method which relates the difficult to measure isotopic content of evaporating water δ_E of a water body such as a lake directly to parameters which describe the isotopic behaviour of a corresponding isolated water body with no inflow such as an evaporation pan. They develop the following equations:

$$\delta_S = \frac{h\delta_A + \varepsilon}{h - \varepsilon} \qquad \text{(Welhan \& Fritz 1977 Eqn 4)} \qquad (12.7)$$

and

$$\frac{\delta - \delta_S}{\delta^0 - \delta_S} = f^m \qquad \text{(Welhan \& Fritz 1977 Eqn 5)} \qquad (12.8)$$

where

$$m = \frac{h - \varepsilon}{1 - h + \Delta\varepsilon + \alpha^* E\rho_L^*} \qquad \text{(Welhan \& Fritz 1977 Eqn 6)} \qquad (12.9)$$

Equation 12.8 describes the isotopic behaviour of water evaporating under constant climatic conditions, while m in 12.9 is predominantly dependant on h. Dividing 12.6 by 12.7 and noting that

$$\frac{\alpha^*(1 + E\rho_L^*)}{h - \varepsilon} = \frac{m + 1}{m} \qquad \text{(Welhan \& Fritz 1977 Eqn 7)} \qquad (12.10)$$

yields

$$m = \frac{\delta_E - \delta}{\delta - \delta_S} \qquad \text{(Welhan \& Fritz 1977 Eqn 8)} \qquad (12.11)$$

Therefore for water evaporating in a pan with no flow, the exponent m describes the relationship between δ and δ_E at any instant.

Application to an Adjacent Lake

Welhan & Fritz (1977) then argue that at any instant a well mixed epilimnion of a lake may be thought of as a closed water body with $f = 1$ and $\delta^0 = \delta_{lake}$ where δ_S and m may be defined by equations 12.7 and 12.9. It follows that for the lake surface an equation taking the form of 12.11 may be written relating the isotopic content of the lake waters to $\delta_{E(lake)}$ $\delta_{S(lake)}$and $m_{(lake)}$.

Welhan & Fritz (1977) then expand equation 12.9 such that

$$m = \frac{h - \varepsilon^* - \Delta\varepsilon}{1 - h + \Delta\varepsilon + \alpha^* E\rho_L^*} \qquad \text{(Welhan \& Fritz 1977 Eqn 10)} \qquad (12.12)$$

and note that since $\Delta\varepsilon << h$ and $\alpha^* E\rho_L^* \approx 0$ then m is mainly a function of temperature as saturation absolute humidity approximately doubles for each 10° rise in temperature. It follows that the difference between m_{pan} and m_{lake} is principally a function of the difference between pan and lake surface temperatures. Similarly from equation 12.7, $\delta_{S(lake)}$ and $\delta_{S(pan)}$ are also related by temperature. Welhan & Fritz (1977) note that δ_S is very sensitive to $\Delta\varepsilon$. Their critical assumption is that $\Delta\varepsilon$ is similar for the lake and the pan. Subject to these assumptions they find that

$$\delta_{S(lake)} \approx \delta_{S(pan)} \text{ and } m_{lake} \approx m_{pan} \quad \text{(Welhan \& Fritz 1977 Eqn 11)} \quad (12.13)$$

which when substituted into equation 12.11 yields

$$m_{pan} \approx \frac{\delta_{E(lake)} - \delta_{lake}}{\delta_{lake} - \delta_{S(pan)}} \quad \text{(Welhan \& Fritz 1977 Eqn 12)} \quad (12.14)$$

This applies where the pan and lake surface are at the same temperature and is the key expression developed by Welhan & Fritz (1977) allowing δ_E of a lake to be related directly to pan parameters *m* and δ_S.

Allison *et al* (1979) provide realistic field methods whereby pan derived parameters can be measured. Welhan & Fritz (1977) in their experiments conducted in Canada were hampered by limited data from short evaporation runs resulting from the use of unsheltered pans. Their experiments typically proceeded for 2-3 days (f<0.8) before rain fell in the pans. They noted that the method was probably better suited to more arid climates where the pans could be monitored for longer time periods under conditions of low or nil precipitation. An additional problem with their original approach is that δ_E is largely a function of relative humidity, δ_A and the isotope fractionation factor for the isotope of interest (Craig & Gordon 1965). Therefore such short term pan experiments are unlikely to provide a value of δ_E which is representative of the varying exchange and evaporative processes occurring over time.

Allison *et al* (1979) also working in Canada used a temperature compensated pan (floating in a lake) and both sheltered and unsheltered pans on shore. They reported that when plotting δ_{pan} against time, rapid changes in relative humidity produced sharp breaks in the curve and noted that while the use of sheltered pans prevents interruption of a run due to precipitation, data still had to be analysed in periods of relatively constant humidity. Even with a sheltered pan Allison *et al* (1979) obtained no run longer than 16 days (f<0.2). Pans did not approach dryness and δ_S was never directly measured. Instead an approximation of equation 12.12 whereby

$$m \approx \frac{(h - \varepsilon)}{(1 - h + \Delta\varepsilon)} \quad \text{(Allison \textit{et al} 1979 Eqn 4)} \quad (12.15)$$

and a graphical solution whereby

$$\ln(\delta - \delta_S) - \ln(\delta^0 - \delta_S) = m\ln f \quad \text{(Allison \textit{et al} 1979 Eqn 8)} \quad (12.16)$$

were used to solve with *m* and δ_S chosen to produce the best straight line fit with ε and Δε estimated from the literature.

12.2.3 Pans Held at Constant Volume

The determination of δ_S using pans evaporated to dryness is problematic. As the volume of water remaining in the pan diminishes, small changes in meteorological conditions can produce large changes in pan isotopic composition. Where pan water contains some salt, this becomes concentrated producing additional undesirable effects. These are further explored later in this chapter (refer section 12.3). When humidity is low (as it frequently is in Perth over the summer), Allison & Leaney (1982) note that δ_S is very difficult to estimate. At relative humidity of about 50% or less (depending on isotopic exchange parameters), such that $m<1$, isotopic steady state pan conditions are never attained.

Allison and Leaney (1982) provide equations applied to a constant feed pan which utilise the m of Welhan and Fritz (1977). Such pans overcome the problems of meteorological conditions perturbing the approach to steady state and by maintaining a constant water volume they allow 'flux weighted' estimates of δ_E to be determined which are applicable for weeks or months. They introduce the term K representing isotopic steady state in a pan evaporated at constant volume.

At some time t

$$\delta = K - (K - \delta^0)exp\left[\frac{-(m+1)Et}{V}\right] \quad \text{(Allison \& Leaney 1982 Eqn 9)} \quad (12.17)$$

where

$$K = \frac{\delta_I}{(m+1)} + \frac{m(h\delta_A + \varepsilon)}{\left[(m+1)(h-\varepsilon)\right]} \quad \text{(Allison \& Leaney 1982 Eqn 10)} \quad (12.18)$$

Welhan (1974 cited Allison & Leaney 1982) showed that where a pan evaporating to dryness is thermally coupled to an adjacent lake, rearranging equation 12.14 yields

$$\delta_{E(lake)} = (m+1)\delta_{lake} - m\delta_{S(pan)} \quad \text{(Allison \& Leaney 1982 Eqn 11)} \quad (12.19)$$

and combining (12.7) and (12.18) yields

$$\delta_{E(lake)} = (m+1)(\delta_{lake} - K) + \delta_I \quad \text{(Allison \& Leaney 1982 Eqn 12)} \quad (12.20)$$

This is the key relationship developed by Allison & Leaney (1982) which expresses the relationship between the isotopic composition of lake evaporate and exchange parameters estimated from a nearby pan evaporating at constant volume. Simpson *et al* (1992) describes a practical demonstration of constant volume pans in a field situation where flux weighted or seasonally applicable values of pan derived δ_E and δ_S are applied to an adjacent water body, in this case a rice paddy.

12.3 PERRY LAKES PAN EXCHANGE PARAMETERS EXPERIMENT

12.3.1 Evaporation Pan Experiment Design Principles

Pans evaporated to dryness, the approach taken by Welhan & Fritz (1977) and pans operated at constant volume, the method developed by Allison & Leaney (1982) represent the two basic approaches described in the literature for estimating the isotopic composition of lake evaporate from an evaporation pan operating nearby. Neither had been field tested either for an extended period or under conditions where the pan and lake temperatures were synchronous. Perry Lakes represented an opportunity to test and compare both approaches.

Pans evaporated to dryness

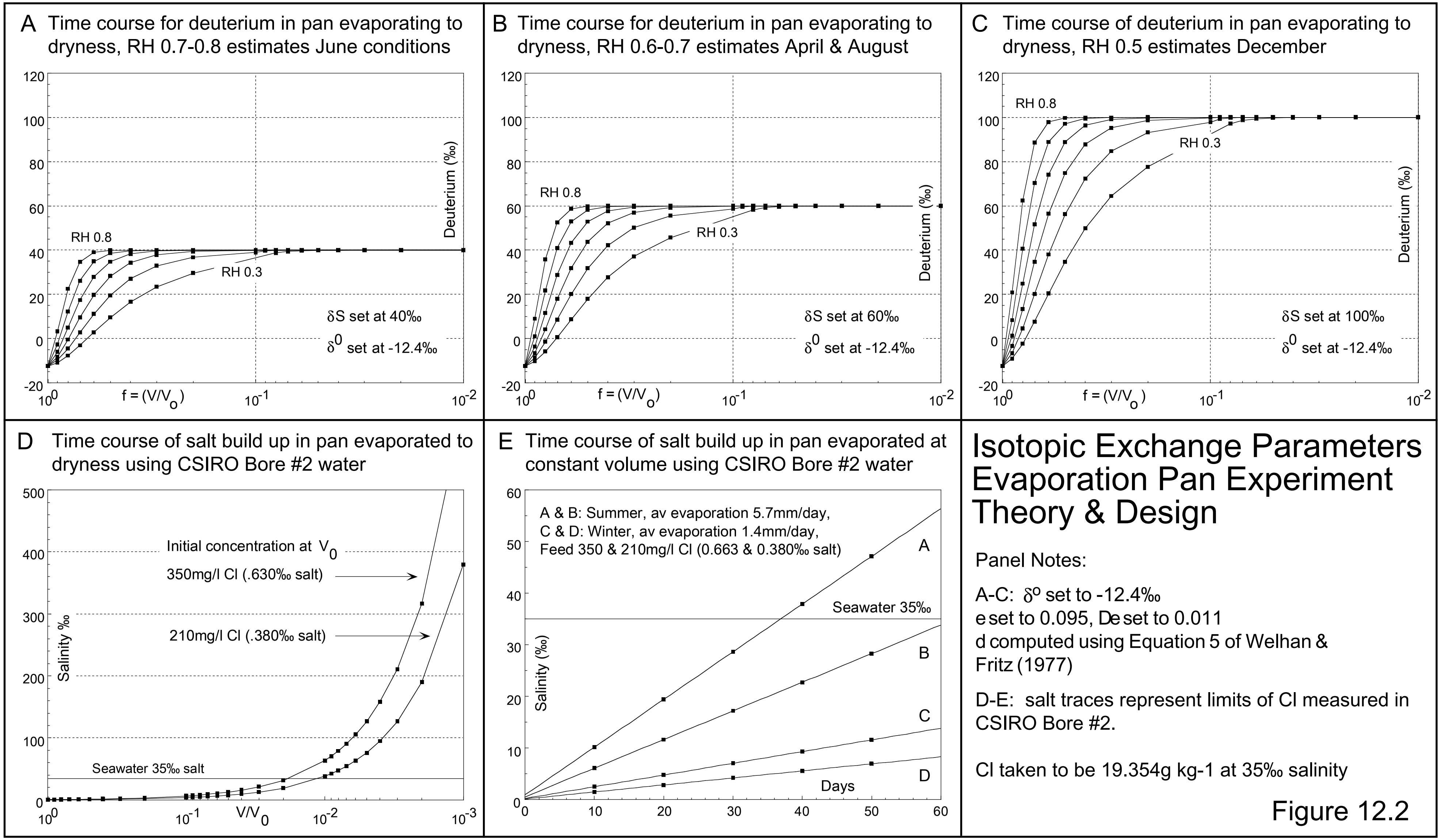
At the time the isotope experiments were being designed there were no detailed meteorological data for the Perry Lakes basin, specifically average monthly relative humidity and open water evaporation. Designing and operating a pan evaporating to dryness in tandem with a constant volume pan is a juggling act. We wanted to operate the experiment over two full years with sufficient pan runs to adequately quantify seasonal changes in exchange parameters. For each run, both pans would commence operation simultaneously. The basic operating premise was that the time course of the 'standard pan' evaporated to dryness should approximately equal the time course of the constant volume pan such that the pan operated at steady state for a minimum of two weeks. This meant that the starting volume for the standard pan would be varied seasonally such that time to dryness approximated adequate operation of the constant volume pan at equilibrium.

In practice this requirement is not terribly stringent because δ_S can be deduced from a pan evaporating to dryness using equation 12.8 even at $f = 0.5$, when only half the water has evaporated (Allison *et al* 1979). This is evident in theoretical curves (Figure 12.2.a-c) developed by rearranging equation 12.8 such that

$$\delta = f^{m}(\delta^{0} - \delta_S) + \delta_S \qquad (12.21)$$

These theoretical curves predict that for Perry Lakes:

- the expected annual range of δ_S would be about 40-110‰
- time to $f = 0.1$ would vary seasonally from about 15-40 days at pan start depths ($f = 1$) of 185-85mm (the volumetric time course of a pan evaporated to dryness simply requires knowledge of local pan evaporation rates)



A Time course for deuterium in pan evaporating to dryness, RH 0.7-0.8 estimates June conditions

B Time course for deuterium in pan evaporating to dryness, RH 0.6-0.7 estimates April & August

C Time course of deuterium in pan evaporating to dryness, RH 0.5 estimates December

D Time course of salt build up in pan evaporated to dryness using CSIRO Bore #2 water

E Time course of salt build up in pan evaporated at constant volume using CSIRO Bore #2 water

Isotopic Exchange Parameters Evaporation Pan Experiment Theory & Design

Panel Notes:

A-C: δ^o set to -12.4‰
e set to 0.095, De set to 0.011
d computed using Equation 5 of Welhan & Fritz (1977)

D-E: salt traces represent limits of Cl measured in CSIRO Bore #2.

Cl taken to be 19.354g kg-1 at 35‰ salinity

Figure 12.2

These curves also demonstrate that as average daily humidity decreases, isotopic content of water remaining at half volume ($f = 0.5$) becomes increasingly removed from steady state δ_S. Therefore in summer with lower humidity it is desirable that evaporation proceed further (approximately $f = 0.1$) to ensure accurate determination of δ_S (Table 12.1).

Table 12.1 Volume change required in standard pan to achieve $0.9\delta_S$

Relative Humidity	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
f to achieve $\delta_S = 0.9$	0.05	0.10	0.25	0.37	0.48	0.59	0.68	0.80

Pans evaporating at constant volume

The isotopic concentration of a constant volume pan at any time is defined by equation 12.17. The time course and ultimate steady state (K) are functions of

- daily average relative humidity h (and associated fractionation factors integrated as m)
- evaporation rate E
- pan volume V (a function of depth where pan geometry is fixed)

Monthly estimates of K and open water evaporation were calculated using mean monthly Fremantle 09:00 hr relative humidity which approximates daily average relative humidity and mean monthly Perth Airport Class A pan evaporation. It was anticipated that evaporation from the small experimental pans would approximate adjacent evaporation from East Lake. A suitable average pan coefficient whereby open water evaporation at Perry Lakes could be estimated from Class A pan evaporation at Perth airport was not yet available. The commonly utilised annual coefficient of 0.7 (Brutsaert 1982) was adopted. Subsequent studies indicated the coefficient for 1997 was 0.67 (refer Chapter 10). Estimates are summarised in Table 12.2.

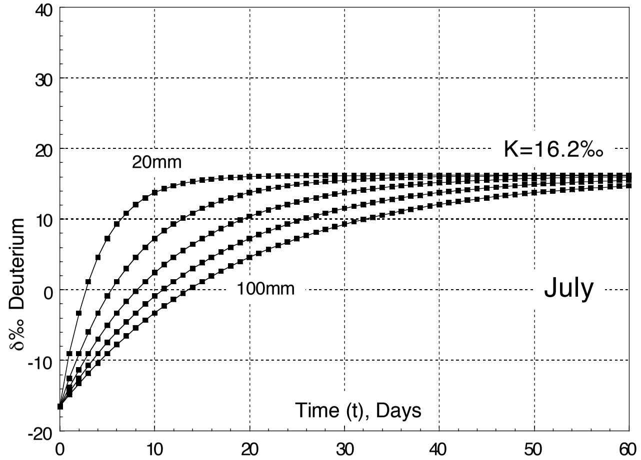
Table 12.2 Estimated daily average humidity, E and K (deuterium) at Perry Lakes

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av daily RH (%)	57	57	60	66	73	75	76	73	69	64	59	56
Av daily E (mm)	5.70	5.44	4.33	2.82	1.86	1.43	1.42	1.79	2.46	3.49	4.43	5.25
m	1.08	1.08	1.23	1.61	2.26	2.51	2.65	2.26	1.85	1.47	1.18	1.03
K (‰)	33.5	33.5	30.8	25.3	19.0	17.1	16.2	19.0	22.6	27.2	31.7	34.5

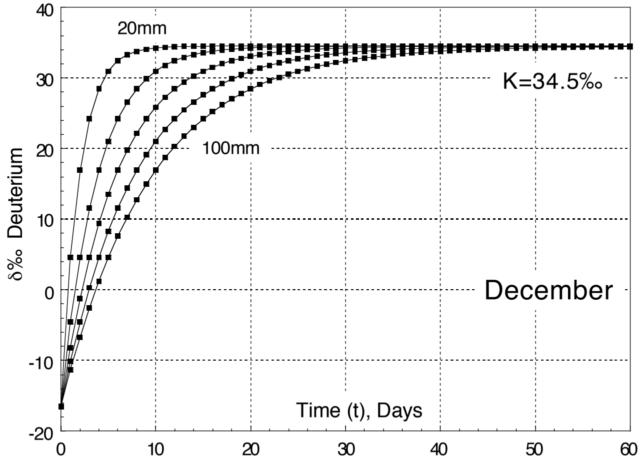
Fremantle humidity data mean 1852-1989, Perth evaporation data mean 1876-1992, m & K calculated using exchange parameters $\varepsilon = 0.095$, $\Delta\varepsilon = 0.011$, δ_I set to -16.5‰ based on groundwater deuterium analysis of sample from irrigation bore P5,
δ_A set to -100‰

It was anticipated that pans would be constructed from 200 litre drum bases (area 2532cm^2). Using equation 12.18 the time course to equilibrium was modelled for each month at varying pan depths. Experimental data is summarised in Figure 12.3 a-c and predicts that for Perry Lakes:

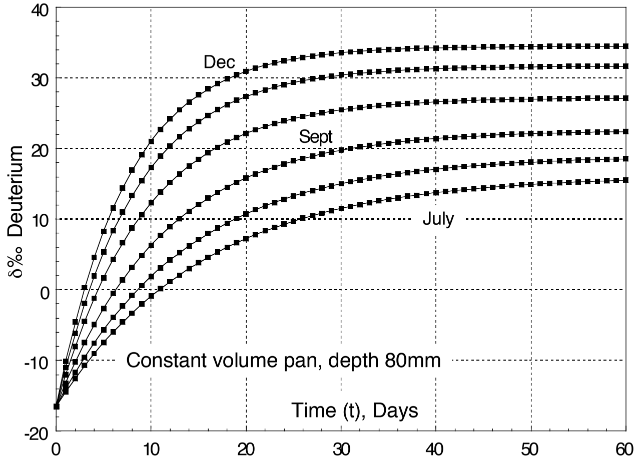
A Time course for deuterium in constant volume pans containing water 20-100mm deep, July



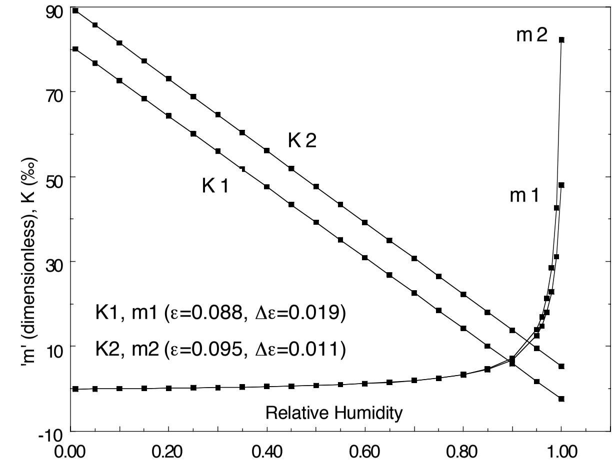
B Time course for deuterium in constant volume pans containing water 20-100mm deep, December



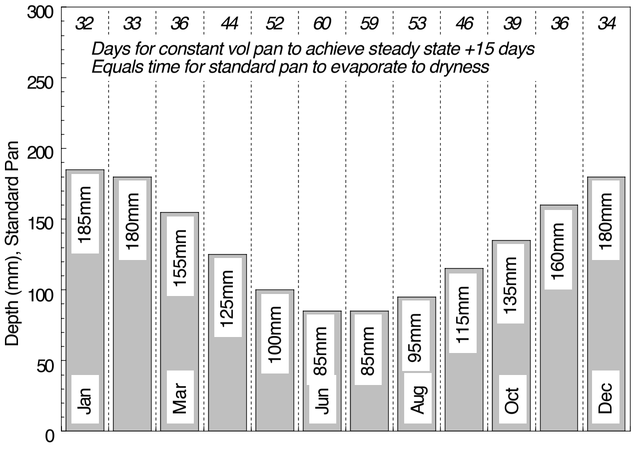
C Time course of deuterium in constant volume pan, water 80mm deep, July-December



D Relationship between relative humidity, 'm' & K at various isotopic exchange parameters



E Initial pan run planning guide (1995) to estimate run time & standard pan start depth.



Isotopic Exchange Parameters Evaporation Pan Experiment Theory & Design

Figure 12.3

Panel Notes:

A-C: δ computed using eqn 12.17 (eqn 9 of Allison & Leaney 1982), δ^o set to -16.5‰, ε set to 0.095, Δε set to 0.011

D: δK computed using eqn 12.18 (eqn 10 of Allison & Leaney 1982), δ_A set to -90‰, δ_I set to -12.4‰ m1 & m2 computed using eqn 12.15 (eqn 4 of Allison *et al* 1979)

E: At start depths indicated, standard pan achieves dryness after constant volume pan has operated a minimum 15 days at steady state (=0.9K)

- the expected annual range of *K* would be about 15‰-35‰
- time to steady state could vary anywhere from 10-60 days depending on pan depth

While the equipment was subsequently constructed such that the constant volume pan depth could be varied, a standard depth for all runs was considered desirable for reasons of simplicity of operation and comparison between runs. The data suggested that a constant volume pan depth of 80-90mm would provide reasonable run lengths consistent with satisfactory standard pan start depths. Allison & Leaney (1982) recommended constant volume pan depths of greater than 50mm and less than 100mm. A bar graph (Figure 12.3e) shows time to achieve constant volume steady state vs standard pan run time to achieve dryness. In the experiments a general rule of thumb was to set standard pan start depth such that evaporation to dryness was achieved in at least double the time required to achieve steady state in the constant volume pan. In practice relative humidity was normalised to lake surface temperature. However, lacking such data in the planning phase, non normalised data was used, knowing that this would result in relative humidity and pan run times somewhat greater than required. In time, as data from the early runs became available, run times were shortened.

12.3.2 Equipment Design and Construction

In order that exchange parameters determined from evaporation pans can be applied to nearby lakes, two criteria must be met:

- the pan temperature must be maintained within a few degrees of the lake surface temperature
- the parameter *m* must be computed from humidity normalised to the lake surface temperature

Principal design concepts are summarised below and in Figure 12.4.

Thermal regulation

- The equipment was located in a Water Corporation sewage pumping station yard adjacent East Lake (Figure 5.1a) which provided security and 240 volt power.
- Lake water was pumped from the centre of East Lake 130m to the experiment. The feed line was weighted with bricks, and buried 100mm into the lake sediments. On shore a buried conduit of 100mm PVC beneath public walk paths carried the inlet line to the site and served as a used water return. While in the conduit the inlet was thus bathed in return water at close to lake temperature ensuring less temperature loss than burying it directly in the ground.
- In summer East Lake approaches dryness (<30cm at its deepest point). Therefore the inlet had to be located at the deepest point within a sediment trap. Shallow lakes on the Swan Coastal Plain are generally well mixed (Davis *et al* 1993). Subsequent monitoring showed that water drawn from the trap was generally within 1˚C of surface water.

- The evaporating pans were constructed from 200 litre steel drum bases and hot dip galvanised. They were mounted eccentrically within two Class A evaporation pans (thermal regulation pans) via welded 30x30mm RHS steel frames. The eccentric mount pattern kept the pans close to the centre of the shelter thus minimising rain drift.

- Lake water drawn by a continuous duty 0.5hp Mono pump entered the thermal regulation pans via a flow splitter. Level was controlled by two fixed outlets with gravity return to the lake. Measured pumping rate was approximately 1900 litres hr^{-1} resulting in a residency time within each pan of about 10 minutes. Water entered close to the base and was directed to create a circular mixing pattern ensuring circulation beneath the evaporation pans with no thermal dead spots.

Pan evaporated to dryness ('standard pan')

- Principal requirement was for accurate daily measurement of depth to compute *f*. An inverted point gauge (Figure 12.4f) adapted from Hunt (1925) was designed which could provide water surface level (and daily evaporation) accurate to 0.2mm. A small rain gauge (not shown) recorded any storm rain drift.

Constant volume pan

- Principal requirement was for precise and consistent level (and hence volume) control. The control system comprised a cylindrical reservoir and manometer (Figure 12.4e) coupled to an agricultural drink trough float valve (Figure 12.4g). Custom arm, float assembly and close coupled float stilling well were designed such that daily level was maintained within ±1mm.

- The reservoir was calibrated such that daily evaporation (accurate to better than 0.1mm) could be computed from a reservoir volume change. Due to its extreme height to width ratio 1mm of pan evaporation resulted in a 14.9mm change in manometer level.

- Output from the float valve was via a small hose to prevent evaporation. Brass counter weights on the float arm allowed precise adjustment of water level.

Feed stock water

Allison & Leaney (1982) note that where pan parameters are to be applied to an adjacent lake, choosing δ_I such that $K \approx \delta_{Lake}$ minimises the effects of errors in *m*. Sampling of lake and groundwater in release zones of other Swan Coastal Plain wetlands (Townley *et al* 1993b) suggested an annual deuterium range of at least 40‰ was likely. There was therefore little point in seasonally varying δ_I. Instead locally derived groundwater was used such that δ_I was similar to groundwater discharge into East Lake. Waters in piezometer nest N3 plot on the meteoric water line (MWL). Discharge to East Lake is therefore unevaporated groundwater. Water from CSIRO irrigation bore #2 plot in the same unevaporated groundwater field (Figure 12.1) and were used as pan feed stock. Feed stock details are summarised below.

- Water was stored in tightly sealed 200 litre plastic drums. Water for immediate use was stored in a 200 litre galvanised steel drum with spigot.

- Transfer from the plastic drums to the steel drum was accomplished by pressurising the plastic drums with an air compressor, forcing water out via a sealed hose precluding exposure to the atmosphere.

Isotope Experiment Layout

Figure 12.4

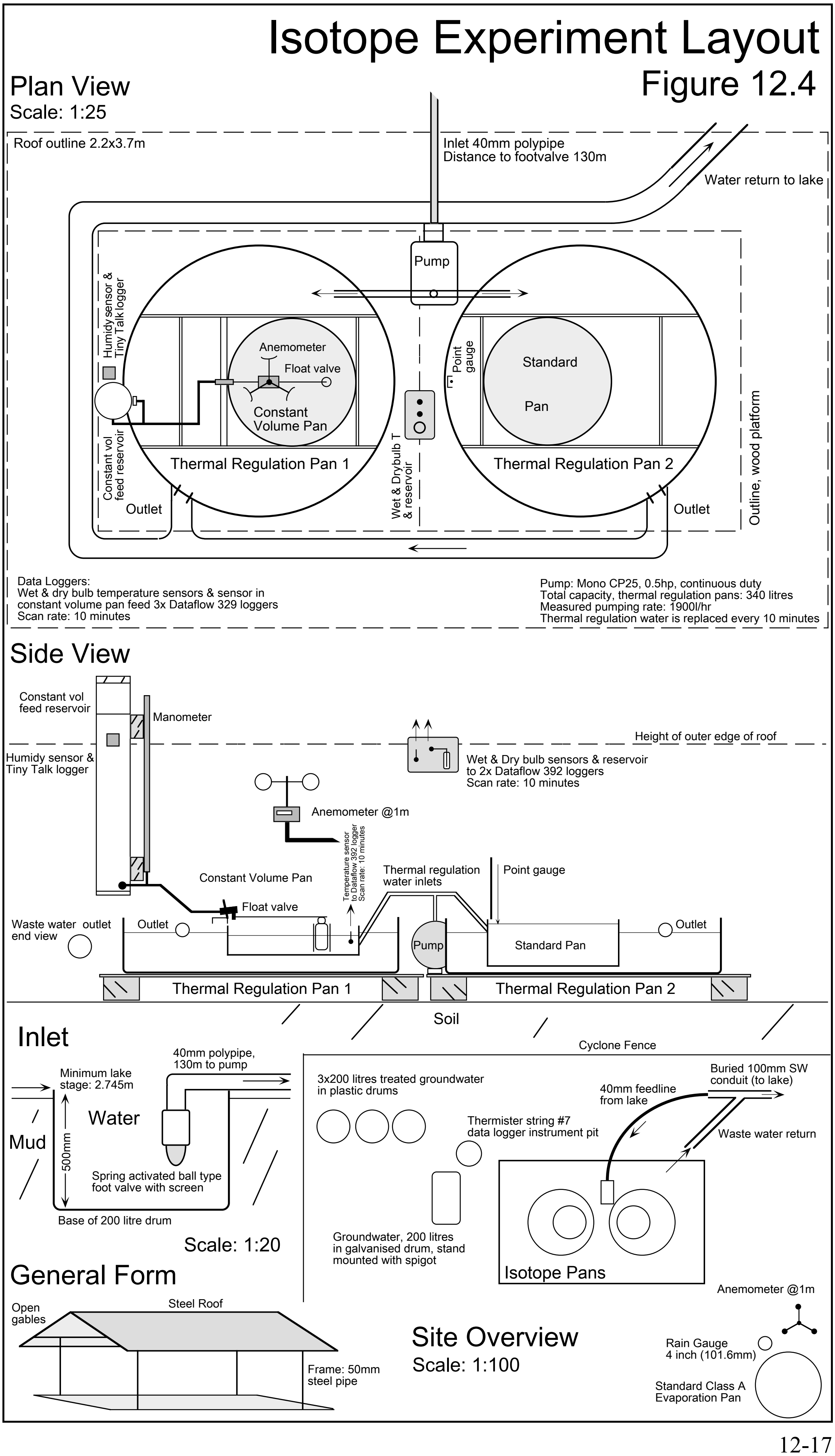
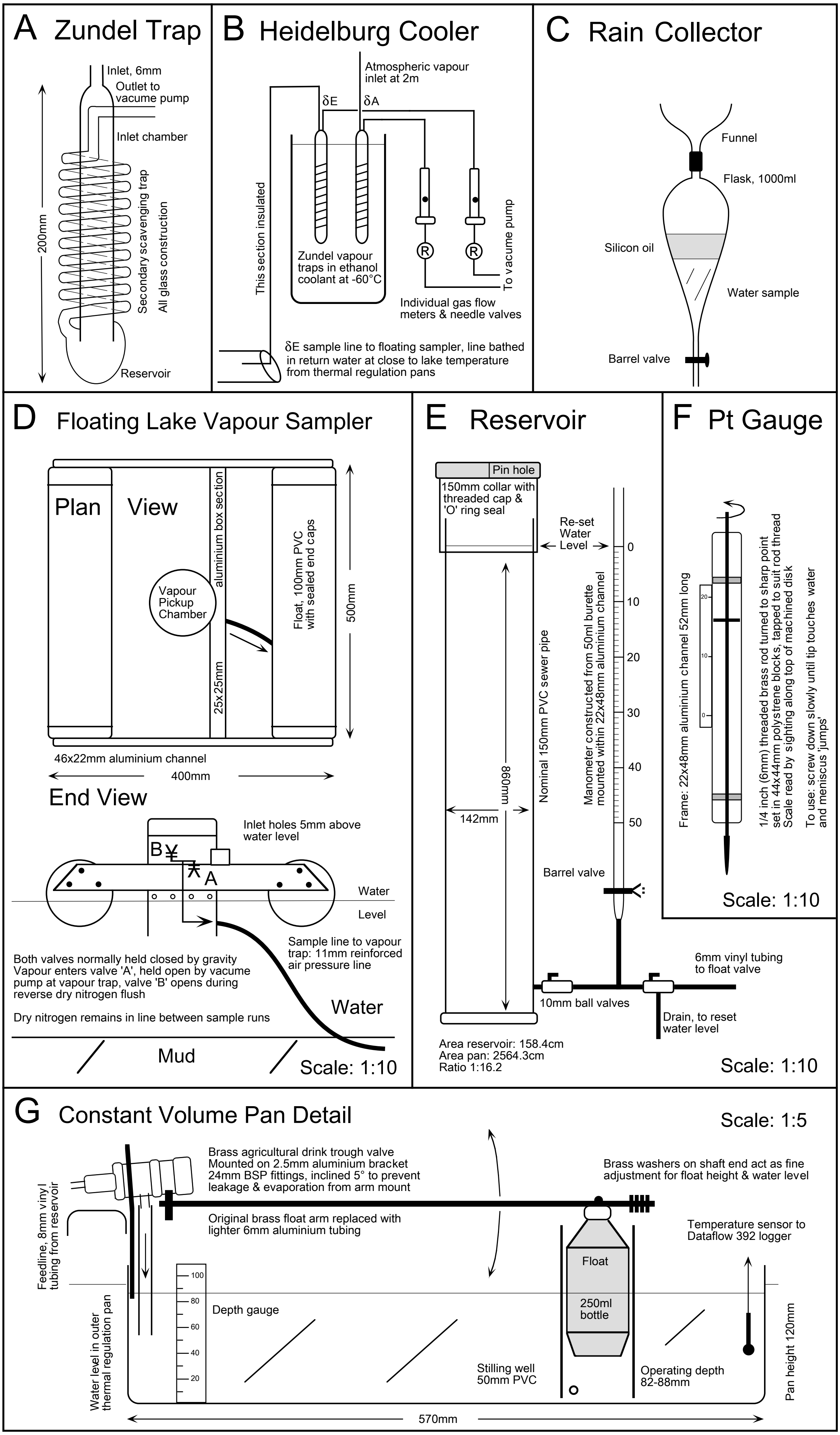


Figure 12.4


A Zundel Trap
Inlet, 6mm
Outlet to vacume pump
Inlet chamber
200mm
Secondary scavenging trap
All glass construction
Reservoir
B Heidelburg Cooler
Atmospheric vapour inlet at 2m
δE
δA
This section insulated
Zundel vapour traps in ethanol coolant at -60°C
R
R
To vacume pump
Individual gas flow meters & needle valves
δE sample line to floating sampler, line bathed in return water at close to lake temperature from thermal regulation pans
C Rain Collector
Funnel
Flask, 1000ml
Silicon oil
Water sample
Barrel valve
D Floating Lake Vapour Sampler
Plan View
aluminium box section
Vapour Pickup Chamber
Float, 100mm PVC with sealed end caps
500mm
25x25mm
46x22mm aluminium channel
400mm
End View
Inlet holes 5mm above water level
B
A
Water
Level
Sample line to vapour trap: 11mm reinforced air pressure line
Both valves normally held closed by gravity Vapour enters valve 'A', held open by vacume pump at vapour trap, valve 'B' opens during reverse dry nitrogen flush
Dry nitrogen remains in line between sample runs
Water
Mud
Scale: 1:10
E Reservoir
Pin hole
150mm collar with threaded cap & 'O' ring seal
Re-set Water Level
0
10
20
30
40
50
860mm
142mm
Nominal 150mm PVC sewer pipe
Manometer constructed from 50ml burette mounted within 22x48mm aluminium channel
Barrel valve
10mm ball valves
6mm vinyl tubing to float valve
Drain, to reset water level
Area reservoir: 158.4cm
Area pan: 2564.3cm
Ratio 1:16.2
Scale: 1:10
F Pt Gauge
Frame: 22x48mm aluminium channel 52mm long
20
10
0
1/4 inch (6mm) threaded brass rod turned to sharp point set in 44x44mm polystrene blocks, tapped to suit rod thread Scale read by sighting along top of machined disk
To use: screw down slowly until tip touches water and meniscus 'jumps'
Scale: 1:10
G Constant Volume Pan Detail
Scale: 1:5
Brass agricultural drink trough valve Mounted on 2.5mm aluminium bracket 24mm BSP fittings, inclined 5° to prevent leakage & evaporation from arm mount
Brass washers on shaft end act as fine adjustment for float height & water level
Original brass float arm replaced with lighter 6mm aluminium tubing
Feedline, 8mm vinyl tubing from reservoir
Float
250ml bottle
Temperature sensor to Dataflow 392 logger
100
80
60
40
20
Depth gauge
Water level in outer thermal regulation pan
Stilling well 50mm PVC
Operating depth 82-88mm
Pan height 120mm
570mm

Initial tests (February 1996) suggested algae could pose a significant problem in the pans. All water was therefore treated as follows:

- Pool chlorine (calcium hypochlorite) was added to all storage drums to achieve approximately 5ppm free dissolved chlorine
- Pans were treated with pool algicide[2] (<1ml) as required

Instrumentation

The most critical parameter is humidity. In hindsight a ventilated wet and dry system such as the design of Alksnis *et al* (1991) would have been preferable particularly under night time high humidity low to nil wind conditions. In the event however a simpler non aspirated wet and dry bulb system (Figure 12.4) was used for the entire experiment.

- Wet bulb sensor comprised cotton wick and distilled water reservoir over Dataflow temperature sensor and adjacent 'dry bulb' sensor within mini naturally ventilated screen constructed from styrofoam sheet. Logger scan rate 10 minutes. Data was reduced using the standard Bureau of Meteorology (BOM) 'Non-ventilated wet bulb depression' chart. This was transcribed into EXCEL as a 'Lookup' chart allowing logger wet and dry bulb data to be converted directly to relative humidity.
- Back up was provided by an 'Orion' Tiny Talk relative humidity logger set to 20 minute scan rate. This instrument is rated to 98% relative humidity (*i.e.* non condensing conditions) and proved inaccurate close to dew point.
- Constant volume pan temperature was logged using a third Dataflow logger also at 10 minute scan rate. Lake surface, mid level and bottom temperatures were logged adjacent to the mid lake water inlet (refer Figures 5.1a and 9.5).
- Wind run at 1m was logged over the constant volume pan and adjacent to the pan shelter using manual readout cup anemometers. A Class A evaporation pan with bird guard and rain gauge were also operated adjacent to the shelter.

Despite the 'low tech' nature of the equipment careful design and calibration allowed very precise measurements to be made. Principal data is included as Appendix 12.1.

12.3.3 Methodology

Commencing and completing a 'pan run'

Run commencement

- Reservoir and all tubing filled, any air removed, both pans filled to operating depth via hose from feed stock reservoirs, constant volume pan manometer reservoir reset to '0' level, 'standard' samples of feedwater at t=0 collected (Nylex 10ml vials).

Run conclusion

- on completion standard pan washed out to remove salt and residual brine, constant volume pan drained via syphon, cleaned, both pans then air dried. Generally a run finished at 08:00 hr. Depending on repair and maintenance required the next run commenced one hour later or at 08:00 hr the following day.

---

[2] 'Alginox', Harcross Chemicals Pty Ltd, active ingredient 150g/litre benzalkonium chloride

Daily methodology

The experiment was operated continuously for 23 months. Daily reading and water sampling was completed about 08:00 hr. A strict daily regimen was developed as summarised below.

- check pump and circulation
- read constant volume pan feed manometer, reset by adding water to reservoir, read level of constant volume pan, adjust float counter weights as required if level is drifting
- read standard pan level with point gauge
- read temperatures in both pans and both thermal regulation pans using glass laboratory thermometers (as check against data logger files)
- take manual humidity measurement using sling psychrometer (as check against wet and dry bulb logger data)
- read anemometers, rain gauge, drift gauge, Class A pan, top up wet bulb reservoir
- take water sample plus duplicate from both pans, (Nylex 10ml vials)
- water sample centre of East Lake (Nylex 10ml vials), walk to West Lake and sample

East Lake centre of lake waters were sampled conveniently via a tap on the pump outlet. Rainwater for isotopic analysis was collected beneath silicon oil (Figure 12.4c) from a site adjacent to CSIRO Laboratories. Isolated rain events were sampled individually, frontal events were integrated and sampled once fine weather resumed (generally after 1-2 days).

12.3.4 Notes on Salinity in Evaporation Pans

Feed stock water varied from 210 to 350mg/l Cl, equivalent to approximately 0.380 to 0.663mg/l salt. Figures 12.2 d&e demonstrate salinity change in pans evaporated to dryness and evaporated at constant volume as a function of volume reduction and time. High levels of solutes reduce evaporation (Raoult's Law) by lowering the saturated vapour pressure of the evaporating water. The activities of isotopic species are likewise reduced (Dinçer 1968). Compared to fresh water, evaporating saline water exhibits less isotopic enrichment and will achieve a lower steady state δ_S when evaporated under the same meteorological conditions (Gonfiantini 1965 cited Dinçer 1968). As salinity increases ion hydration, and the incorporation of crystallisation water in saline precipitate impart additional effects (Clark & Fritz 1997).

The isotopic time course of saline waters evaporated to dryness typically display distinctive 'hooked' patterns. This phenomenon has been extensively documented in natural salinas (Lloyd 1966, Fontes & Gonfiantini 1967, Horita & Gat 1989), in pan experiments using sea water (Gonfiantini 1965 cited Dinçer 1968, Lloyd 1966) and in theoretical modelling (Sofer & Gat 1972 & 1975, Vlasova & Brezgunov 1978 cited Ferronsky & Polyakov 1982, Gat 1981c).

Using distilled water as feed stock it should be possible to run a constant volume pan for a year or longer, providing a continuous record of *K*. In the Perry Lakes experiments however salt accumulation from the groundwater feed stock precluded continuous operation. In the pan evaporated to dryness salinity rose exponentially as dryness was approached (Figure 12.2d). Depending on start depth (50-200mm) and feed stock, sea water salinity was reached at pan depths of 0.5 to 4.0mm (Table 12.3).

Table 12.3 Depth (mm) at which S equals sea water (35‰)

Depth at V_O	V/Vo	50mm	100mm	150mm	200mm
210mg/l Cl at V_O	0.01	0.5	1.0	1.5	2.0
350mg/l Cl at V_O	0.02	1.0	2.0	3.0	4.0

V is pan depth at time t, V_o is initial pan depth at t=0

12.3.5 Notes on Fractionation Enrichment Factors and 'm'

Isotope fractionation is a physio chemical process ultimately controlled by the difference in bond strengths of isotopic species (Clark & Fritz 1997). A number of more subtle factors also affect isotopic exchange calculations. These corrections are frequently omitted in simple estimates or in reactions where fractionation is small. Where fractionation is strong or δ values large however these corrections often become significant. In depth discussions are provided by Craig & Gordon (1965) and Gat (1981c). Four fractionation factors appear in equations presented in this chapter:

ρ_L^* isotropic transport resistance of water
ε^* equilibrium enrichment factor
$\Delta\varepsilon$ kinetic enrichment factor
ε total enrichment factor (equals $\varepsilon^* + \Delta\varepsilon$)

Transport resistance ρ_L^* is small and is usually neglected (Craig & Gordon 1965). The equilibrium term ε^* is temperature dependent, increasing as temperature decreases (Dinçer 1968, Table 1) being for deuterium 0.0958 at 0˚C and 0.0733 at 20˚C decreasing to 0.069 at 25˚C (Craig & Gordon 1965). Majoube (1971) cites a value of 0.082 at 17.2 ˚C while experimental values determined from constant volume pans (Allison & Leaney 1982) ranged from 0.087 to 0.091 at room temperature.

The kinetic enrichment factor $\Delta\varepsilon$ for deuterium is known to vary greatly depending on environmental conditions and appears to vary diurnally with humidity and wind speed (Gat 1970). Allison *et al* (1979) note that if there is a choice between the use of ^{18}O and ^{2}H in a water balance study, deuterium is preferable due to the smaller influence of $\Delta\varepsilon$ which is both variable and difficult to determine. Merlivat (1970) determined kinetic enrichment factors in the range 0.009-0.015 (at mean relative humidity 0.5-0.65) for both ^{2}H and ^{18}O. Craig and Gordon (1965) cite 0.019 for ^{2}H at 25˚C. In this study ε^* was set to 0.084 and $\Delta\varepsilon$ 0.011 yielding ε of 0.095. These values are unlikely to introduce significant errors under the meteorological conditions encountered at Perry Lakes. The parameter *m* is frequently approximated by h/(1-h) (Allison *et al* 1979) however the errors imposed by ignoring or applying incorrect the isotopic enrichment factors become unacceptable at high relative humidity (Figure 12.3d). This figure also demonstrates the relationship between *h, m,* and *K* at different ε & $\Delta\varepsilon$.

12.4 PAN EXPERIMENT PERFORMANCE ASSESSMENT

12.4.1 Volume Regulation

The constant volume pan depth was maintained within 2mm of start depth, representing volume excursions of no more than ± 2.4%. Table 12.4 summarises pan volume data.

Table 12.4 Comparative pan statistics Runs 1-20

Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mean depth	85.1	84.2	84.3	84.3	83.2	82.3	82.0	81.8	82.3	82.3	81.3	82.2	82.4	83.3	83.5	83.2	83.1	81.7	82.1	81.6
Mean volume	21.80	21.58	21.60	21.60	21.32	21.10	21.02	20.97	21.10	21.10	20.85	21.07	21.12	21.35	21.40	21.32	21.30	20.95	21.05	20.92
Start depth	156	75	75	75	75	120	100	100	100	100	100	75	75	50	50	50	100	150	200	
Start volume	40.97	19.86	19.86	19.86	19.86	31.59	26.38	26.38	26.38	26.38	26.38	19.86	19.86	13.35	13.35	13.35	26.38	39.41	52.44	

Mean depth-volume refers to constant volume pan, start depth-volume refers to pan evaporated to dryness ('standard pan')
All depths in mm, all volumes in litres

12.4.2 How Typical of the Lake was the Isotope Experiment Site?

Evaporation pans and any adjacent lake of interest must be evaporated under similar meteorological conditions if pan derived exchange parameters are to be applied to the lake with any degree of confidence. In this section we compare wind run, water temperature and evaporation over East Lake and at the pan experiment.

Wind Run

The pan site was comparatively sheltered compared to the open water surface of the lake. Table 12.5 summarises wind run. Pan anemometers were not operated runs 1-6. Figure 12.5c compares pan and lake weekly mean wind velocity for 1997.

Table 12.5 Comparative wind run at 1m over pans and East Lake

Run	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pans (km)	1125	1021	854	1321	1625	1489	1027	1246	982	1377	1767	2169	1894	2428
Lake (km)	3020	2796	2405	3074	3460	3348	3073	3796	2779	3727	4664	5336	4130	5597
Pan:Lake %	37.3	36.5	35.5	43.0	47.0	44.5	33.4	32.8	35.3	36.9	37.9	40.6	45.8	43.4

Higher values (runs 10-12 and 18-20) occur over summer when strong easterlies alternate with strong southwest afternoon sea breezes. Lowest values (runs 13 & 14) occur in late summer and early winter marked by weak frontal activity and lighter, generally westerly winds. Average pan:lake wind run ratio was 39.3%. This large difference was expected. A site less sheltered from the wind would have been desirable but was simply not possible for security reasons. On the basis of wind run alone, the pan site would appear to be a poor analogue of the lake however the fact that pan and lake evaporation were often similar suggests that reduced wind run had little effect on the outcome of the experiment.

Temperature Control

Adequate temperature regulation was considered to be the single most important criteria in the pan experiments. The concept of operating pans isothermally with a nearby lake appears frequently in the literature (Gat 1970, Welhan & Fritz 1977, Allison & Leaney 1982) although Perry Lakes appears to be the first time the concept has been applied under field conditions. Table 12.6 summarises pan-lake thermal regulation statistics.

Table 12.6 Comparative pan:lake temperature statistics Runs 1-20

Run	1	2	3	4	5	6	7	8	9	10
Av pan T	19.1	14.9	15.8	18.3	20.5	23.5	23.7	25.4	25.8	24.8
Av lake T	19.4	14.8	16.5	19.5	22.3	24.6	25.0	26.5	27.0	25.8
Av difference	0.2	-0.2	0.7	1.1	1.7	1.1	1.3	1.2	1.2	1.0
Max lake-pan	2.6	1.4	2.1	2.3	2.9	3.3	2.6	3.0	3.3	3.9
Min lake-pan	-1.7	-1.5	-1.4	0.5	0.6	-0.4	0.1	-0.2	-0.5	-1.5
Std Dev of dif	0.49	0.32	0.43	0.37	0.39	0.54	0.38	0.65	0.83	1.05
Run	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Av pan T	24.2	21.9	19.1	16.3	13.7	15.3	19.4	22.0	23.8	24.0
Av lake T	26.1	23.5	20.2	16.6	14.0	16.2	21.0	23.4	26.2	25.4
Av difference	1.8	1.6	1.1	0.3	0.3	1.0	1.5	1.3	2.4	1.4
Max lake-pan	6.3	6.0	4.2	2.4	2.6	2.6	4.4	3.6	10.6	8.2
Min lake-pan	-0.7	-0.3	-0.6	-1.7	-2.2	-1.4	0.1	-0.6	-1.8	-2.3
Std Dev of dif	1.55	1.12	0.57	0.46	0.57	0.48	0.55	0.81	2.56	2.05

Average pan and lake temperature refers to temperature in constant volume pan and lake surface temperature in centre of East Lake. Maximum and minimum are maximum difference between instantaneous lake and pan temperatures. Std Dev is standard deviation of the difference between instantaneous lake surface and pan temperatures. Temperatures recorded every hour Runs 1-5, every 10 minutes Runs 6-20. Data for Run 20 is January 20-February 14 1998 (following pump re-build).

In general thermal regulation was better over winter (Runs 1-6 and 13-18) than summer (runs 7-12 and 19-20). This occurred for the following reasons:

- greater summer head difference between inlet and pump and reduced water viscosity resulting in reduced summer pump efficiency
- reduced summer lake area (particularly Runs 19 and 20) resulted in cooling from the feed line exposed on the lake bed
- sediment build up in the feed line and general degradation of pump efficiency reduced the pumping rate as the experiments proceeded and culminated in pump failure early in Run 20 when the experiment was lacking thermal regulation for five days

Figures 12.5 a &b demonstrate typical lake-pan temperature regimes over weekly periods in early summer and early winter. Over summer the pans tended to lag behind the lake and at any time were typically about 1 degree cooler than the lake. Over winter the pans tracked lake temperature very closely. Typically the lake midday surface maximum exceeded pan temperature by about 0.5° while at other times the difference was less than 0.5° and often within 0.2°. It is worth remembering that water could not be drawn from the surface of the lake so in summer the thermal regulation water was typically 1 degree cooler than the surface and in winter (with positive sediment heat fluxes) was sometimes up to 1 degree warmer than the surface water.

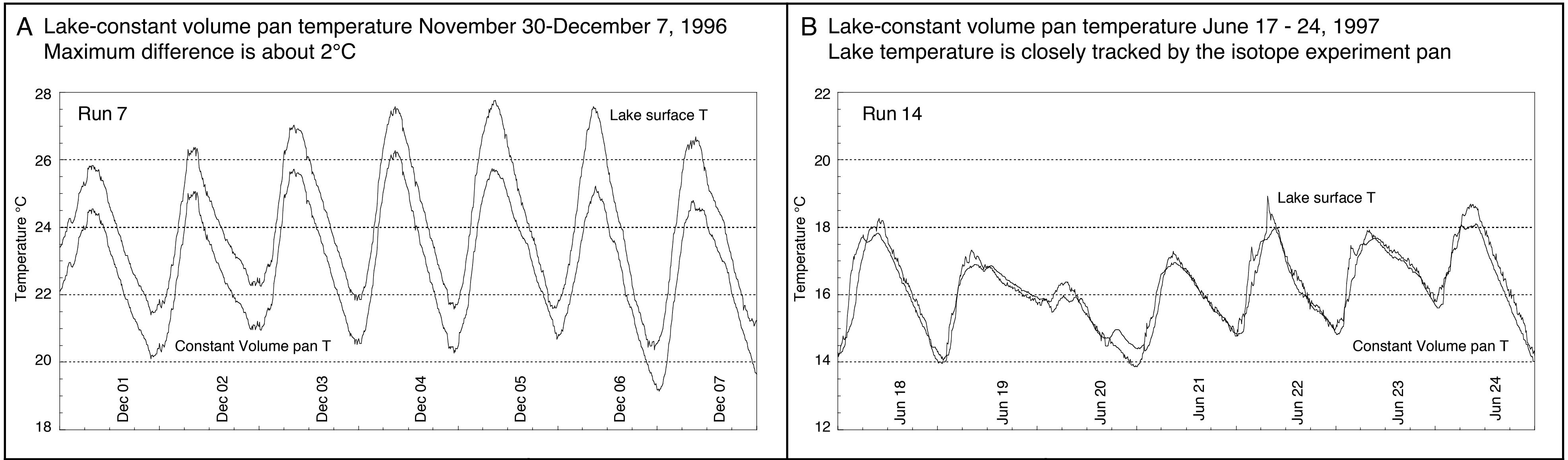
Evaporation

Evaporation is the best indicator of whether exchange parameters determined from pans can be applied to an adjacent lake. If evaporation in the pans and lake are similar it can be concluded that the aggregate meteorological conditions at both sites were also similar. An ideal experimental site would have allowed the pans to be located in a large flat clear area immediately adjacent to the water. No such sites were possible. The sewage pumping compound represented a less than ideal compromise.

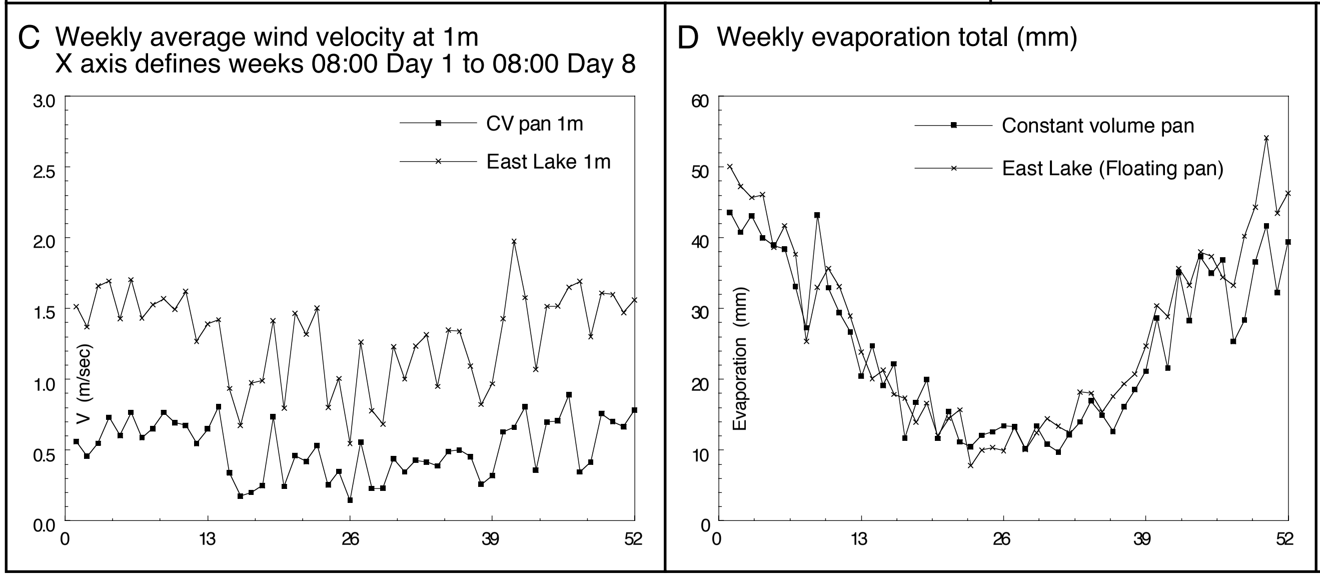
It was expected that:

- Pan evaporation would be less than the lake due to reduced wind and little direct solar heating. Pans were partially within direct sunlight only at low winter sun angles
- Constant volume pan evaporation would more closely approximate the lake than the pan evaporated to dryness due to reduced wind exposure at low pan levels as dryness was approached

Unknown factors included the effects of radiant heating and cooling from an adjacent brick building and the metal pan shelter roof, and reduced efficiency of the pan


A Lake-constant volume pan temperature November 30-December 7, 1996
Maximum difference is about 2°C

B Lake-constant volume pan temperature June 17 - 24, 1997
Lake temperature is closely tracked by the isotope experiment pan


C Weekly average wind velocity at 1m
X axis defines weeks 08:00 Day 1 to 08:00 Day 8

D Weekly evaporation total (mm)

Meteorological Comparison CV pan and East Lake

Figure 12.5

Notes

A&B: December data represents typical maximum summer difference between pans and lake. During cooler weather pans tracked with 0.5°C of lake

C: Sheltered position of the isotope experiment severely attenuated wind run compared to the lake. The lake itself is severely sheltered compared to open areas

Data 1997	Daily Av (m/sec)	Daily Run (km)	Annual Run (km)
CV pan 1m	0.51	44.2	16175
Lake 1m	1.30	112.2	41055
Lake 2m	1.38	119.0	43555
Lake 5m	1.54	132.8	48622
Perth Airport 3m	2.75	237.7	87011

temperature regulation at low summer lake levels. Pan and lake evaporation is summarised on a pan run basis (Table 12.7) and weekly (Figure 12.5d).

Table 12.7 Comparative evaporation Runs 1-20

Run	1	2	3	4	5	6	7	8	9	10
CV pan	165.6	83.8	80.7	77.5	93.8	139.6	116.6	122.7	108.0	123.7
East Lake	209.9	97.3	83.4	84.2	92.4	142.4	118.9	141.1	123.8	128.6
Pan: Lake %	78.9	86.1	96.8	92.0	101.5	98.0	98.1	87.0	87.2	96.2
Std pan	156	75	75	75	75	120	100	100	100	100
East Lake	209.9	97.3	83.4	85.2	83.5	139.9	118.9	134.8	123.8	125.0
Pan: Lake %	74.3	77.1	89.9	88.0	89.8	85.8	84.1	74.2	80.8	80.0
Run	11	12	13	14	15	16	17	18	19	20
CV pan	124.8	98.3	88.4	61.5	62.8	67.3	129.2	195.3	162.9	234.7
East Lake	118.0	105.0	82.9	58.4	63.2	76.5	152.4	213.8	207.6	265.9
Pan: Lake %	105.8	93.6	106.6	105.3	99.4	88.0	84.8	91.3	78.5	88.3
Std pan	100	75	75	50	50	50	100	150	200	
East Lake	113.0	104.0	84.0	57.7	62.5	66.8	134.3	184.8	281.8	
Pan: Lake %	88.5	72.1	89.3	86.7	80.0	74.9	74.5	81.2	71.0	

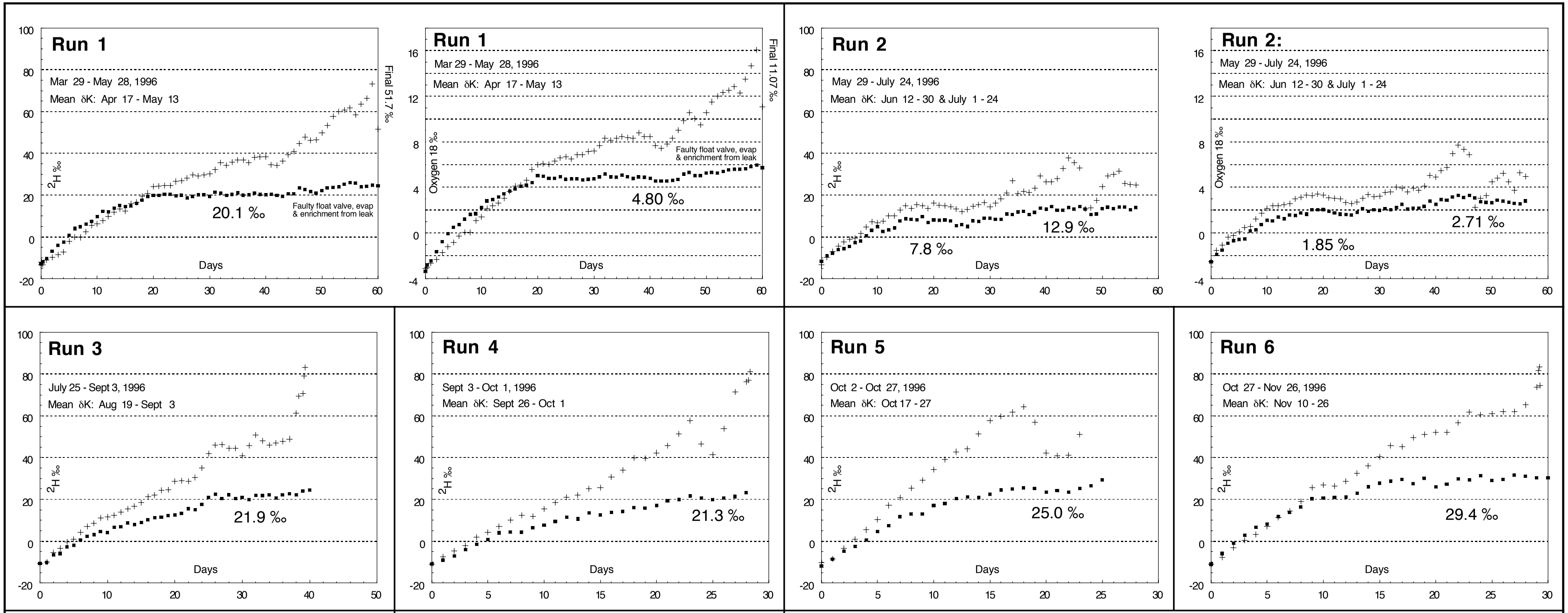
Notes: All pan and lake figures in mm. Area Constant Volume pan: 2532cm^2, Standard pan 2551cm^2. Difference represents 19cm^2 occupied by stilling well and float. Lake evaporation for Runs 1 & 20 partially calculated using pan:lake coefficient for Class A pan at Perth Airport.

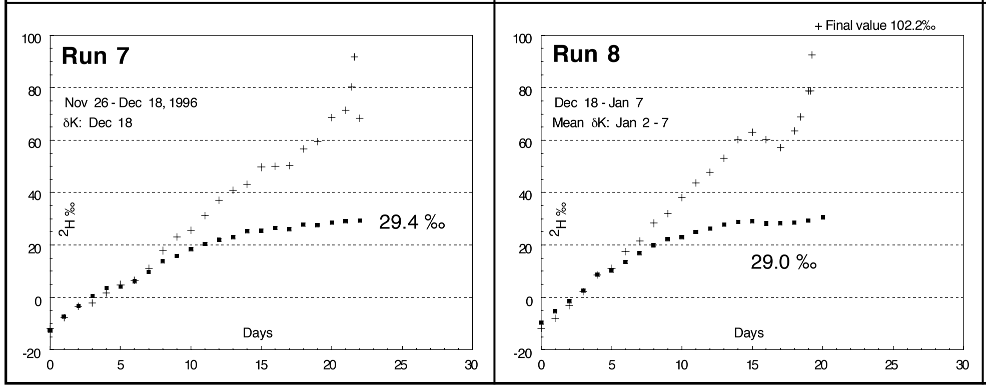
The data largely agree with the expectation that pan evaporation would be somewhat less than lake evaporation. The only real surprise was that on four runs constant volume pan evaporation exceeded the lake by up to 6.6%, concentrated between March and June 1997. The reasons are unclear.

The isotope experiment ran continuously from March 29, 1996 to February 14, 1998 representing 688 days of continuous operation and almost two complete years of flux weighted data. Mean run time was 34.4 days. A total of 1077.3 litres of water were evaporated through the experimental pans (constant volume pan: 596.4 litres, pan evaporated to dryness: 481.9 litres).

12.5 RESULTS

Isotopic time course as raw data, Runs 1-20 for both pans is summarised in Figure 12.6 a&b. Note the frequent salt induced, sudden reduction in deuterium or 'hook' patterns (Section 12.3.4) as water volume diminished in pans evaporated to dryness. Constant volume pan steady state δ_K is apparent in all runs. Mean δ_K is indicated on each graph. Figures 12.7 a&b show graphical representation of steady state δ_S in pans evaporated to dryness. The two pan experiments simply represent different techniques for establishing the same exchange parameters. In the following section experimental results from the two techniques are presented separately. Section 12.5.9 compares exchange parameters determined using both techniques. Data appears as Appendix 12.1.





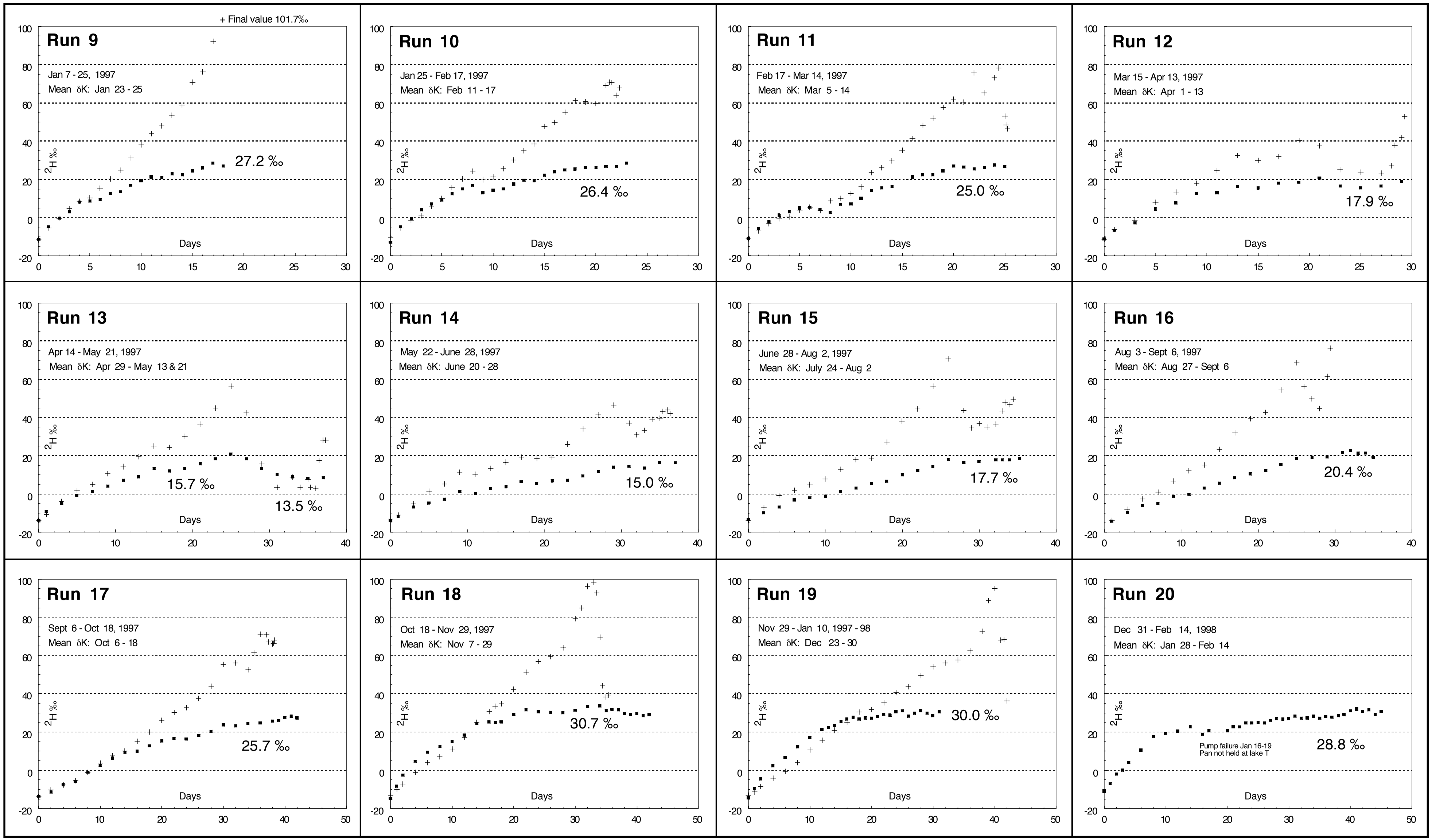
Isotopic Time Course
Constant Volume and Standard Pans

Figure 12.6a

Notes

Standard pan designated by + symbols and always run to dryness
Constant volume pan designated by rectangles
Pans sampled & anaysed daily Runs 1-11, Runs 12-20 analysed every second day
All runs analysed for Deuterium, Oxygen 18 determined for Runs 1 & 2 only
Run length to achieve steady state estimated from theoretical curves (see text)
Note x axis (run time in days) varies from 30 to 60 days
Per mille values are mean steady state (δK) values over period indicated

Figure 12.6b


+ Final value 101.7‰
Run 9
Jan 7 - 25, 1997
Mean δK: Jan 23 - 25
27.2 ‰
Run 10
Jan 25 - Feb 17, 1997
Mean δK: Feb 11 - 17
26.4 ‰
Run 11
Feb 17 - Mar 14, 1997
Mean δK: Mar 5 - 14
25.0 ‰
Run 12
Mar 15 - Apr 13, 1997
Mean δK: Apr 1 - 13
17.9 ‰
Run 13
Apr 14 - May 21, 1997
Mean δK: Apr 29 - May 13 & 21
15.7 ‰
13.5 ‰
Run 14
May 22 - June 28, 1997
Mean δK: June 20 - 28
15.0 ‰
Run 15
June 28 - Aug 2, 1997
Mean δK: July 24 - Aug 2
17.7 ‰
Run 16
Aug 3 - Sept 6, 1997
Mean δK: Aug 27 - Sept 6
20.4 ‰
Run 17
Sept 6 - Oct 18, 1997
Mean δK: Oct 6 - 18
25.7 ‰
Run 18
Oct 18 - Nov 29, 1997
Mean δK: Nov 7 - 29
30.7 ‰
Run 19
Nov 29 - Jan 10, 1997 - 98
Mean δK: Dec 23 - 30
30.0 ‰
Run 20
Dec 31 - Feb 14, 1998
Mean δK: Jan 28 - Feb 14
Pump failure Jan 16-19
Pan not held at lake T
28.8 ‰
^2H ‰
Days
100
80
60
40
20
0
-20
0
5
10
15
20
25
30
40
50

12.5.1 Graphical and Mathematical Determination of Steady State δ_S

Pans evaporating to dryness represent the more difficult technique for determining exchange parameters because as dryness is approached small meteorological changes coupled with the effects of increasingly saline water have very large effects on heavy isotope enrichment. The problem is compounded in summer when relative humidity is low. Theoretically steady state δ_S cannot be achieved under these conditions when $m < 1$ (Allison & Leaney 1982). This is the case for relative humidity less than about 50%.

Graphical solutions for δ_S were computed by fitting least squares curves. These took the form of second or third degree polynomials. Steady state δ_S was calculated at $V/V_o = 0.0001$. It is evident that steady isotopic enrichment was always possible to about $V/V_o = 0.5$ and frequently to $V/V_o = 0.1$. This 'early' data is in fact highly 'flux weighted', representing 50-90% of total evaporative loss and therefore can be used to determine steady state δ_S even where data close to dryness is absent or spurious. In Figure 12.7 different symbols indicate data points used and excluded from the curve fits.

Steady state was also computed mathematically. Rearranging equation 12.8 yields

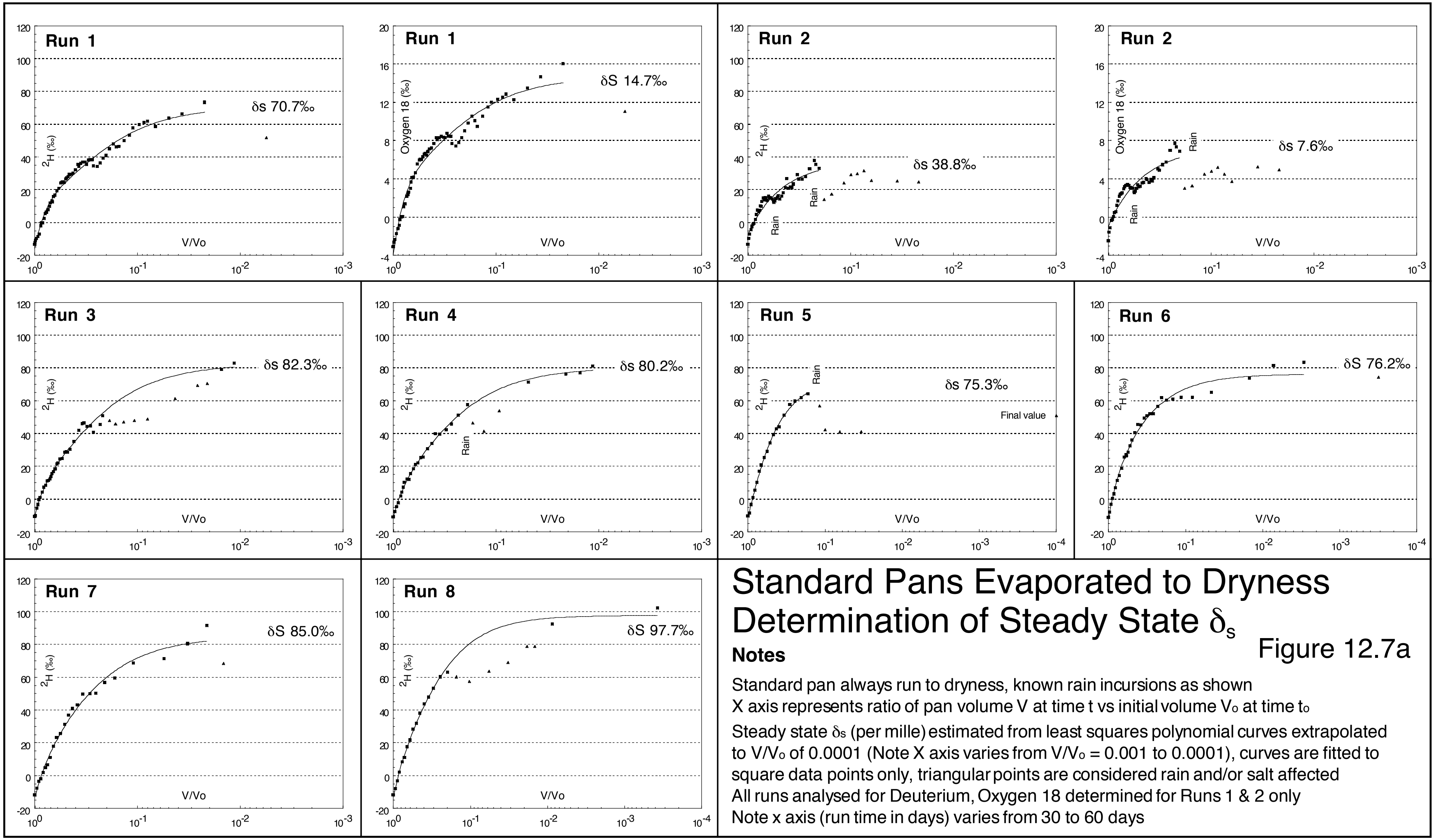
$$\delta_S = \frac{\delta - f^m \delta^0}{1 - f^m} \qquad (12.22)$$

This describes δ_S for constant (in this case daily average) values of h, $\Delta\varepsilon$, $E\rho_L^*$ & α^*, incorporated as m. On a daily basis, computed δ_S varies widely, however, mean daily computed δ_S was usually close to the graphical solution. Again obviously spurious data was excluded. Table 12.8 summarises the data.

Table 12.8 Comparative determination of steady state δ_S Runs 1-19

Run	1	2	3	4	5	6	7	8	9	10
Graphical	70.7	38.8	82.3	80.2	75.3	76.2	85.0	97.7	100.2	74.5
Maths (part)		38.5	59.5	67.6	110.2	113.9	99.0	117.0		86.8
Maths (full)	61.3		60.4	68.2	96.7	103.5	98.2	105.4	98.8	85.2
Run	11	12	13	14	15	16	17	18	19	
Graphical	80.3	60.8	83.6	54.9	103.5	79.4	76.4	103.0	96.8	
Maths (part)	72.9	67.8	51.2	31.9	59.6	60.5	59.2	119.3	81.0	
Maths (full)	70.7			34.3		60.1	61.0	106.8	78.2	

All values are permil (‰), graphical solution employed polynomial curve fit, extrapolated to V/Vo=0.0001, mathematical solutions employ equation 12.22 (Eqn 5 of Welhan & Fritz 1977), 'part' refers to initial part of deuterium time course unaffected by rain and/or salinity, 'full' employed entire data set for each pan run



Standard Pans Evaporated to Dryness Determination of Steady State δ_s

Figure 12.7a

Notes

Standard pan always run to dryness, known rain incursions as shown
X axis represents ratio of pan volume V at time t vs initial volume V_o at time t_o
Steady state δ_s (per mille) estimated from least squares polynomial curves extrapolated to V/V_o of 0.0001 (Note X axis varies from V/V_o = 0.001 to 0.0001), curves are fitted to square data points only, triangular points are considered rain and/or salt affected
All runs analysed for Deuterium, Oxygen 18 determined for Runs 1 & 2 only
Note x axis (run time in days) varies from 30 to 60 days

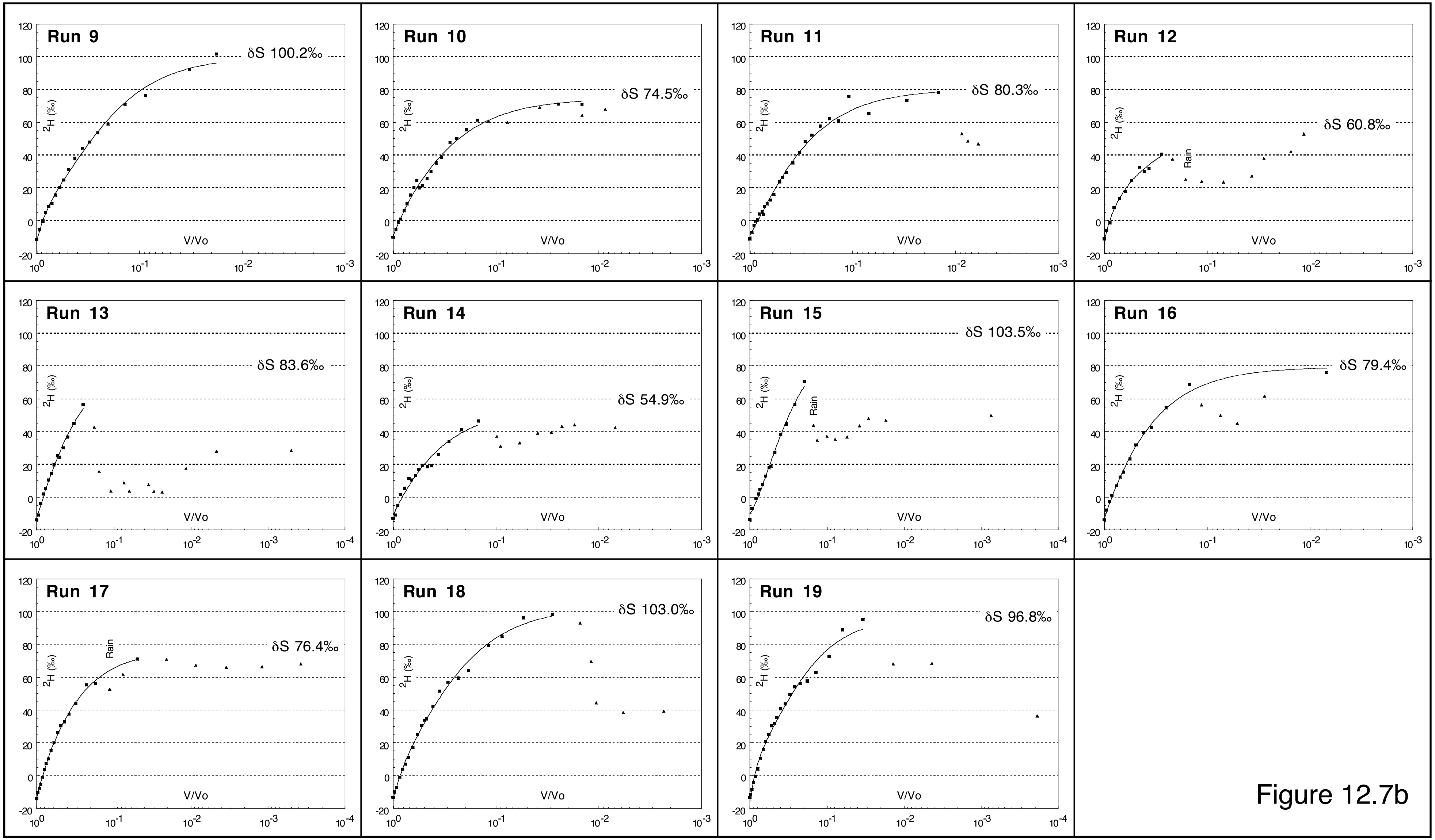

Run 9
δS 100.2‰
Run 10
δS 74.5‰
Run 11
δS 80.3‰
Run 12
δS 60.8‰
Rain
Run 13
δS 83.6‰
Run 14
δS 54.9‰
Run 15
δS 103.5‰
Rain
Run 16
δS 79.4‰
Run 17
δS 76.4‰
Rain
Run 18
δS 103.0‰
Run 19
δS 96.8‰
^2H (‰)
120
100
80
60
40
20
0
-20
V/Vo
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}

Figure 12.7b

An annual δ_S curve was developed as a cosine function fitted to graphical and theoretically derived data (Figure 12.8a). Steady state reflects meteorological parameters ultimately controlled by the annual solar cycle. Steady state maxima and minima appear to be centred on or close to the summer and winter solstice. Daily δ_S is defined by

$$35Cos0.017214x + 75 \tag{12.23}$$

with an annual winter to summer range of 40 to 110‰ and amplitude of 70‰. An annual theoretical relative humidity function was developed in a similar fashion (Figure 12.8b) based on average bi-monthly wet and dry bulb data normalised to lake surface temperature where daily average humidity is defined by

$$11.5Cos0.017214x + 66.5 \tag{12.24}$$

with an annual winter to summer range of 78 to 55%. Note that unlike δ_S, relative humidity is seasonally offset from the solstice with minimum on February 1 and maximum August 3. In these expressions for both δ_S and relative humidity December 21 is taken to be Day 0 and Day 366.

12.5.2 Annual δA from Pan Evaporated to Dryness

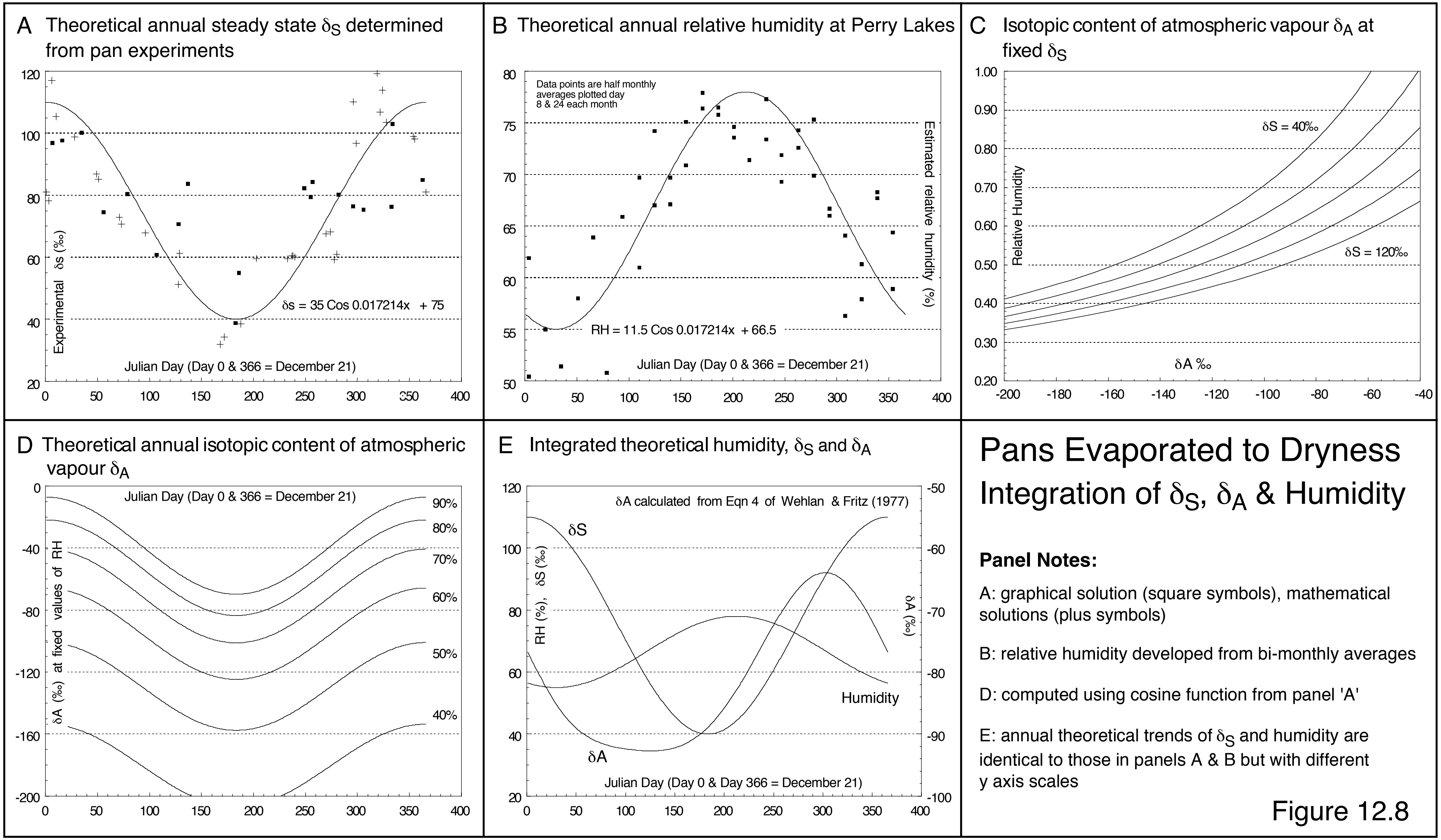
Rearranging equation 12.7 yields

$$\delta_A = \frac{\delta_S(h - \varepsilon) - \varepsilon}{h} \tag{12.25}$$

which defines δ_A for any value of δ_S, *h*. and ε. Setting δ_S to fixed values allows δ_A to be defined for varying relative humidity (Figure 12.8c). More realistically using equation 12.23 to define seasonal variation in δ_S, the seasonal variation in δ_A can be predicted at fixed relative humidity (Figure 12.8d).

12.5.3 Integrated Annual δ_S and δ_A from Pan Evaporated to Dryness

Defining δ_S and *h* by equations 12.23 and 12.24 allows a 'best guess' prediction of annual daily average δ_A calculated from equation 12.25 rearranged from equation 12.7 and equation 4 of Welhan & Fritz (1977). Figure 12.8e shows the predicted annual trend of δ_A plotted along with annual δ_S and relative humidity. The experimental δ_S data suggests that daily average δ_A will diminish (contain less deuterium) over summer and increase over winter with a range of about -92‰ to -64‰. These experimetally predicted trends are compared with measured δ_A later in this chapter.


A Theoretical annual steady state δ_S determined from pan experiments

B Theoretical annual relative humidity at Perry Lakes

C Isotopic content of atmospheric vapour δ_A at fixed δ_S

D Theoretical annual isotopic content of atmospheric vapour δ_A

E Integrated theoretical humidity, δ_S and δ_A

Pans Evaporated to Dryness Integration of δ_S, δ_A & Humidity

Panel Notes:

A: graphical solution (square symbols), mathematical solutions (plus symbols)

B: relative humidity developed from bi-monthly averages

D: computed using cosine function from panel 'A'

E: annual theoretical trends of δ_S and humidity are identical to those in panels A & B but with different y axis scales

Figure 12.8

12.5.4 Estimation of δE_{lake} from Pan Evaporated to Dryness

Rearranging equation 12.14 yields

$$\delta_{E(lake)} = m_{pan}\delta_{lake} - m_{pan}\delta_{S(pan)} - \delta_{lake} \qquad (12.26)$$

Theoretical families of curves for $\delta_{E(lake)}$ can then be generated for varying pan *h* (and hence *m*) and fixed pan δ_S and isotopic concentrations of lake water δ_L (Figure 12.9). All curves pass through a common point where $m = 1$. Remember that a value of unity for *m* is the approximate cut-off for practical development of δ_S using pans evaporated to dryness since for conditions where $m<1$ steady state pan composition is never attained (Allison & Leaney 1982). In some plots one value of $\delta_{E(lake)}$ plots as a vertical line. This occurs where $\delta_S = \delta_L$.

Constant Volume Pan

12.5.5 Graphical Determination of Steady State δ_K

Steady state δ_K was only determined graphically. Data from Figure 12.6 are summarised as Table 12.9. Runs 1 and 2 include ^{18}O data. All other data is deuterium. The seasonal range of the experimentally derived limiting values (12.9‰ to 30.7‰) is similar to the theoretically predicted range (Table 12.2) of 16.2‰ to 34.5‰.

Table 12.9 Experimental steady state δ_K Runs 1-20

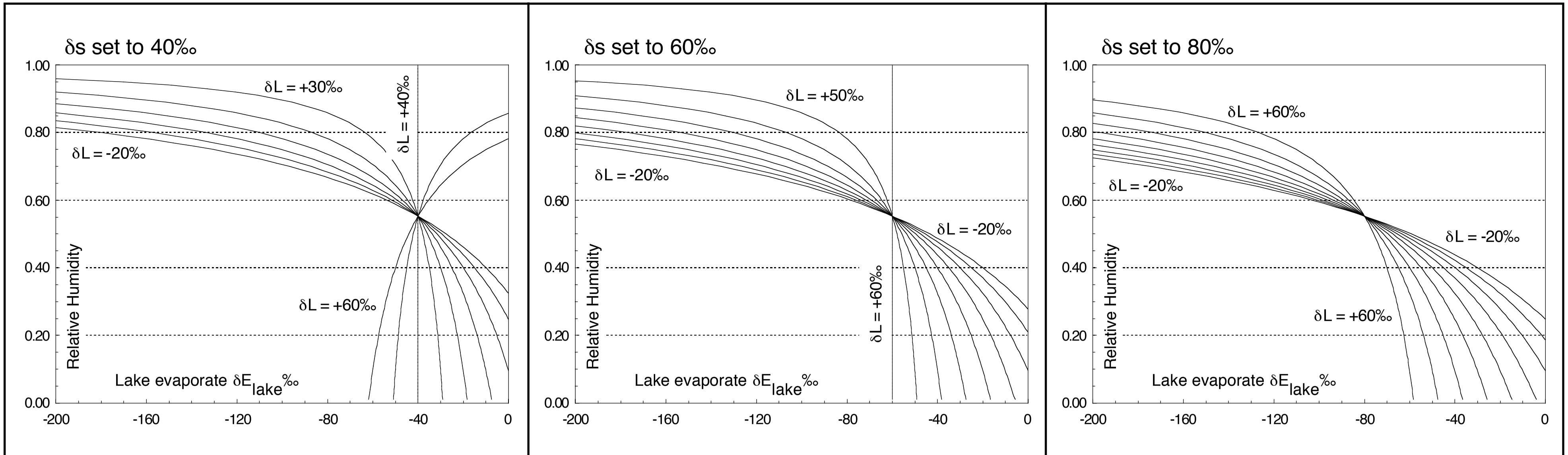
Run	1 ^2H	1 ^{18}O	2 ^2H	2 ^{18}O	3	4	5	6	7	8	9
Mean δ_K (‰)	20.1	4.80	12.9	2.71	21.9	21.3	25.0	29.4	29.4	29.0	27.2
Run	10	11	12	13	14	15	16	17	18	19	20
Mean δ_K (‰)	26.4	25.0	17.9	15.7	15.0	17.7	20.4	25.7	30.7	30.0	28.8

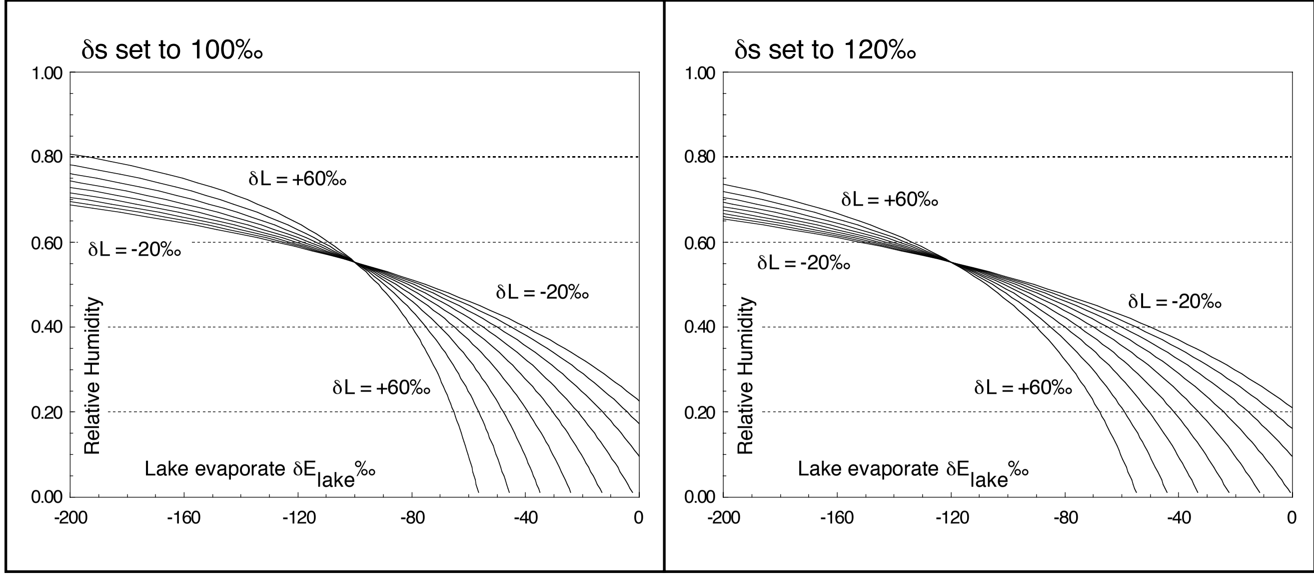
All data is deuterium except as indicated

An annual δ_K curve was also developed as a cosine function but fitted to graphical data only (Figure 12.10a). Again steady state maxima and minima appear to be centred on or close to the summer and winter solstice with summer to winter maximum and minimum of 30.5 to 11.5‰. Daily δ_K is defined by

$$9.5Cos0.017214x + 21 \qquad (12.27)$$

Compared to the data developed from pans evaporated to dryness (Figure 12.8a), the constant volume pan derivation of δ_K displays far less scatter.





Predicted Values of $\delta_{E\ lake}$ at fixed δ_S and δ_L and varying relative humidity

δE_{lake} computed using Equations 11 & 12 of Welhan & Fritz (1977)

δ_S corresponds to annual range of values observed in pans evaporated to dryness

All δ values are per mille (‰)

Figure 12.9

12.5.6 Annual δA from Constant Volume Pan

Rearranging equation 12.18 yields

$$\delta_A = h\left[\left[\frac{\left(K - \dfrac{\delta_I}{(m+1)}\right)(m+1)(h-\varepsilon)}{m}\right] - \varepsilon\right] \qquad (12.28)$$

which defines δ_A for any value of K, δ_I, h and m, (containing h, $\Delta\varepsilon$ and ε). Fixing K allows δ_A to be defined for varying relative humidity (Figure 12.10c). More realistically using equation 12.27 to define seasonal variation in K, δ_A can be similarly predicted at fixed relative humidity (Figure 12.10d).

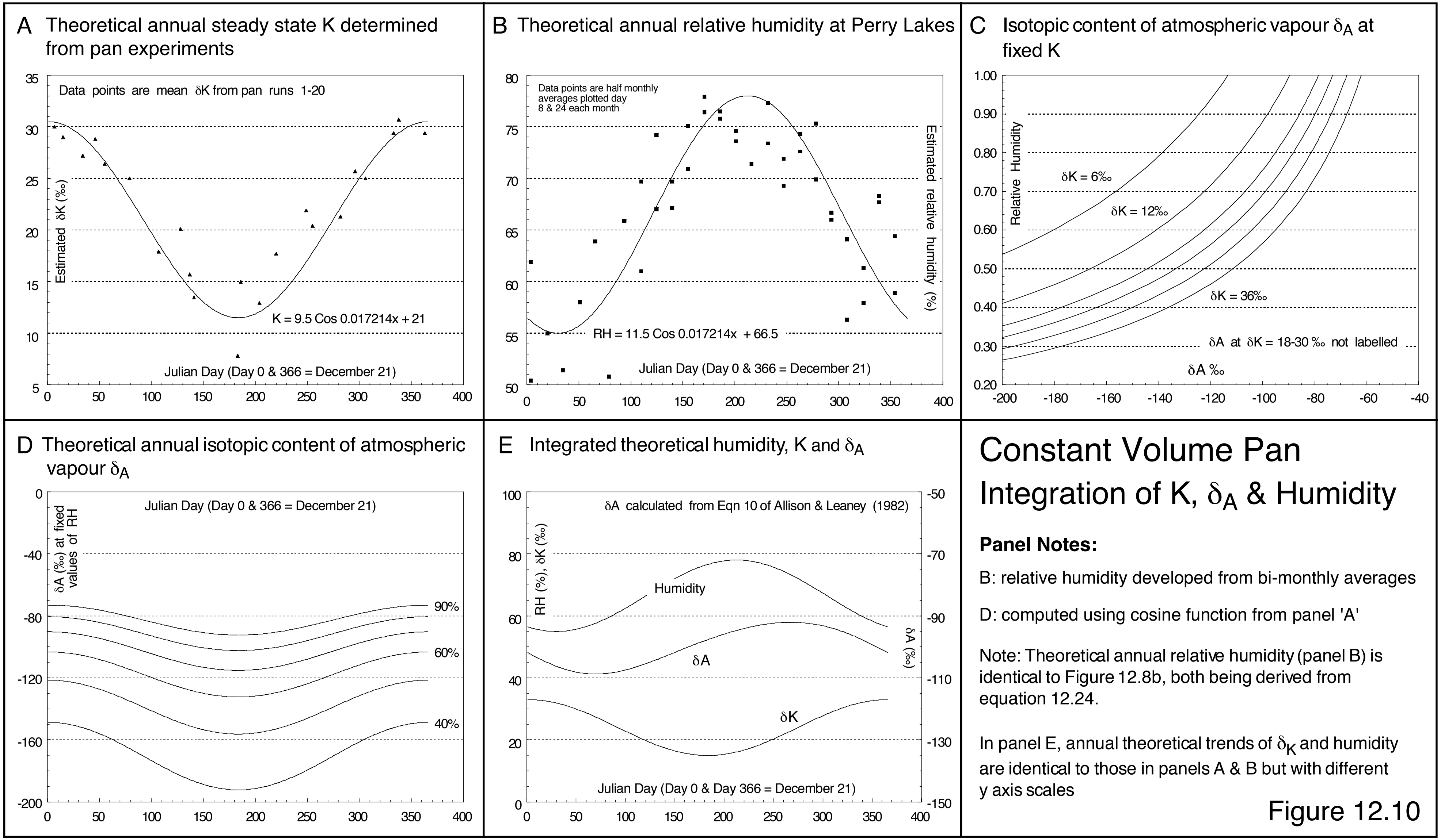
12.5.7 Integrated Annual *K* and δ_A from Constant Volume Pan

Finally, by substituting the annual trend of measured relative humidity (equation 12.24) and the annual trend of experimentally determined δ_K (equation 12.27) into equation 12.28 allows a 'best guess' prediction of annual daily average δ_A (Figure 12.10e). Plotted along with it are annual K and relative humidity. These are identical to the plots appearing in Figures 12.10 a&b but with different y axis scales.

12.5.8 Estimation of $\delta_{E(pan)}$ and $\delta_{E(lake)}$ from Constant Volume Pan

Employing equation 12.20, theoretical families of curves for $\delta_{E(lake)}$ can then be generated for varying pan h (and hence m) and fixed pan K and isotopic concentrations of lake water δ_L (Figure 12.11). Pans evaporated at constant volume will achieve steady state K regardless of h (and hence m). The range of daily average relative humidity recorded during the pan experiments (Table 12.10) demonstrates that for all runs there were days when average relative humidity was less than 50% and steady state could not be obtained in a pan evaporated to dryness. During summer, days when the minimum daily average relative humidity is less than 50% are quite common. The commonness of this condition demonstrates the benefit of determining exchange parameters from a constant volume pan.

Table 12.10 also shows the recorded range of δ_{lake}. It is evident that where $K = \delta_{lake}$ then $\delta_{E(lake)}$ is constant for all values of h. In Figure 12.11, if K is set at -12.4‰, then $\delta_{E(lake)}$ plots as a vertical line. This is analogous to the situation where $\delta_S=\delta_L$ in pans evaporated to dryness.


A Theoretical annual steady state K determined from pan experiments

B Theoretical annual relative humidity at Perry Lakes

C Isotopic content of atmospheric vapour δ_A at fixed K

D Theoretical annual isotopic content of atmospheric vapour δ_A

E Integrated theoretical humidity, K and δ_A

Constant Volume Pan Integration of K, δ_A & Humidity

Panel Notes:

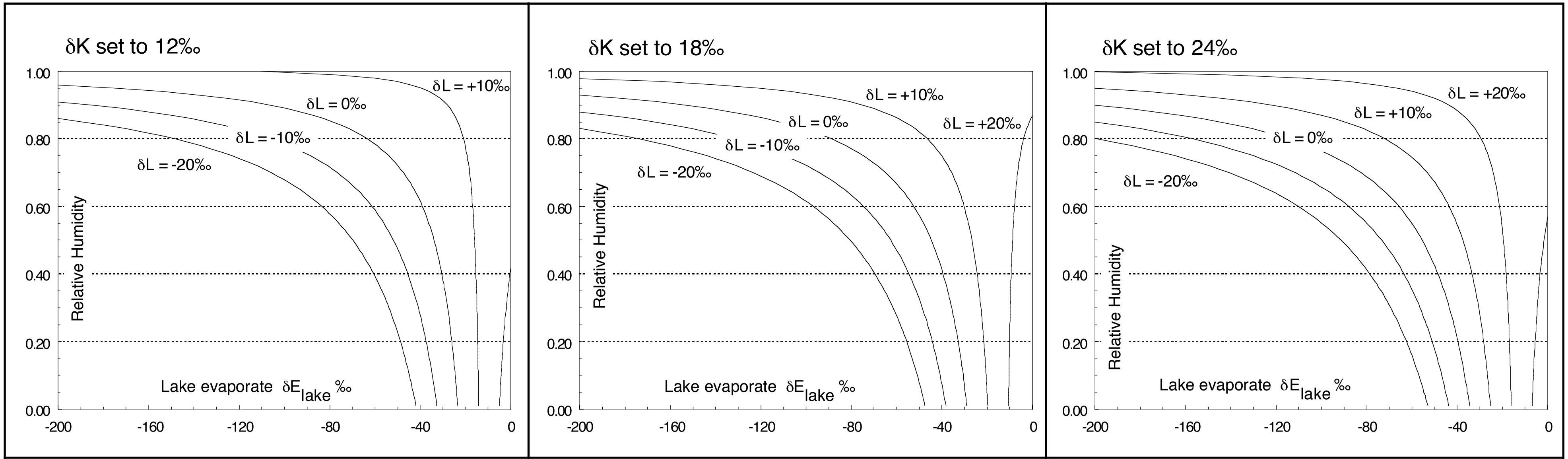
B: relative humidity developed from bi-monthly averages

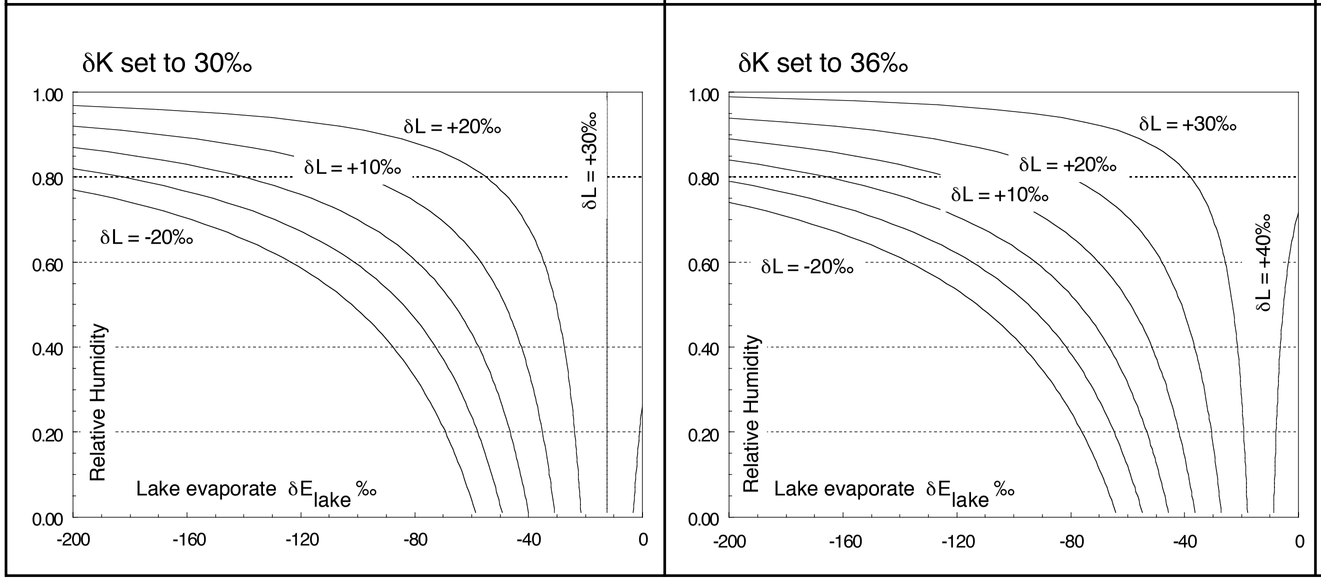
D: computed using cosine function from panel 'A'

Note: Theoretical annual relative humidity (panel B) is identical to Figure 12.8b, both being derived from equation 12.24.

In panel E, annual theoretical trends of δ_K and humidity are identical to those in panels A & B but with different y axis scales

Figure 12.10





Predicted Values of $\delta_{E_{lake}}$ at fixed K and δ_L and varying relative humidity

δE_{lake} computed using Equation 12 of Allison & Leaney (1982)

δK corresponds to annual range of values observed in evaporation pan experiments

All δ values are per mille (‰)

Figure 12.11

Table 12.10 Comparative daily average humidity and δ_{lake} Runs 1-20

Run	1	2	3	4	5	6	7	8	9	10
Min daily av RH	39.7	49.8	43.1	43.2	41.5	33.6	38.2	31.6	36.2	39.3
Max daily av RH	78.0	88.2	87.1	75.2	73.6	75.3	62.3	54.6	59.9	69.9
Min δ_{lake}	-6.8	-16.1	-6.2	2.5	5.1	5.1	11.1	10.2	9.9	-2.7
Max δ_{lake}	3.1	-1.9	2.3	7.1	14.5	16.6	18.4	18.9	18.5	13.3
Run	11	12	13	14	15	16	17	18	19	20
Min daily av RH	39.0	43.7	42.9	50.6	41.7	45.5	36.3	30.0	36.2	37.4
Max daily av RH	75.3	83.2	87.8	88.4	83.4	82.0	72.5	70.8	64.7	77.5
Min δ_{lake}	-1.0	-6.4	-3.9	-10.9	-5.7	-4.6	-20.3	5.5	-0.5	ND
Max δ_{lake}	8.8	17.0	6.9	0.5	-1.2	1.8	1.8	33.2	67.7	ND

Relative humidity (RH) normalised to constant volume pan temperature (= lake surface temperature), ND = no data

12.5.9 Comments on $\delta_{E(lake)}$ determined from δ_S and K

Even a cursory examination of Figures 12.9 and 12.11 confirms that estimates of $\delta_{E(lake)}$ made using exchange parameters determined from δ_S and K will not be the same. Equations developed to determine such parameters are premised on numerous assumptions not the least of which is the condition of steady evaporation and humidity. Evaporation usually reaches a maximum in early afternoon and a minimum just before dawn. Relative humidity displays exactly the opposite pattern. Instantaneous (10 minute) relative humidity at Perry Lakes ranged from 9% to 100% over the course of the pan experiments. Evaporation pans smooth or integrate these fluctuations to provide 'flux weighted' estimates of m and δ_S or K. The steady state parameters δ_S or K are applied somewhat differently to further estimate $\delta_{E(lake)}$ resulting in curve families which are similar but far from identical. The same comments apply to annual trends in daily average δ_A (Figures 12.8e and 12.10e) predicted from δ_S or K.

12.6 ANNUAL RELATIONSHIP BETWEEN δ_S AND δ_K

Combining field data from the pan experiments and theoretical curves allows mean monthly steady state estimates to be developed for Perry Lakes (Table 12.11).

Table 12.11 Relationship between δ_S and δ_K, median monthly values

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
δK (‰)	29.6	26.6	22.2	17.2	13.4	11.6	12.3	15.4	20.1	24.9	28.7	30.5
δS (‰)	106.8	95.5	79.4	61.1	47.0	40.2	42.8	54.3	71.5	89.2	103.5	109.8

Minimum values occur June 21 (11.5‰ and 40.0‰) and maximum values December 21 (30.5‰ and 110.0‰). The theoretical trigonometric functions describe a simple linear relationship between δ_S and δ_K such that

$$\delta_S = 3.68\delta_K - 2.36 \qquad (12.29)$$

12.7 DIRECT FIELD MEASUREMENT OF δ_A AND $\delta_{E(lake)}$

The isotopic composition of ambient water vapour δ_A and humidity are the principal factors influencing heavy isotope enrichment of a water body undergoing evaporation (Simpson *et al* 1987). Under conditions of low relative humidity vapour flux from a water surface can be approximated by a Rayleigh distillation where

$$\delta = -1000(1 - f^{a^*}) \qquad \text{(Whitehead 1990 Eqn 7)} \qquad (12.30)$$

Where relative humidity is high some evaporation and Rayleigh distillation do occur, however isotopic composition of the residual water becomes dominated by exchange of isotopes between air vapour and the water surface. The water now approaches isotopic equilibrium with respect to air vapour δ_A.

Knowledge of δ_A is required in isotopic water balance determinations (Chapter 6) and evaporation pans can be used to estimate δ_A (this chapter). Direct field measurement represents a second approach and is useful as a validation of pan derived values. Field measurement however is costly and time consuming rendering continuous direct measurement of δ_A impractical. Therefore such measurements only provide a 'snap shot' of δ_A over the air sampling period, typically several hours. As a result little detail is known regarding the isotopic composition of atmospheric water vapour in Australia (Whitehead 1990). In general δ_A varies diurnally, primarily in response to humidity and seasonally in response to this and other factors such as varying air mass provenance.

12.7.1 Direct Field Measurement of δ_A

Sampling of atmospheric vapour must be done without fractionating the isotopes (Yurtsever & Gat 1981). Typically this has been accomplished by freezing out the water at extremely low temperatures using dry ice or liquid air (Craig & Horibe 1967, Merlivat & Coantic 1975, Sofer & Gat, 1975). Atmospheric water vapour at Perry Lakes was collected using glass vapour traps after the design of Zundel *et al* (1978). These consist of a primary inlet chamber and a secondary coiled scavenging trap. With reference to Figure 12.4a, the traps are immersed in ethanol chilled to approximately -60°C by means of a 'Heidelberg' cooler[3]. The cooler comprises a single stage compressor and cooling chamber containing three ethanol filled wells allowing three traps to be operated simultaneously. The vapour traps are immersed in these wells. Air is drawn through the

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[3] The cooler uses R502 gas which under single stage compression will theoretically cool to -70°C. Thermocouple tests indicated actual ethanol temperature was about -50 to -55°C. The cooling vessel was further insulated with insulfoam (high density rubber foam). Styrofoam. and insulfoam inserts were made to fit over the ethanol wells. Under daytime summer field conditions typical operating temperature was -58°C.

traps via a vacuum pump, each trap being controlled by a separate needle valve and gas flowmeter (Figure 12.4b). A minimum of about 5ml liquid water is required for ^{2}H and ^{18}O analyses.

Condensation and freezing are fractionating processes, however if all vapour is collected the frozen vapour when thawed and mixed within the sealed trap is representative of the atmospheric vapour, the critical point being that all vapour must be trapped. Zundel *et al* (1978) reported a 99.9% extraction efficiency at flow rates of 1m^3/hr. Tests at this rate using two traps in series indicated over 5% of vapour was not being frozen in the first trap. Optimum rate (extraction efficiency, sample size and run time) was found to be 4 litres/min (0.24m^3/hr). Merlivat & Coantic (1975) using dry ice cooled traps recommended 2.5 litres/min to achieve complete extraction. By running two traps in series, extraction efficiency was calculated for each sampling run. Average extraction efficiency over 108 runs was 99.3%. The lowest extraction efficiency was 96.0% (sample A047, June 9, 1997). There was never sufficient water in the second trap to analyse however possible errors were tested using a mass balance calculation of the form

$$\delta sample = \frac{massT1 \bullet \delta T1 + massT2 \bullet \delta T2}{mass(T1 + T2)} \qquad (12.31)$$

where *massT* is water mass (grams) in trap and *δT* is deuterium ratio of the water (expressed as permil). Sample A047 (measured δT1 -90.7‰) was used as a 'worst case' example. Assuming extreme fractionation and setting δT2 in the range -80.0‰ to 0.0‰ the maximum fractionation effect on δsample was only about 3‰ (Table 12.12).

Table 12.12 Fractionation effect of incomplete recovery in Trap 1 Sample A047

δ Trap 2 (‰)	-80	-70	-60	-50	-40	-30	-20	-10	0.0
δ Sample (‰)	-90.3	-89.9	-89.5	-89.1	-88.7	-88.3	-87.9	-87.5	-87.1

mass T1: 5.743g, mass T2: 0.239g

Quite clearly even extreme fractionation from vapour escaping trap 1 would not be sufficient to significantly perturb the measured isotopic composition of trapped vapour. Average sampling time was 4 hours representing an air volume of 0.96m^3 however in practice, this varied anywhere from 45 minutes (0.18m^3) to 5hr 45 minutes (1.38m^3). Air was sampled from a height of 2m adjacent to the isotope pan experiment. As time progressed the sampling routine was modified from one four hour run once a week to more numerous shorter runs. The cooler, which was permanently mounted in a light commercial van, was frequently left running overnight so that it could be used immediately while other routine sampling work was carried out during the early morning.

Method Detail

Methodology for a typical δ_A sampling run was as follows:

- start cooler and allow trap wells to reach operating temperature (about 1 hour)
- connect inlet and outlet tubing to traps and insert in ethanol wells, wait 5 minutes to allow traps to chill and ethanol to re-cool to -60˚C
- start vacuum pump, adjust flow to 4 litres/minute, periodically readjusting as required
- at completion, remove tubing from traps and seal trap inlets & outlets with mini bungs
- remove traps, allow ice to melt and weigh traps after they have reached room temperature with contained water and bungs (ensuring there is no condensation on the outside of the traps). Each trap had an identifying number and dedicated bungs which were included in the empty weight
- remove bungs and transfer water gently into clean, dry 10ml Robertson bottle, cap immediately
- purge trap with ethanol and blow out with dry nitrogen, heat trap in drying oven at 105˚C for minimum 2 hours, purge while hot with dry nitrogen and seal with bungs

Pouring the water from the trap to the bottle is the only point where trapped water is momentarily exposed to evaporation. Ideally water should be vacuum distilled from the traps however lacking such equipment, gentle pouring in which the water is exposed to evaporation for only several seconds is considered to introduce negligible error (J. Dighton[4], pers com). Figure 12.12a shows results of all δ_A sampling. Data appears in Appendix 12.2.

Diurnal Variation

Diurnal changes in δ_A occur in response to air mass changes (land and sea breezes for example), temperature (condensation and dew fall at night should further deplete heavy isotopes in the vapour), near ground effects such as temperature inversions and evaporation from nearby water bodies and the soil under low wind conditions. At Perry Lakes there appeared to be a progressive enrichment in heavy isotopes from dawn to dusk during 1997 (Table 12.13).

Table 12.13 Diurnal changes in δ_A deuterium

	Jul 07	Aug 11	Aug 18	Oct 06	Oct 13	Nov 23	Nov 30	Dec 07
Dawn					-90.5	-88.9	-83.6	-98.1
Day	-92.8	-96.1	-86.5	-89.4	-79.4	-84.5	-78.4	-85.0
Dusk	-89.3	-91.5	-79.1	-85.7				

Samples collected consecutively, average sampling time 3 hours. Insufficient sample precluded many ^{18}O determinations

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[4] Isotope technician, CSIRO Land & Water, Glen Osmond, South Australia

At Perry Lakes this may (in part) be explained by the abundance of phreatophytic vegetation within the immediate vicinity. Note that transpiration is non fractionating (Clark & Fritz 1997). During the day such vegetation will transpire vapour whose composition is similar to local groundwater (about -12.4‰ and -2.72‰ ^{2}H and ^{18}O respectively). Unfortunately we only had four Zundel traps so were unable to collect multiple sequential samples over one 24 hour period to properly test this hypothesis.

Seasonal Variation

Winter weather on the west coast of Australia is dominated by moisture bearing frontal systems moving off the Indian Ocean. Winds are predominantly westerly. Summer weather is dominated by continental high pressure systems (subtropical anticyclones) resulting in a persistent easterly flow of dry continental air (Gentilli 1972). Also over summer moist oceanic air originating from the tropics is frequently funnelled south by the 'West Coast Trough' (Sturman & Tapper 1996). Surprisingly there is little average seasonal variation in Perry Lakes δ_A measurements by season and thus air mass provenance (Table 12.14).

Table 12.14 Perry Lakes δ_A measurements seasonal means

	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Day and Night Data	-85.5	-93.8	-84.7	-82.6
Day time ONLY	-85.5	-95.3	-85.0	-82.4

Mean of all data (108 analyses) is -85.2‰. The most isotopically depleted samples (for example -121.4‰ deuterium 12 May 1997) tended to be associated with dry easterly winds moving from the centre of the continent.

Land breeze and sea breeze experiments

Extreme diurnal heating of the land relative to the ocean produces strong sea breezes along the west coast. Consecutive δ_A samples collected during east winds followed by a sea breeze display a slight isotopic enrichment from the air moving off the ocean (Table 12.15). Clearly however these are local effects which operate on a much smaller scale than the continental air masses noted above.

Table 12.15 Land-sea breeze experiments

Date	Oct 6	Oct 13	Nov 23	Nov 30	Dec 7
Land breeze	-89.4	-90.5	-88.9	-83.6	-98.1
Sea breeze	-85.7	-79.4	-84.5	-78.4	-85.0

All dates are 1997

The greatest enrichment of δ_A appears to be associated with moist tropical air during west coast trough conditions. These were particularly common during early summer 1997 and corresponded with three vapour sampling sessions (Table 12.16). Mean trough air mass δ_A was -74.4‰.

Table 12.16 δ_A during west coast trough

Date	Nov 4	Nov 9	Dec 11
δ_A trough air	-72.6	-75.8	-74.8

All dates are 1997

The observation that isotopic enrichment is enhanced in air masses of tropical origin compared to air masses from higher latitudes is consistent with other observations from Australia (Brunel *et al* 1992) and from North America (White & Gedzelman 1984).

12.7.2 Direct Field Measurement of $\delta_{E(lake)}$

Introduction

Craig & Gordon (1965) provide a model of the physical processes (including stable isotope fractionation) which occur at an air-water interface. They assumed a multi layered process (Figure 12.12c). Within the lake well mixed water is overlain by a thin laminar layer where fractionation may occur through molecular diffusion. The fluid-atmosphere interface is a thin vapour layer within which humidity decreases from a saturated lower contact and approaches local atmospheric humidity at the top. The isotopic concentration of the vapour in this interface is δ_E. Above this is a laminar vapour layer where again molecular diffusion and fractionation may occur. Above this turbulent mixing predominates with rapid transition to local atmospheric isotopic concentration δ_A. The fractionation paths are shown schematically by heavy lines. Similar models have been proposed by Sverdrup (1937), and Brutsaert (1975) comprising a diffusive sub layer 'd' directly over the interface and an overlying 'fully turbulent layer'.

Sampling requires attempting to capture vapour from the base of the laminar air layer. Merlivat and Coantic (1975) provide experimental estimates of the thickness of this layer 'd' under varying air velocities (Figure 12.12e). Curve fitting and extrapolation provided estimates of 'd' as still air is approached (Table 12.17). This suggested that under still air conditions, sampling within several cm of the water surface would approach the base of the laminar layer.

Table 12.17 Thickness of laminar layer 'd' as still air conditions are approached

Air V (cm/sec)	500	200	70	50	20	10	5	1
Air V (km/hr)	18.0	7.2	2.5	1.8	0.72	0.36	0.18	0.036
Thickness 'd' (mm)	0.7	2.2	6.5	9.8	27.7	60.7	132.9	820.5

Craig & Gordon (1965) provide estimates of marine δ_E as a mass balance where mean δ_E must be equal to the mean isotopic enrichment of precipitation being returned to the sea. They also provide an equation describing the relationship between δ_E and the composition of a water body (at constant volume without liquid outflow) undergoing evaporation:

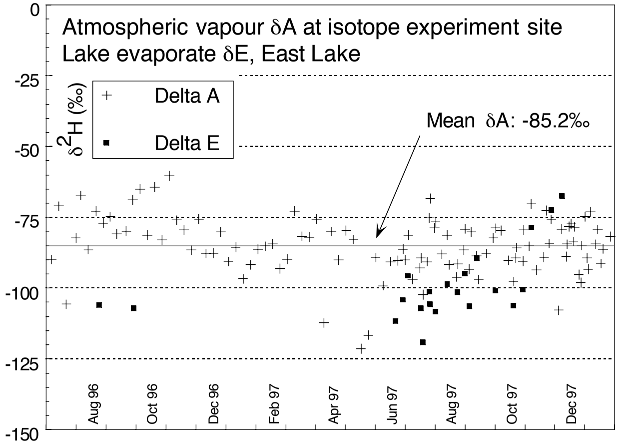
$$\delta_E = \frac{\alpha * \delta_L\left(1 + E\rho_{iL}\right) - h\delta_A - \varepsilon}{\left(1 - h\right) + \Delta\varepsilon + \alpha * E\rho_{iL}} \quad \text{(Craig \& Gordon 1965 Eqn 23)} \qquad (12.32)$$

Allison & Leaney (1982) present a simplified form as Eqn 7. This expression for δ_E shows it to be largely a function of the isotopic composition of atmospheric water vapour δ_A, relative humidity and the isotope fractionation factors for the isotope of interest. From a practical point of view δ_A is seldom known with any degree of accuracy. Alternative methods of estimating δ_E using pan derived exchange parameters have been explored earlier in this chapter. The literature provides little in the way of practical field methodology for confirming theoretically derived estimates of δ_E. Allison *et al* (1979) note that estimation of δ_E under field conditions of varying wind, temperature and humidity is virtually impossible. Merlivat & Coantic (1975) sampled vapour under controlled conditions within a large (40m long) sealed wind tunnel. The author is not aware however of any other practical field measurement of evaporate from a water body.

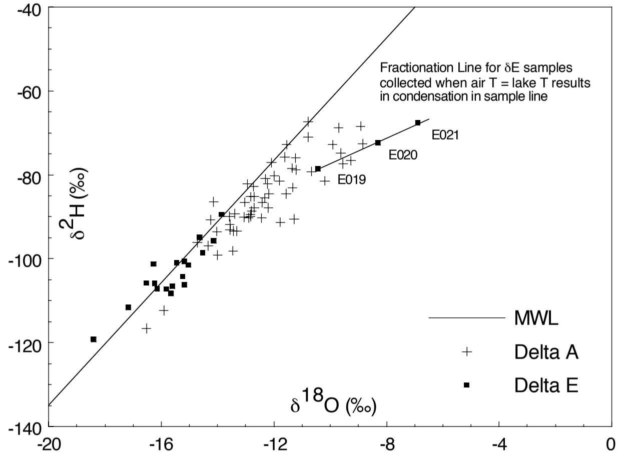
Method

On cold still mornings at Perry Lakes vapour is frequently visible rising from the warmer water into the cooler air. This is evaporated lake water vapour, made temporarily visible through condensation. Initial experiments to sample lake evaporate were carried out by fixing the open end of a sampling line on the East Lake staff gauge support. The open end was positioned about 2cm above the water surface. The feed line was weighted, sinking into the water column which was 10-11°C warmer than the air, thus precluding any condensation in the feed line. The Heidelberg cooler unit was positioned on the lake shore and operated in an identical manner to that used for δ_A sampling. The small length of exposed feed line between the water and the vapour trap was insulated with high density rubber foam pipe insulation, maintained at or above lake temperature with heat lamps. At completion any feed line condensation was purged using dry nitrogen, passed through the vapour trap. Two such experiments carried out on dead still nights between

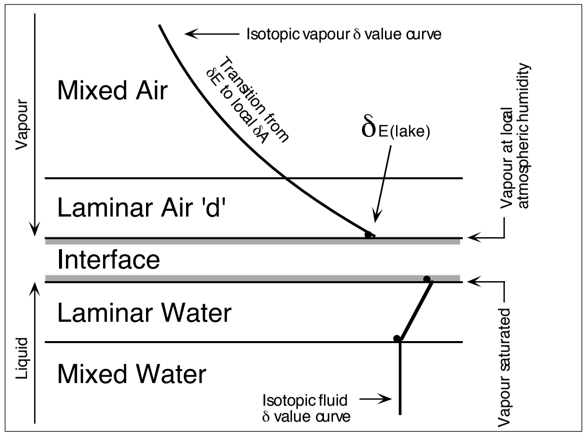
A Atmospheric vapour δ_A & lake vapour $\delta_{E(lake)}$ sampling 1996-1997



B East Lake δ_A & $\delta_{E(lake)}$ samples plotted relative to Perth meteoric water line

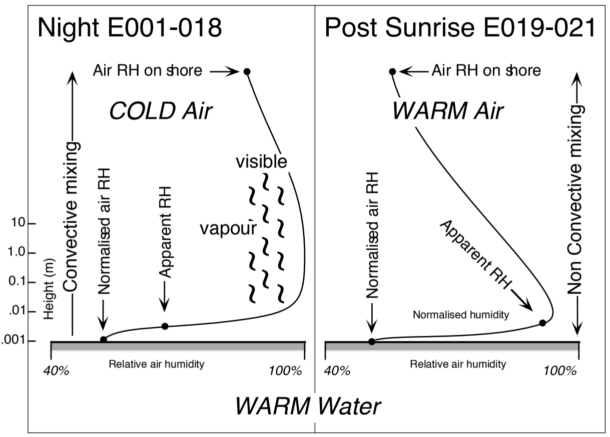


C Laminar layer diffusion model of surface water evaporation of Craig & Gordon

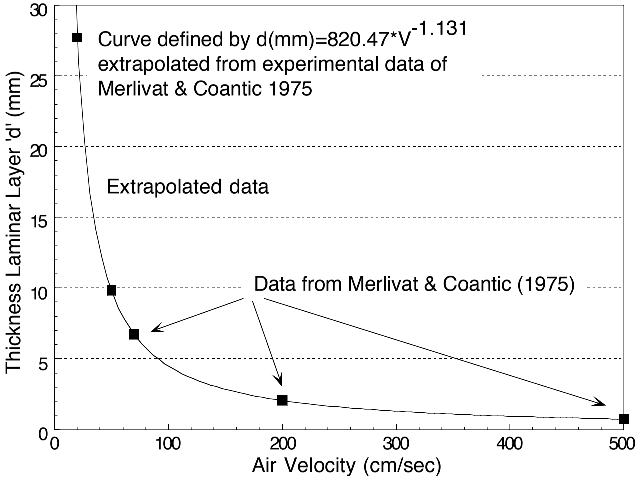


Adapted from Craig & Gordon (1965) Figure 13

D Still air humidity conditions during lake vapour sampling



E Thickness of laminar air layer 'd' as still air conditions are approached



Direct Field Measurement of δA and δE

Notes

A: δ_A samples average one per week, additional samples in 1997 are samples taken concurrently with δ_E

δ_E sample distribution largely reflects periods when cold calm nights occur (winter & early summer)

B: samples E019-021 were the only samples collected well after sunrise when air T approached lake T resulting in probable condensation & isotopic fractionation in the collector line. The samples plot on a line similar to the 'low evaporation line' displayed by evaporated water

E: Merlivat & Coantic provide experimental data at 500, 200 & 70 cm/sec (18, 7.2 & 2.5 km/hr). Extrapolating curve provides estimates of 'd' under near still conditions Curve defined by $d(mm) = 820.47Vel^{-1.131}$
Vel = air velocity (cm/sec)

Figure 12.12

midnight and dawn confirmed the viability of sampling lake evaporate however the experimental procedure was cumbersome. Possibly the greatest problem was the unpredictability of when satisfactory sampling conditions were likely to occur. If any number of samples were to be collected, a sampling technique was required which could be rapidly deployed on an opportunistic basis.

The most time consuming aspect of the initial tests was deploying the pickup line in the lake and supplying 240 volt power via 200m of extension cords from the isotope experiment. A floating sampling system (Figure 12.4d) was designed which could be left permanently in place. The principal features of this system were:

- a permanently installed inlet line bathed in lake water, connected to the shore and bathed in return water (approximately 1˚C <lake) from the pan experiment in the service conduit
- a system of pressure controlled inlet valves which remained closed except under conditions of vacuum suction (when sampling) or purge back pressure (when purging with dry nitrogen)
- an anchored floating inlet which maintained a constant inlet height of 5mm above the water surface

In operation the van containing the Heidelberg unit was positioned adjacent to the isotope experiment pans. The final feed from the service conduit to the vapour traps was insulated and warmed by heat lamps as before. At completion this section of line was purged via the vapour traps with dry nitrogen as was the feed line back to the floating pickup. An inspection point at the lake edge (the coolest point in the line) allowed inspection of a clear insert to check for line condensation. Occasional very minor misting occurred, however estimates of possible fractionation error using equation 12.31 and data plots relative to the local meteoric water line (Figure 12.12b) suggested minimal line fractionation.

During δ_E sampling, a simultaneous δ_A sample was collected in the normal manner (Figure 12.12a and Appendix 12.2). Using this system a total of 21 lake evaporate samples were collected. The floating pickup allowed opportunistic sampling not only during the night but also during normal data collection activities at dawn and at dusk.

Results

Data are plotted (along with δ_A) in Figure 12.12a and are summarised in Table 12.18. Here humidity of the air and humidity normalised to the lake surface temperature correspond to the average recorded during the sampling period (typically 45 to 240 minutes). K (pan average) is the mean seasonal value determined from pan experiments, K (instantaneous) is K calculated for the sampling period only using equation 12.18.

There is a very large difference between the two, the former being 'flux weighted' over many days, the latter being that occurring only over several hours. Lake δ_E is shown as measured and as calculated from equation 12.20 in three different ways:

- normalised relative humidity and pan averaged K
- non normalised relative humidity and pan averaged K
- normalised relative humidity and instantaneous K

The quantity 'apparent RH' is the relative humidity which would be required in equation 12.20 to produce the sampled value for δ_E assuming averaged K. It is evident from equation 12.18 that K incorporates δ_A. Calculating δ_E using equation 23 of Craig & Gordon (1965) (equation 12.32) and measured δ_A produces identical estimates of δ_E suggesting that measured δ_A and experimentally derived K are essentially correct. Raw data appear as Appendix 12.3.

The δ_E measurements were made at dusk, night and dawn under varying meteorological conditions, the only uniform criteria being still air. Three general observations can be made:

1: for all measurements taken at night, early dawn and most taken at dusk (E001-E018) 'apparent RH' tends to lie between air RH and normalised RH and $\delta_E < \delta_A$

2: for measurements taken after sunrise (E019-E021), 'apparent RH' exceeds air RH and $\delta_E > \delta_A$

3: δ_E calculated using normalised RH and instantaneous K closely approximates δ_E measured directly by vapour sampling

Discussion

The 'night time' data (E001 to E018 in Table 12.18) suggests that under conditions of warm lake surface and cool still air, there is a relative humidity gradient immediately above the water surface (Figure 12.12d). Warm air and lake evaporate rise convectively into the cold overlying air. Normalised relative humidity is that of the local air mass (as measured nearby on shore) normalised to the lake surface temperature. Sampling occurs in the 10-20mm zone above the air-water interface and may have an effective normalised relative humidity (under still non mixing night time conditions) intermediate between that of the local air mass and the air-water interface (Figure 12.12d). Tendrils of visible vapour were frequently observed rising up to 10m above the lake. The tendrils do not form at the water surface but a few mm above it. Their appearance coincides with the height where moist air cools to saturation point. Their disappearance with height suggests that maximum excess of saturation occurs in a blanket several metres thick over the lake. Above that height, humidity probably deceases approaching that measured nearby on shore.

The 'sunrise data' (E019 to E021) presented unique and unusual conditions where vapour was collected well after sunrise in early summer but still under windless conditions. On all previous sampling occasions air T<<lake T. Here however air temperature was approximately equal to lake temperature. Under these conditions natural convective mixing would be less (or absent) and perhaps replaced by mechanical or molecular mixing. A blanket of humid air effectively forms at the air-water interface. In the case of E021 the apparent normalised humidity of the air approached saturation (Figure 12.12d) with δ_E approaching or exceeding δ_A measured nearby. Plotting all data relative to the Perth meteoric water line (MWL) however suggests that isotopic fractionation occurred while sampling E019-021 (Figure 12.12b). These three samples plot below the MWL. It is likely that as air temperature approached lake water temperature, some condensation occurred in the sample feed line. Estimating δ_E from very short term (non flux weighted) values of K generally produces the closest approximations of the experimental data, however these short term (effectively instantaneous non flux weighted) K values are strongly influenced by δ_A.

With reference to equation 12.20 and Figure 12.11 it is apparent that δ_E is particularly sensitive to changes in humidity at given values of δ_I δ_L and δ_K. This is particularly so at high relative humidity when very small changes in humidity result in very large changes in δ_E. Under such conditions accurate measurements using wet and dry bulb thermometers are suspect since Bureau of Meteorology wet bulb depression tables for non ventilated thermometers assume a minimum natural (wind) ventilation of 1-3m sec^{-1}. Lack of ventilation raises the wet bulb temperature resulting in an over-estimation of true vapour content (Fritschen & Gay 1979 p150). This is apparent in the calculated δ_E which exhibits very large excursions from the experimentally measured $\delta_{E.}$ These extremes largely reflect errors in measuring humidity.

Therefore any attempt to compare theoretical and experimental measures of $\delta_{E(lake)}$ must include accurate measurement of relative humidity at the vapour sampling site. This is complicated by the meteorologically 'abnormal' conditions under which vapour was collected, at night with nil wind and a pronounced air temperature gradient from the warm water surface to cold air. Under such conditions the experimental data suggest that relative humidity measured on land adjacent to the lake will be too high (and possibly subject to additional errors due to non ventilation) and this same data normalised to lake surface temperature will be too low. In other words the true relative humidity at the sampling site under still, convective mixing meteorological conditions is likely to be between the two. Finally, estimating δ_E using equation 12.32 also indicates a high sensitivity to δ_A. Errors in measuring δ_A (or its proxy K) will likewise have large effects on calculated δ_E.

Table 12.18 Direct measurement of $\delta_{E(lake)}$ deuterium

Sample	E001	E002	E003	E004	E005	E006	E007	E008	E009	E010	E011	E012	E013	E014	E015	E016	E017	E018	E019	E020	E021
Date	05-09-96	08-10-96	14-06-97	21-06-97	26-06-97	07-07-97	10-07-97	16-07-97	17-07-97	22-07-97	02-08-97	11-08-97	18-08-97	23-08-97	30-08-97	17-09-97	04-10-97	13-10-97	21-10-97	09-11-97	19-11-97
Start Time (hr)	03:45	00:50	19:00	21:10	18:00	20:00	18:00	17:45	17:40	05:00	17:45	17:45	17:45	05:00	18:10	18:30	04:00	05:00	06:15	06:40	06:20
Duration (hr)	2.8	4.7	4.0	3.5	3.5	3.5	4.0	4.2	3.0	2.4	2.2	2.0	2.0	1.8	1.8	2.0	2.0	1.5	0.8	0.8	1.5
Lake T (°C)	19.1-16.3	23.3-21.8	17.3-16.1	16.7-16.1	18.8-17.2	14.0-12.8	14.0-12.4	13.9-12.3	14.2-13.2	11.1-10.1	19.5-18.1	16.4-15.7	17.1-16.2	15.3-14.7	19.2-18.5	23.4-22.7	20.4-20.1	21.4-21.4	21.9-22.1	21.8-22.3	19.9-20.6
Air T (°C)	6.6-5.5	13.1-10.5	9.6-6.7	10.5-11.2	14.8-11.2	7.0-4.5	6.8-2.7	11.3-8.0	10.7-5.2	2.3-0.9	13.7-10.5	12.4-8.7	13.6-8.9	9.8-7.0	14.5-11.8	17.5-14.6	11.8-11.6	10.2-10.5	19.4-21.1	15.0-20.2	11.5-19.4
Av Norm RH	45.8	46.0	51.6	67.1	71.8	59.0	55.5	52.9	56.9	50.2	60.2	61.8	57.2	55.7	54.4	53.3	55.4	48.4	51.3	49.6	47.7
Av Air RH	90.0	89.5	87.3	91.5	92.5	90.8	92.9	76.5	79.9	88.4	87.6	83.6	76.8	82.4	72.4	81.4	87.5	92.3	54.9	62.9	65.3
Apparent RH	84.8	86.4	79.1	81.8	82.2	80.9	82.0	80.4	82.3	83.1	80.3	77.0	76.0	80.7	77.7	62.1	82.1	74.4	70.4	83.4	100.3
δL	4.8	7.9	-8.8	-4.4	-2.2	-4.5	-5.7	-3.1	-2.2	-1.2	-1.6	-4.5	-3.2	-1.2	0.7	-14.7	5.0	0.0	4.3	19.1	30.2
δK (pan average)	21.5	23.1	15.0	15.0	15.0	16.4	16.6	17.0	17.0	17.7	18.0	19.0	19.4	19.8	20.4	23.0	24.5	25.7	26.5	30.7	30.7
δK (instantaneous)	53.6	53.5	49.0	35.9	36.0	40.5	35.6	53.8	55.2	54.8	44.7	36.7	48.4	40.8	44.8	51.4	38.4	48.8	57.7	55.7	55.2
δE at Norm RH	-40.1	-37.6	-56.5	-64.7	-66.1	-57.8	-57.2	-50.6	-52.2	-46.4	-56.3	-67.2	-59.5	-54.8	-51.0	-84.6	-51.4	-57.0	-53.2	-33.0	-13.3
δE at Air RH	-150.1	-131.9	-170.7	-197.4	-195.5	-198.8	-261.0	-87.2	-95.3	-148.8	-144.9	-135.6	-97.5	-115.0	-75.2	-187.6	-144.0	-280.8	-56.4	-40.2	-13.7
δE (instantaneous K)	-93.3	-88.2	-119.4	-120.9	-131.6	-110.3	-95.3	-120.4	-131.4	-113.2	-116.0	-108.3	-120.0	-97.1	-98.8	-139.0	-79.4	-97.1	-110.5	-77.5	-55.4
δE measured	-105.9	-107.2	-111.6	-104.2	-95.7	-107.1	-119.2	-101.2	-105.8	-108.3	-98.6	-101.5	-94.9	-106.5	-89.4	-100.9	-106.2	-100.6	-78.5	-72.4	-67.6
δA measured	n/a	n/a	n/a	-86.3	-81.4	-89.3	-102.3	-75.2	-68.4	-76.6	-81.4	-91.5	-79.1	-93.4	-88.6	-78.8	-97.7	-90.5	-70.2	-75.8	-79.2

Notes: All delta 'δ' values are in permil (‰) notation, δI set to -12.4‰ (mean of 41 samples, SD = 1.4‰), ε set to 0.095 and Δε 0.011, lake temperature is surface temperature in centre of lake, air temperature taken with shielded laboratory thermometer 1.5m above ground level at isotope pan experiment site, RH determined from non aspirated wet & dry thermistors & loggers at isotope pan experiment site (10 minute readings), 'Norm' RH is air RH normalised to the lake surface water temperature, all temperatures are range from start to end of δE sampling period, δE calculated using Eqn 12 of Allison & Leaney (1982), δE at air and normalised RH estimated using pan averaged K for period, δE (instantaneous K) uses K calculated (Allison & Leaney Eqn 10) for sampling period only , δA where noted sampled concurrent with δE, lake δL interpolated from samples collected every four days (refer Water Balance Data Sheets), δK (pan average) interpolated graphically from isotopic pan experiment. Apparent RH - refer text.

Conclusions

Direct measurement of δ_E is possible but only under highly abnormal meteorological conditions. Theoretical estimates using equation 12.20 are compromised by the difficulties in measuring relative humidity at the air-water interface under such conditions.

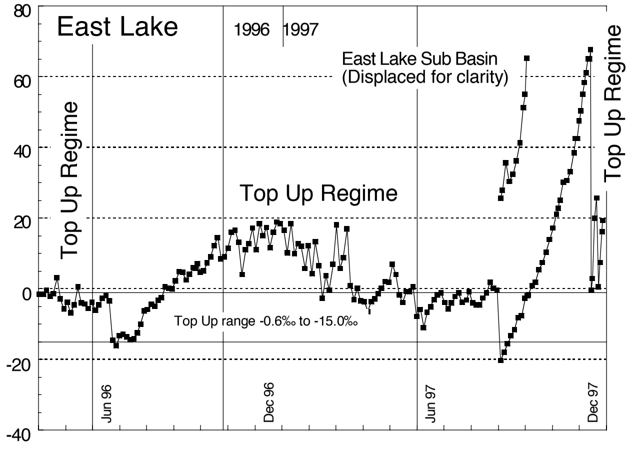
Certainly the field experiments were valuable in confirming that directly measured δ_E is in many cases similar to δ_E calculated by other means. Probably the single most important observation was the confirmation that δ_E calculated using equation 12.32 (Craig & Gordon 1965 eqn 23) and measured δ_A produced identical estimates of δ_E calculated using equation 12.20, suggesting that measured δ_A and experimentally derived K were essentially correct. This provided the confidence to apply δ_E derived experimentally from the pan experiments in the final isotopic balances (Chapter 6).

12.8 LAKE AND PAN LIMITING VALUES

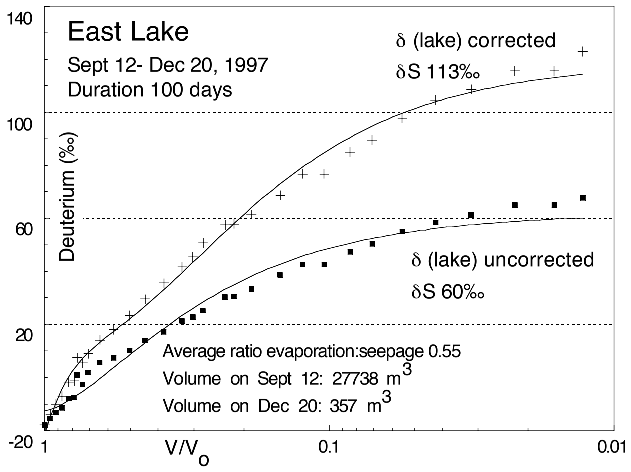
The whole objective of pan experiments is to use a small controlled evaporation environment (a pan) as a simple physical model of an adjacent lake. Figure 12.13 a&d show the time course of deuterium in East and West Lake over two years. West Lake shrinks to a small pond over summer. Small amounts of groundwater are added occasionally to ensure sufficient habitat for long necked tortoises, but in general levels are controlled solely by the falling regional groundwater table and a local groundwater gradient controlled by frequent top up pumping into East Lake. West Lake retains a partially sandy bottom at all but its lowest summer levels and mini piezometer tests (Chapter 7) confirm a flow through regime is maintained in summer. Over summer 1996 and 1997 West Lake shows a steady rise in deuterium enrichment, peaking around years end. This peak reflects both an annual solar cycle (identical to the same cycles described in the pans) and the increased effect of groundwater recharge as a local groundwater mound builds up around East Lake. Small increases in the West Lake stage occur within hours of water being added to East Lake where top up pumping peaks in January and February. We know from our inability to integrate the mass, solute and isotopic balances however (Chapter 6) that this apparent peak was, in fact, an effect of achieving an isotopic steady state.

At East Lake the regional groundwater table has fallen below the lakes deepest basin for a number of summers. In 1996 the lake was subject to a routine level maintenance regime commencing with occasional top up from October onwards peaking in January and February. The top up water comes from a number of bores and has variable deuterium levels in the range -0.6 (bore 1 lying in the East Lake release zone) to -15.0‰

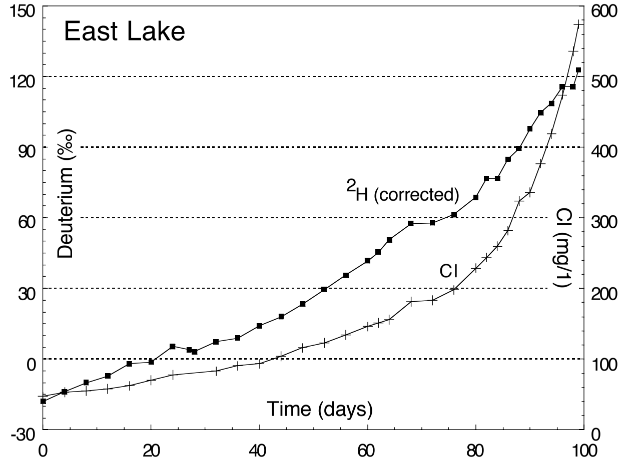
A East Lake deuterium time course 1996-1998
T/U regimes = periods regular level maintenance



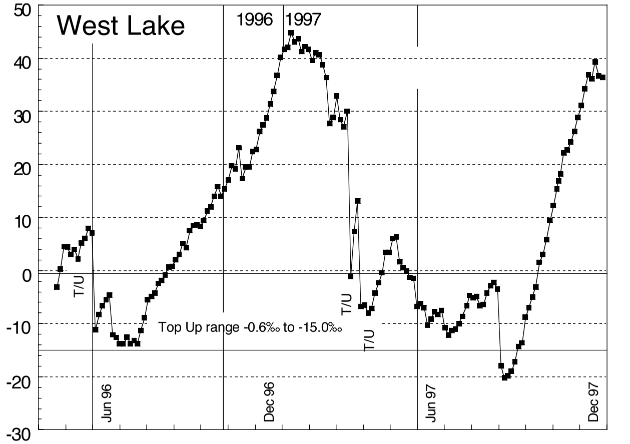
B Determination of steady state δ_S, East Lake



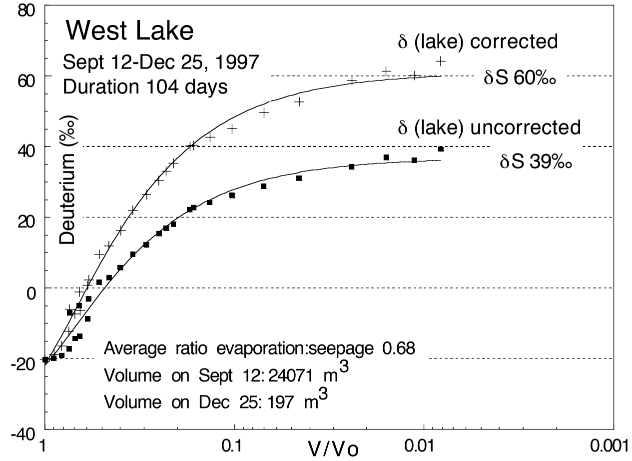
C Time course of deuterium corrected for seepage loss and Cl



D West Lake deuterium time course 1996-1998
T/U indicates isolated minor top up



E Determination of steady state δ_S, West Lake



Perry Lakes as Index Lakes

Panel Notes:

A & D: West Lake displays typical summer enrichment of lake shrinking & dominated in summer by evaporation but retaining flow-through status with groundwater flux . It mimicks an evaporation pan with both input & leakage

East Lake exemplifies lake where water table falls below lake bed over summer. In 1996 lake was maintained by groundwater top up. In 1997 lake was left to evaporate towards dryness. As this happens flow-through flux diminishes as lake is increasingly isolated from aquifer by clay lining, effectively mimicking a leaky evaporation pan. Evaporation and seepage loss (imposed by a falling regional water table) are approximately equal.

Figure 12.13

(bores 2-7 lying up gradient and within an unevaporated groundwater field, Figure 6.7). During summer 1996-97 deuterium enrichment in East Lake never exceeded +20‰.

In late 1997, the wetland managers agreed to let East Lake recede almost to dryness. The time course of deuterium (and Cl) is evident in Figures 12.13 a&c. Treating this as a pan evaporating to dryness (Figure 12.13b) an apparent limiting steady state of about 60‰ was achieved. Mini piezometer tests during this period (Chapter 7) confirm that a flow through regime is maintained as dryness is approached, however recharge appears to be << discharge because the lake becomes insulated from the aquifer by its clay lining. Then daily volume reduction is a combination of approximately equal parts evaporation and seepage loss to a falling regional water table. Gat (1981d) notes that in the general case of a lake with both inflow and outflow the enrichment of heavy isotopes is reduced in proportion to the weight of the non-fractionating outflow relative to evaporation. Setting recharge to zero, $\delta_{(lake)}$ was corrected against evaporation and discharge as calculated in the daily mass balances (Figure 12.13b), suggesting a true $\delta_{S(lake)}$ of about 113‰ around December 20th. This is in reasonable agreement with the equivalent $\delta_{S(pan)}$ of 103.0‰ and 96.8‰ (Runs 18 and 19) covering the same period.

Importantly this data strongly suggests that exchange parameters determined from evaporation pans adjacent to Perry Lakes can provide valid approximations of the same parameters in the lake and validates equations 12.13, 12.14 and 12.20.

Data was similarly corrected for West Lake however this is not strictly valid because a groundwater flux is maintained such that steady state of about 39‰ is maintained. This is obviously similar but not directly equivalent, to values of *K* obtained from the constant volume pan of 30.7‰ & 30.0‰ (Runs 18 & 19).

12.9 APPLICATION TO DAILY WATER BALANCES AT PERRY LAKES

12.9.1 Calculation of Daily δ_A and $\delta_{E(lake)}$

Average daily $\delta_{E(lake)}$was estimated using three different methods:

1: Equation 23 of Craig & Gordon (1965), critical parameters humidity, $\delta_{(lake)}$, δ_A with daily estimated average δ_A computed by interpolating weekly atmospheric sampling.

2: Equation 12 of Welhan & Fritz (1977), critical parameters humidity (as *m*), $\delta_{(lake)}$, and δ_s calculated from pans evaporated to dryness

3: Equation 12 of Allison & Leaney (1982), critical parameters humidity (as *m*), $\delta_{(lake)}$, and K calculated from pans evaporated at constant volume

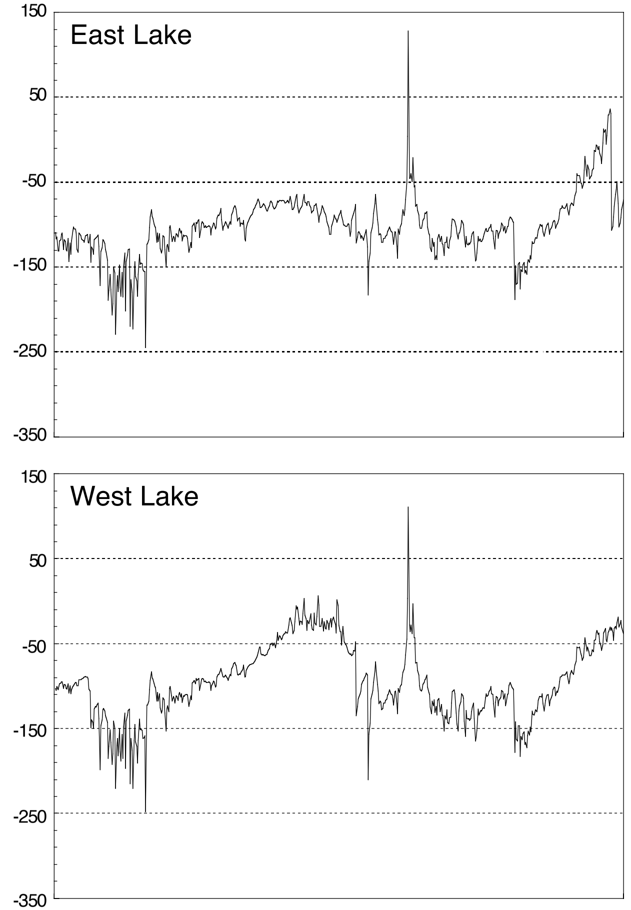
Daily δE East & West Lake

Figure 12.14

Notes:
Each panel is daily average calculated δE (‰) for East and West Lake over period April 22, 1996 to January 3, 1998 (Balance periods 1-50). Humidity normalised to lake surface temperature

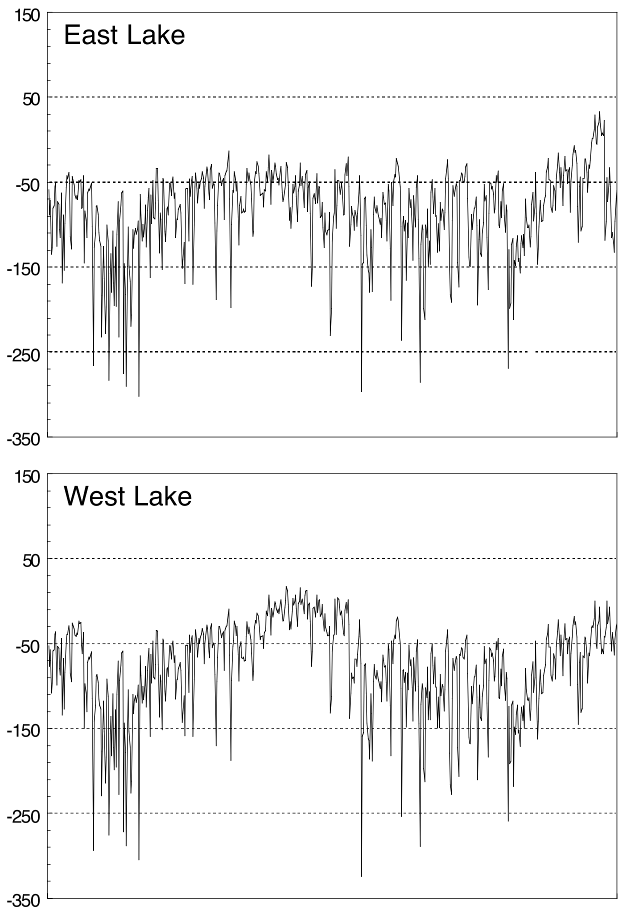
δE determined using δA interpolated from weekly sampling Craig & Gordon 1965 Eqn 23

Critical parameters: h, δ(lake), δA



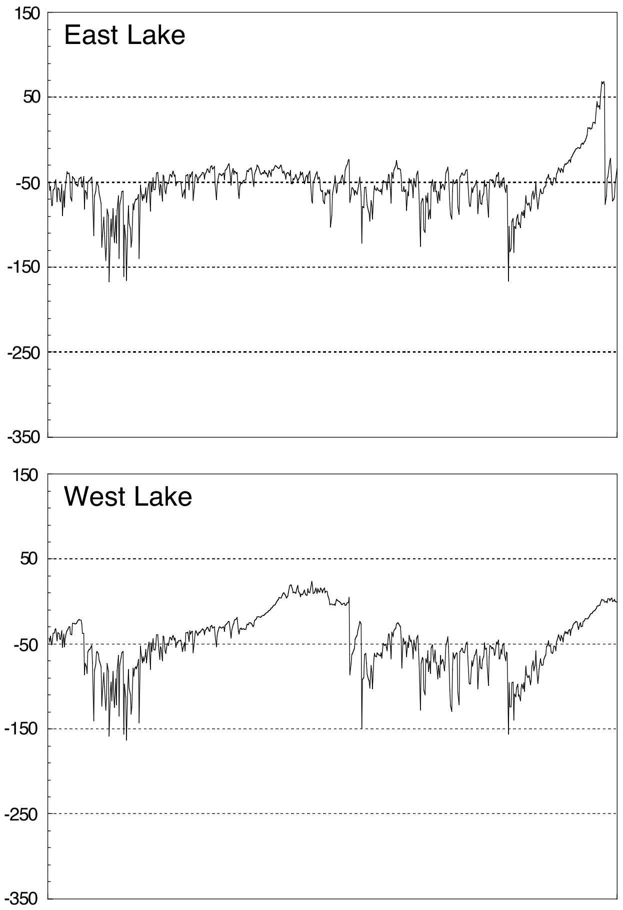
δE determined using δS (COS function), pans evaporated to dryness & Welhan & Fritz 1977 Eqn 12.

Critical parameters: h (as m), δ(lake), δS



δE determined using K (COS function), constant volume pans & Allison & Leaney 1982 Eqn 12.

Critical parameters: h (as m), δ(lake), K



In all cases humidity was normalised to lake surface temperature. Daily δ_E calculated for East and West Lake using each method can be compared in Figure 12.14. The differences reflect the differing critical parameters upon which each is based and the assumptions used in extrapolating exchange parameters from pans to lake. The same calculations were made using non normalised humidity. Mean values of daily average δ_E were calculated for balance periods 1-50 (22 April 1996 to 03 January 1998) and for calendar year 1997 (Table 12.19). The table includes non normalised data.

Table 12.19 Mean values of $\delta_{E(lake)}$ East and West Lake (per mille)

East Lake	RH (air) K (Cos)	RH (norm) K (Cos)	RH (air) δ_S (Cos)	RH (norm) δ_S (Cos)	RH (air) Craig & Gordon	RH (norm) Craig & Gordon
Bal 1 to 50	-65.5	-53.3	-131.9	-84.1	-107.3	-101.7
Year 1997	-63.2	-50.5	-128.9	-81.8	-96.6	-92.7
West Lake						
Bal 1 to 50	-57.5	-46.0	-123.9	-76.8	-85.2	-94.5
Year 1997	-58.0	-44.4	-123.7	-75.7	-88.1	-86.6

In East Lake the mean $\delta_{E(lake)}$ calculated by pan derived K was 42.2‰ greater than the value calculated using Craig & Gordon (1965) equation 23. The data however is much smoother than that using pan derived δ_S although this is closer to the Craig & Gordon figure in terms of annual mean, being just 10.9‰ greater. Daily isotopic balances were computed and integrated with mass and solute balances (Chapter 6) using both method 1 and method 3. Final balances used the locally derived pan data of method 3. The difference between the two methods (in terms of water balance mass) was less than 1%.

Allison & Leaney (1982) show how errors in $\delta_{E(lake)}$ estimated from pan parameters are minimised by choosing δ_I such that K is approximately equal to δ_{lake}. This approach involves 'spiking' the feed water to produce the desired δ_I. Under such conditions relatively large errors in evaluating *m* (up to 30%) can be tolerated since they result in relatively small errors in estimated $\delta_{E(lake)}$. This study took the approach of using groundwater such that δ_I in the pan experiments was identical to the isotopic content of groundwater discharge in the adjacent lake. At Perry Lakes where multiple experiments using large quantities of water were run continuously over two years the use of 'spiked' feed water was considered unwarranted on the basis of added complication and cost.

Notation Chapter 12

I	rate of inflow per unit area to a water body
δ_I	isotopic composition of inflow
O	rate of outflow per unit area from a water body
δ_L	isotopic composition of lake water
P	precipitation on water body surface per unit area
δ_P	isotopic composition of precipitation
E	evaporation rate
δ_E	isotopic composition of evaporating water from a lake surface
$E\rho_{iL}$	liquid transport resistance (very small and usually ignored)
K	limiting steady state isotopic composition of water remaining in pan held at constant volume
T	temperature ˚C
V	evaporation pan volume
f	the fraction V of original volume of liquid V_o remaining, $f = V/V_0$
f^{a*}	fraction of residual water (f), $a*$ combined equilibrium and kinetic fractionation factors
h	relative humidity, relative humidity normalised to surface water temperature
m	refer text
t	time since initiation of pan run , start t=0
δ, δ_L	isotopic composition of a well mixed body of water subject to evaporation only
δ^*	isotopic steady state limiting value of Gat (1981)
δ_A	isotopic content of atmospheric water vapour
δ_E	isotopic composition of evaporating water vapour
δ_K	alternate designation for K
δ_L^{ss}	isotopic steady state in a terminal lake
δ_{in}	isotopic content of inflow to a terminal lake
δ_I	isotopic composition of feed water in a constant volume pan
δ^0	initial isotopic content of water in a constant volume pan at $f = 1.0$
δ_S	limiting steady state isotopic composition of water remaining under E with no flow
α^*	equilibrium isotope fractionation: $\left(R_{vapour}/R_{liquid}\right) < 1$ where R is the ratio of isotopic water molecules DHO/H_2O or H_2O^{18}/H_2O^{16}
$\Delta\varepsilon$	kinetic enrichment factor
ε^*	equilibrium enrichment factor $= 1 - \alpha^*$, $\alpha^* = 1 - \varepsilon^*$
ε	total enrichment factor, equals: $\varepsilon^* + \Delta\varepsilon$
ρ_L^*	isotopic transport resistance in the liquid

CHAPTER

13

CLIMATE, URBANIZATION & WETLANDS

13.1 INTRODUCTION

When viewed within the broader time frame of geological time (even just Holocene time), it becomes evident that wetlands are far from being permanent features. Perry Lakes, like many other Swan Coastal Plain wetlands are merely shallow deflation hollows whose base lies below the present groundwater table. As we examined in Chapter 2, Perry Lakes as known since colonisation, have existed within an unconfined aquifer whose level fluctuated between approximately 3 to 4m AHD. In recent summers the groundwater level has fallen below this range. Leaving aside for a moment the reasons why this might be happening, what we are observing is a process which occurs naturally in water table wetlands everywhere. As the water table declines the area of open water diminishes and a well documented sequence of vegetational changes follow. The distribution of emergent wetland plants adjusts quickly to the altered hydrologic regime, occupying areas which were formerly open water. Trees and other non aquatic vegetation quickly become established in areas which were formerly seasonally inundated. In East Lake mature stands of flooded gums (*E. rudis*) now occupy areas which 40 years ago were permanent open water. While wetland managers and conservationists may mourn their disappearance, they must accept that such wetlands on a geological time scale are at best ephemeral, existing only under very specific groundwater conditions.

Pre colonisation, the unconfined aquifer below the Swan Coastal Plain was in a state of approximate dynamic equilibrium, controlled by recharge (ultimately reflecting rainfall) and discharge (ultimately into the Indian Ocean and Swan River) plus water drawn by phreatophytes. Over time frames of a few years the mean water table level at any point fluctuated seasonally around an average level which probably varied little from year to year, and which reflected the prevailing average rainfall. Within the longer time frame of decades and centuries rainfall and the water table changed.

Variations in rainfall or the more inclusive term 'climate change' are viewed with fear and misunderstanding by many. Understanding of this largely natural phenomenon is not aided by poorly substantiated speculation and scare mongering in the popular press. Human beings do not like change and uncertainty, preferring instead constants and predictability. In part, this may be why the notion of 'average rainfall' arose in the first place, yet the concept is arguably flawed because rainfall, like all natural processes is constantly changing. When viewed over the shorter context of decades, (and even the period over which Australia has maintained meteorological records) rainfall may appear to be more or less constant, but over centuries and longer, the notion of average rainfall becomes less and less viable. Table 13.1 shows average decade rainfall for Perth over 12 decades. The current average (1875 - 2002) is 861.3mm, while the 'official' average quoted by the Bureau of Meteorology remains 869mm. The average 2000 to 2002 was only 741mm.

Table 13.1 Perth average decade rainfall

Decade	1880-89	1890-99	1900-09	1910-19	1920-29	1930-39
Average (mm)	844	833	881	868	992	927
Range	630-1016	602-1188	688-1008	514-1161	799-1251	753-1161
Decade	1940-49	1950-59	1960-69	1970-79	1980-89	1990-99
Average (mm)	895	876	860	772	820	816
Range	509-1339	617-1182	574-1042	560-974	691-930	648-960

Possibly water engineers and hydrologists in Perth should cease quoting an average rainfall and deal with the reality that the last decade average is only 816mm. Wetland managers must face the same reality. Perth is now into its fourth decade of declining rainfall. The overall trend since records commenced in 1875 is one of decreasing rainfall. This trend is substantially greater in the period 1955-2002 (Figure 13.1). The water table is declining and wetlands are shrinking or disappearing altogether. This is largely a natural process, modified by urban effects. Under the prevailing climatic regime, wetlands can only be maintained in their former configurations through non natural intervention. This then becomes a decision influenced by cost, and the cultural, recreational and conservation value placed on the wetland.

The Town of Cambridge are the wetland managers for Perry Lakes. The key and over riding management issue is declining groundwater levels. Perry Lakes are disappearing. The original four wetlands (Camel Lake, South or 'Hidden Lake', East Lake and West Lake) present in the 1950's are now reduced to just East and West Lake (Chapter 2). West Lake dried out completely (apart from the small artificially deepened sump around the staff gauge) in 1995, and has done so every summer since. East Lake is now (2002) reduced to the South Basin (Figure 2.15), and must be artificially maintained by pumping groundwater for approximately half the year. Without this pumping, East Lake would also completely dry out every summer.

There is no single cause for the present hydrologic situation at Perry Lakes. Rather it is the end result of a number of natural and anthropologic factors which in combination have resulted in a large decline in the local groundwater level. These include:

- natural short term climatic cyclicity
- natural long term climatic change
- anthropologic effects on climate (global warming and greenhouse gas increase)
- urbanization and effects from changing land use patterns
- public and private groundwater extraction from the unconfined aquifer
- aquifer hydrogeology

This chapter will examine each of these factors. Chapter 14 provides some possible management options.

13.2 NATURAL CLIMATIC VARIABILITY

When viewed from the long perspective of geological time, it becomes abundantly evident that the only aspect of climate which is constant is change. Discussion of climatic change is meaningless without examining the concept of climatic cycles. Many of the phenomena which in sum total combine to form the earth's climate, if taken as a time series, show cyclicity (Burroughs 1992). The problem is that regardless of the chosen time frame, cyclicity is usually present. Quite simply, cyclicity is an inherent feature of climate. On a very large time scale such as the 3 billion or so years represented in the geological record, major ice ages occur roughly in cycles of several hundred million years. At the opposite extreme, are much shorter cycles. Between 1880 and 1980, 23 warm cycles associated with the El Niño Southern Oscillation (ENSO) have been recorded (Jones and Kelly 1988), on average one every 4 years.

The sun is the ultimate energy source driving the earth's weather systems. Frohlich (1988) discusses the 'solar constant', the level of energy output from the sun. Between 1980 and 1985 solar output decreased 0.019%, a decrease which must ultimately be reflected in our climate. In the shorter term, Frohlich has identified prominent cyclicity in the sun's output with periods of 51.4 to 4.8 days. These variations must also affect the heat balance of the earth and in time contribute to climatic change. He notes that within a larger time frame, variations in the solar constant appear to modulate the climate on a period of 11 and 22 years corresponding to the waxing and waning of sun spots on the solar surface. Mitchell (1990) has tied the rhythm of drought in the mid west USA to this 22 year solar cycle.

Three separate cyclic changes in the earth's movements through space can also combine to produce overall changes in the amount of solar radiation received by the earth. These have come to be known as the Milankovich Model after the Yugoslav Milutin Milankovich who first suggested that these astronomical variations could be linked to the ice ages (Gribbin 1979). The longest cycle is 90 to 100,000 years corresponding to variations in the shape of the earth's orbit around the sun from almost circular to elliptical. In an elliptical orbit, there is variation in the distance from earth to sun, the net result being a greater contrast in the seasons. The second cycle has a period of about 40,000 years corresponding to changes in the tilt of the spinning earth. When the tilt is pronounced, seasonal differences also increase. The third cycle known as the precession of the equinoxes has a period of 20,000 to 25,000 years and is effectively a wobble in the earth's rotation resulting from variations in the gravitational pull of the sun and the moon. Each cycle alone would result in variations in the amount of solar radiation received at different latitudes during the year. The sum total of the additive effect of the cycles is constantly changing. Imbrie (1985 & 1987) has suggested that the very abrupt changes in climate or 'terminations' which mark the ends of several of the late Pleistocene ice ages occurred when the sum or additive effects of these orbital variations was very large. Kerr (1986) suggests that Milankovich cycles account for 80% of the climatic variability on time scales of 20,000 to 100,000 years.

Climatic records for the Holocene have long shown that the 10,000 years since the end of the last ice age was far from being climatically tranquil. These records, based on dendrochronology, palynology, glacial ice and sediment cores, corals and other 'proxy data' show a highly dynamic world climate in which temperature and rainfall distribution displayed pronounced variability on all time scales from year on year to century on century (Pearce 1996, Crowley 2000). In Australia, such independent evidence also suggests that similar variability is likely to persist in the future regardless of any human influences (De Deckker *et al* 1988). More recently there has been growing acceptance of evidence indicating that the earth is prone to sudden and drastic changes in climate. Rather than the gradual change often predicted by climate models, the proxy data indicate that the global climate operates on a number of stable states, and that the change from one to another can be very rapid. The Sahara is possibly the best known example. It was covered in forest around 6000 years ago, the change to desert occurred within a few decades (Pearce 2001).

Climate researchers have long believed that underlying these seemingly chaotic climatic records there may be a more fundamental order (Burroughs 1992). The search for predictable cyclicity has been given added impetus by the spectre of anthropologically induced (or at least) exacerbated global warming. Proving that human activity has contributed to climate change implies an ability to differentiate between natural and non natural climatic patterns. If natural variations can be identified then the ability to recognise and quantify non natural changes are enhanced. Cycles with frequencies of decades to centuries are believed to be paced by the oceans and polar ice where ponderously slow currents and massive reservoirs of heat provide the timing mechanism (Kerr 2000). For example one such oscillation first identified in the Atlantic Ocean appears to affect global climates. It has a frequency of approximately 70 years (Delworth & Mann 2000). Simulations using a coupled ocean-atmosphere model predict the oscillation and simulate observed warming patterns from instrument records (Delworth & Knutson 2000). The combination of instrument data, proxy climate records and climate models all point to a 50 to 70 year oscillation. The data and models predict that much of the current global warming is therefore part of a natural cycle which will persist for the next few decades (Kerr 2000).

Evidence for shorter cycles linked to solar variability and in particular the sunspot cycle have predominated in the search for global climatic patterns (Burroughs 1992). Sunspot density fluctuates with a mean period of approximately 11.2 years. The total solar radiance varies with sunspot number by about ± 0.04%. In climatic studies generally however 20 to 22 year cycles are prevalent. These roughly correspond to the Hale magnetic cycle[1] (or 'double solar cycle') of 22.4 years.

13.3 ANALYSIS OF PERTH RAINFALL

Historic rainfall data for Perth are reviewed in Chapter 2. The data show an apparent cyclicity and over the past forty years there has been an obvious decline in average rainfall (Table 13.1). Perth monthly rainfall data 1876 to 1998 was analysed by discrete Fourier transform. The power spectrum (Figure 13.1) displays distinct peaks centred around 10.3 and 20.1 years. There is also a weak peak at 30.1 years. McFarlane (1984) using auto correlation techniques noted an 11 year assumed sunspot cycle. Allison & Davis (1993) applying geostatistical techniques to a 100 year rainfall data set found a 22 year 'double solar' signal (Figure 13.1). Examination of the power spectrum using Fourier analysis (Pittock & Lean cited Allison & Davis 1993) suggested only an 11.2 year signal. The current analysis based on a longer data set of 123 years suggests a similar signal. This analysis approximates the 11 year solar cycle of Allison & Davis (1993) for Perth data. The 8.0, 5.6, 4.0, 3.0 and 2.2 year signals of Gentilli (1971 p196) could not be substantiated by Fourier analysis. The 30 year signal is of a similar period to the Inter-

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[1] In one 11.2 year sunspot cycle leading spots in the sun's northern hemisphere will have positive polarity while trailing spots will be negative. The polarities are reversed in the sun's southern hemisphere. The pattern reverses in successive 11.2 year cycles.

decadal Pacific Oscillation (Luntz 1999), which may control El Niño and La Nina events in the Pacific.

The Perth rainfall data of 123 years covers far too short a time span to be a useful long term predictive tool. When plotted together, the sunspot and averaged rainfall data do not particularly display an obvious correlation (Figure 13.1). Because of the slightly different period they are out of synchronisation. The International Sunspot Number time series records go back to 1700 (SIDC 2002), with the periodicity determined from 26 complete cycles. The Perth rainfall data comprises only six 20 year cycles, probably too short to determine an accurate period. This lack of absolute correlation between observed cycles and the solar cycle is not unique to the Perth data and is commonly reported in many climate studies. Over longer time series such as the 2556 year tree ring data of Nordemann *et al* (2001) an 11 year signal is commonly reported. The presence of such solar related cycles corresponding to sunspot, solar irradiance and the solar magnetic cycles (Lean 1991, Webb *et al* 1984) is common in meteorological time series (Burroughs 1992).

Just how changes in irradiance translate into changes in rainfall is problematic. Goode *et al* (2001) have suggested that during sun spot minima (when the sun's magnetic field is also weaker), more galactic cosmic rays enter the sun-earth system. These may, in part act to seed clouds resulting in increased rainfall. Most of the irradiance variations associated with sunspot activity are in the UV range. UV is absorbed by stratospheric ozone and oxygen and then warms the lower stratosphere (Gribbin 1996). Small changes in irradiance are therefore amplified in the Earth's atmosphere. Evidence from the UK (Lawrence 1996) suggests that rainfall peaks about two years before each sunspot maxima. While astronomers and meteorologists have long suspected a link between solar activity and weather the specific mechanisms are not understood and the link with rainfall appears to vary from area to area. Certainly Perth rainfall exhibits an approximate 20 to 21 year cycle which may be linked to solar activity.

The data suggest that the next rainfall peak will occur about 2013. In absolute terms however it is doubtful that rainfall in the next few decades will be anything like the historic average of approximately 860mm. The present decrease in Perth rainfall is part of a regional phenomena. Since the 1950's there has been a major reduction in rainfall throughout the south west of Western Australia (Wright 1992). Research in progress (Nicholls 1998) suggests that neither ENSO events nor variations in Indian and Southern Ocean sea surface temperatures display a strong correlation with this change. Allan & Haylock cited Wright (1992) note that long term rainfall variation may have multiple

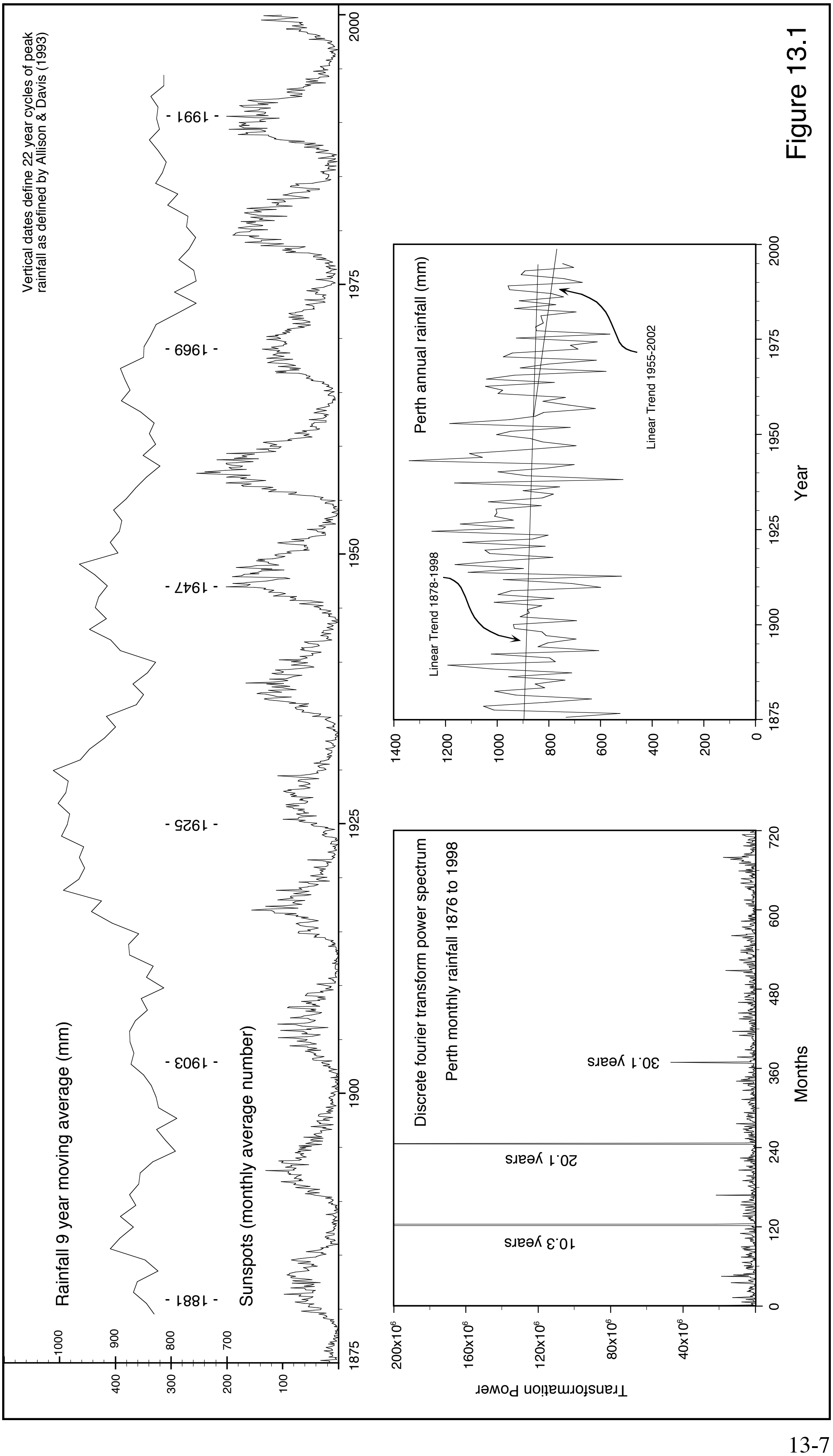
Rainfall 9 year moving average (mm)
Sunspots (monthly average number)
Vertical dates define 22 year cycles of peak rainfall as defined by Allison & Davis (1993)
1000
900
800
700
400
300
200
100
1881
1903
1925
1947
1969
1991
1875
1900
1925
1950
1975
2000
Discrete fourier transform power spectrum
Perth monthly rainfall 1876 to 1998
10.3 years
20.1 years
30.1 years
Transformation Power
200x10^6
160x10^6
120x10^6
80x10^6
40x10^6
0
120
240
360
480
600
720
Months
Perth annual rainfall (mm)
Linear Trend 1878-1998
Linear Trend 1955-2002
1400
1200
1000
800
600
400
200
0
1875
1900
1925
1950
1975
2000
Year

Figure 13.1

causes including natural long term variations, random fluctuations in rainfall pattern and natural or anthropologically induced climate change, acting alone or in combination.

Much of Australia has been getting wetter since about 1910. The south west of Western Australia however (which includes the Perth metropolitan area) has been getting drier with a 19% total reduction and 25% winter rainfall reduction over the period 1910-1995 (Hennessy *et al* 1999). This drying is in agreement with some models of greenhouse warming. However the issue of greenhouse versus natural variability is difficult to resolve. Models show that long dry periods spanning decades occur naturally without any input from the greenhouse effect. The problem for wetland managers is that no one really has any firm idea what the climate and in particular rainfall over the next few decades is likely to do. Depending on the global climate model used, regional climate change scenarios (CSIRO 1996) predict both a continuation of this drying trend and a reversion to wetter conditions. The general trend over the past 125 years as expressed by a simple linear regression is decreasing rainfall (Figure 13.1).

The Indian Ocean Climate Initiative (IOCI) is currently examining the current decline in rainfall in the south west of Western Australia. In particular the initiative hopes to investigate the effects of the Indian and Southern Oceans on inter-seasonal and inter-decadal climate variability in the region (Bates 1999). Preliminary conclusions suggest that the pronounced drying over the past 30 years is unusual both at a regional and global scale. Within an historical context the recent dry years are very unusual. Drying has resulted from both a reduction in the number of rain days and rainfall amounts in extreme events including extreme intensity and extreme frequency (Nicholls *et al* 1999). Linkage has been demonstrated between atmospheric pressure over the continent represented by Perth mean sea level pressure (MSLP) and regional rainfall. When pressure increases mid-latitude depressions pass further to the south of Australia (Wright 1992, Allan & Haylock 1993). Nicholls *et al* (1999) believe that about half the observed rainfall decline can be attributed to changes in regional circulation as represented by Perth MSLP. When viewed at decadal and longer scales however, little of the observed rainfall decline can be attributed to the El Niño - Southern Oscillation or to changes in Indian Ocean sea surface temperatures (Nicholls *et al* 1999).

Climate model simulations for the south west of Western Australia run over 1000 years suggest that natural variability alone can explain decadal and longer dry spells and that these can occur without any obvious external factors (Hunt *et al* 1999). The simulations suggest that the present drying trend is not unique but neither are such trends a particularly common occurrence. The return period of a 10 year rainfall trend is about 1000 years with annual rainfall losses of 20-30%.

13.4 GREENHOUSE WARMING

The greenhouse effect is an anticipated global climate change associated with increased atmospheric concentrations of CO_2 and other gases. These allow sunlight through to the earth's surface but impede the passage of infra-red radiation back into space resulting in a net warming (Pittock 1988). There is general agreement that global warming in excess of that which would be expected from natural climatic variation is already occurring (IPCC 2001, NRC 2002) although the amount which can be attributed to human activity and the anticipated effects on future global climate remain controversial (Calamai 2001). It will not be until there is widespread agreement that the actual climate changes observed exceed natural climatic variability that we will be able to ascribe these changes to the greenhouse effect (Pittock 1988). Regardless of the causes, such warming results in gross changes in global climate patterns including rainfall.

Climate model simulations of global warming from increased greenhouse gas for south west Western Australia include average temperature increases of 1.5° to 5.2° between 2030 and 2070 (Pyper 2001) and reduced rainfall. Model simulations suggest that greenhouse effects will become more pronounced later in the twenty first century. Using the CSIRO Mark 2 coupled climate model Hunt *et al* (1999) allowed carbon dioxide to triple over the period 1881 to 2083. The model predicts declining rainfall through to at least 2100 (Figure 13.2) however the constant decline predicted from 1881 to 2120 is contrary to observed rainfall and suggests that while greenhouse effects may influence climate they are not the sole cause of the declines noted since the 1960's.

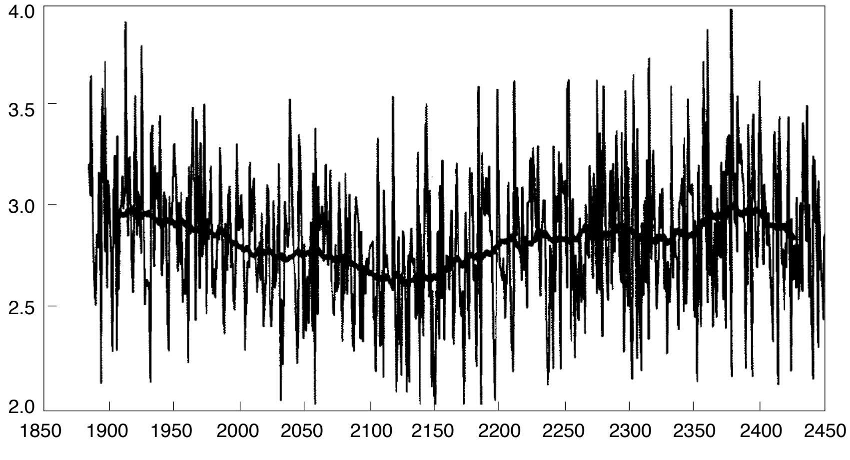

Figure 13.2 Simulated annual mean winter rainfall changes over south west WA under greenhouse conditions. Effective atmospheric CO_2 content tripled between 1881 and 2083 and held constant thereafter. Thin lines are annual mean values for each year, thick line is smoothed trend, y axis is rain mm d^{-1} (Figure 35 of Hunt *et al* 1999)

Where does all this uncertainty leave wetland managers? The most prudent approach must be to assume that the present trends (reduced average rain and general lack of summer rain) will continue. Perth rainfall has declined by more than a third over three decades. None of the drought simulated by Hunt *et al* (1999) lasted more than 30 years (Adler 1999). An optimistic approach would be to assume imminent change. The uncertainties of differentiating between natural variability and greenhouse effects however preclude this as a responsible option. Predicting long term rainfall trends anywhere remains difficult.

Neville Nicholls[2] (pers com) has put the difficulties in predicting Perth rainfall into perspective. Nicholls believes the only predictions which have any real credibility are those based on the enhanced greenhouse effect and these are strongly scale dependent. Predictions for a small area such as Perth are doubtful. Just a small change in the prevailing winds, for example, could produce a large (and unforeseen) change in rainfall. The decline in rainfall is a true research problem which is unlikely to be understood quickly (if at all). Nicholls believes that the likelihood of developing credible means for predicting Perth rainfall 20 to 30 years ahead are 'vanishingly small'.

This places wetland managers in the difficult position of either attempting to minimise the impact of climate change by acting on the basis of theory or waiting and potentially risking situations which are irredeemable. Wetland managers therefore need to approach the future management of Perry Lakes using trends over the past 30 years and current predictions of likely ongoing rainfall decline. Decisions will have to be approached on the basis of risk assessment, probabilities and inadequate records. These are routine problems in engineering and business (Pittock 1988) and form the basis for exploring long range management options. They include:

- do nothing
- increased groundwater top up
- dredging
- importing water
- reducing regional bore extraction thereby raising the regional water table

These options are examined more closely in Chapter 14.

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[2] meteorologist, Bureau of Meteorology Research Centre, Melbourne.

13.5 URBAN EFFECTS

Urbanisation over unconfined aquifers has long been recognised to disturb their long term dynamic equilibrium. In general urbanisation leads to an increase in recharge and a rise in the water table. In Perth four separate factors act in combination (McFarlane 1981) once native vegetation is removed:

- reduction in interception losses from native vegetation
- reduction of transpiration losses
- additional recharge from imported water (lawn irrigation and septic systems)
- increased recharge from impervious shedding surfaces (roofs and roads)

Impervious shedding surfaces make up 30 to 40% of urban areas. They collect most of the rain which falls on them and redirect it back to the water table. In Perth, roofs and roads drain either to soak wells or storm water drains which terminate in wetlands. These shedding surfaces effectively circumvent the high interception, evaporative and transpirative losses associated with native vegetation. Urban areas are also dominated by lawns. Their extremely shallow root systems lead to significant recharge both from heavy rainfall and lawn irrigation (McFarlane 1984). In Perth, groundwater recharge below individual residential blocks may be many times that of natural recharge. Williamson & Cole (1976) estimated that where natural recharge below native bushland was 250 mm, recharge (rain and imported water) from residential blocks was as high as 940 mm yr^{-1}.

The increase in recharge is moderated by other urban factors. These include:

- extraction from bores
- flood mitigation drains (eg Herdsman Lake)
- sewering of areas serviced by septic tanks

The competing gains and losses are seldom in equilibrium so in the short term at least the effect of urbanisation is for the water table to rise or fall. In Perth recharge generally exceeds extraction and levels rise. However elsewhere, such as the Perry Lakes area, losses now appear to exceed recharge and the water table is falling. The reasons for this are examined in the following sections. Ultimately the aquifer will achieve a new state of dynamic equilibrium however in a rapidly expanding urban area such as Perth this is unlikely to be achieved in the short term.

13.6 GROUNDWATER EXTRACTION

The whole issue of groundwater extraction is a contentious one (not just at Perry Lakes but world wide) centred around the key concept of sustainability. Bredehoeft *et al* (1982) argue that 'sustainable' groundwater extraction is a myth. Their key argument hinges on the concept that under natural conditions (before human interference) aquifers are in a state of approximate dynamic equilibrium. Theis (1940) argued that extraction represents an additional discharge superimposed upon a previously stable system. Under such conditions the water table will remain unchanged only if there is an increase in recharge, or decrease of the natural discharge. Bredehoeft *et al* (1982) believe that there exists a widespread misconception among hydrologists and water managers that the water budget determines the magnitude of possible (*i.e.* sustainable) groundwater development. They argue that truly sustainable extraction (that which will cause no long term decline in the water table) depends on how much the rate of natural recharge or discharge can be changed. Increase rainfall, say, or capture through pumping water naturally lost from the system would satisfy these requirements for truly sustainable human groundwater extraction. In practice capture of natural discharge is largely impossible and increasing recharge (as rain) cannot be controlled. At Perry Lakes urbanization has already increased natural recharge however this occurred 60-70 years ago and is not now likely to change much.

In many situations, extraction is simply groundwater mining. Water managers 'get away with it' because of the generally slow response times of aquifers (Bredehoeft *et al* 1982). These depend on aquifer parameters transmissivity, and storage co-efficient (confined aquifers) or specific yield (unconfined aquifers) and boundary conditions. In Perth, water managers have maintained an illusion of sustainability because of the partial counterbalancing effect of increased urban recharge. Even here however overall extraction now exceeds recharge and despite the effect of changing land use overall declining water levels will continue unless absolute recharge is increased or high volume extraction is moved to the discharge margins of the Gnangara Mound (Salama *et al* 2003).

As early as 1915 the idea that significant quantities of water could be extracted 'regularly and permanently without dangerous depletion of the storage reserve' was a concept widely accepted by hydrogeologists (Lee 1915 cited Fetter 1994). Lohman (1972) reviewed the definitions of safe (or 'sustainable') yield. He concurred with Thomas (1951 cited Lohman 1972) that the concept is an illusion, describing it as an 'Alice in Wonderland' term which means whatever its user chooses. Todd (1959) took a more practical approach suggesting that safe yield was the amount which could be abstracted 'without producing an undesirable result'. Fetter (1994) suggests that taking into account the important concept of environmental degradation, a composite definition as currently used might be 'the amount of naturally occurring groundwater that can be withdrawn from an aquifer on a sustained basis, economically and legally, without impairing the native groundwater quality or creating an undesirable effect such as environmental damage'. Applying this more pragmatic approach to Perry Lakes it can be argued that at least within the Perry Lakes sector of the Gnangara Mound, abstraction is having an undesirable effect on wetlands and is therefore unsafe. This concept is not new. Almost half a century ago Kazmann (1956) argued that the term safe yield be abandoned because it failed to address the intimate link between groundwater and surface water. Sophocleous (2000) and Glennon (2002) provide current examples from the United States. Critical examination of sustainable yield has lead many to the conclusion that it is largely a myth. Fetter (1994) describes safe yield as a paradox while Bredehoeft *et al* (1982) conclude that in most cases 'sustainable' groundwater extraction is simply an acceptance that such extraction will inevitably result in a new state of dynamic equilibrium and that such changes (usually a lowered water table) are deemed 'sustainable' simply because they are environmentally (or just politically) tolerable.

In the Perry Lakes Sector discharge to the ocean or Swan River cannot be captured (although pumping from the downstream end of the aquifer system could reduce discharge). Recharge from rain has decreased, recharge from elsewhere in the aquifer (boundary input) is either constant or declining slowly as more water is used for domestic supply. On the basis of rainfall alone, a decline would have occurred anyway. If rainfall increased markedly (as it did around 1920) we could factor in some truly sustainable extraction. The situation now is that pumping is not sustainable (neither in its true hydrologic sense nor in its 'acceptable decline of water table' sense) and is probably seriously contributing in a 'death by a thousand cuts' sense to the declining wetland water levels. Sadler *et al* (1988) predicted that for the Perth metropolitan area, a 20% reduction in mean annual rainfall would necessitate a 40% reduction in groundwater draw from bores supplying potable water. Arnold (1988) suggested that on the Swan Coastal Plain the combined effect of reduced rainfall and increased demand for groundwater extraction by both public and private users would inevitably result in many wetlands disappearing. These predictions are now coming to fruition.

13.7 DOMESTIC BORE MAPPING

In order to quantify what effect bores might be having in the Perry Lakes area a comprehensive program of bore mapping was initiated. Bores are unlicensed in Perth and hence there are absolutely no records of bore locations or density. Perth residents have laboured for many years under the illusion that there is an abundance of groundwater. This impression has not been helped by the fact that domestic bores for garden watering require no licence and are actively encouraged by the authorities as a means of reducing the pressure on treated reticulated water. In the wake of the 2002 drought Water Corporation were offering a $500 rebate on new domestic bores. Maps indicating areas considered hydrologically suitable for bores continues to include the Perry Lakes/Floreat area.

13.7.1 Mapping of Public and Private Bores

Domestic 'back yard' bores were mapped on the ground in an area of about 6x3 km around Perry Lakes (Figure 13.3). This involved walking all streets within the survey area during summer (January-March) and looking for well irrigated lawn and gardens and the ubiquitous iron staining. Groundwater contains dissolved iron which is stable under reducing conditions (Davidson 1995, p89). Upon exposure to air this is oxidised to ferric iron which imparts distinctive yellow-brown stains on walls and pavement. Iron concentrations in the superficial aquifer vary from 1 to greater than 50mg/l. This mapping program was a slow and tedious task which took two summers (1996-97 and 1997-98) to complete.

Depth to the water table is probably the single biggest factor in bore density within any area. Most domestic bores use simple centrifugal pumps which have a net maximum suction lift of less than one atmosphere or about 10m (Bouwer 1978, p186). In many older installations centrifugal pumps are frequently installed at the bottom of dry wells 10-15m deep thereby allowing access to water 20-25m below surface level. Beyond this depth small submersible pumps are employed. Shallow installations where limestone is absent frequently use spear points installed by jetting or sludge pump. Deeper bores or bores in limestone must be drilled, substantially increasing costs. Block size and general affluence are also factors. Many new houses in established suburbs are on small subdivided blocks where the cost of a bore cannot be justified. More affluent home owners also frequently opt to use scheme water to avoid iron staining on pavement. Some developments specifically ban the use of bore water for this reason. In general however, depth to water is the single greatest factor determining domestic bore density (Table 13.2). Where bores are very expensive to construct, a single, larger capacity bore is frequently shared between 2 to 4 homes. These have been mapped as single bores.

Based on average residential block density of 1000-1200 blocks per km^2 bore density ranges from 100 - 125 per km^2 in elevated limestone areas such as City Beach to 650 - 775 per km^2 in low areas such as those immediately adjacent to Perry Lakes.

Table 13.2 Topographic Influence on Domestic Bore Density

Depth[1]	Area	Blocks	Bores	Percent	Comments
5-10	Floreat	136	88	64.7	adjacent to Perry Lakes, no limestone
5-10	Churchlands	279	159	57.0	adjacent Herdsman Lake, no limestone
10-20	City Beach	374	71	19.0	limestone (?)
10-20	Wembley	311	138	44.4	mostly sand
10-20	Floreat	168	88	52.4	adjacent to Perry Lakes, no limestone
20-25	Floreat	419	210	50.1	mostly sand
25-30	Floreat	170	57	33.5	sand and limestone
25-30	Floreat	275	72	26.2	sand and limestone
30-40	Floreat	194	35	18.0	sand and limestone
over 40	City Beach	353	36	10.2	limestone, depth to water >60m in places

1: approximate depth to water table (m)

Bores used to irrigate public open space and large private lawns employ either 'turbine pumps' (impellor pumps which operate below the water surface, driven from the surface by a rotating shaft), and submersible pumps. Bore location, pump type and capacity were obtained from the Town of Cambridge and City of Nedlands. Where capacity was not known, it was estimated based on pump type and outlet pipe diameter. Pump data are included in Figure 13.3.

13.7.2 Estimates of Extraction and Recharge in Parks and Reserves

Water usage in parks and reserves is difficult to estimate. Groundwater extraction is not monitored nor are records kept by any of the local councils on bore usage. These general comments apply equally to Perry Lakes Reserve.

At Perry Lakes there are 9 production bores (Figure 3.3). These have differing pumping capacities and usage (Table 13.3). Bores 1-8 are connected to a ring main system which allows irrigation water to be distributed from any bore or combination of bores to various parts of the reserve. Top up maintenance water to East Lake is drawn from the ring main via two outlets (Figure 5.1a). The ring main between these two outlets can be isolated via a gate valve such that the south outlet can be fed by bores 1 and 6 only and the north by bores 2-5 and 7. Bore 8 irrigates Alderbury Flats and the median strip within Oceanic Drive between Perry Lakes and Brookdale Street. Bore 9 irrigates the verge and median strip only, west from Perry Lakes Drive.

The irrigation rates are manufacturer's recommended rates feeding a pressurised system. When bores 1, 3 or 6 were operated alone for lake top up, the ring main operated at very low pressure resulting in substantially increased pump output. Top up was typically performed using bores 1,2,3 and 6 or occasionally in combination with bores 4, 5 and 7. Generally no more than five bores were operated at one time. Top up flow meter

382000
383000
6467000
6466000
6465000
6464000
Indian
Ocean
8
Bowls
Club
9
Retirement
Village
Water
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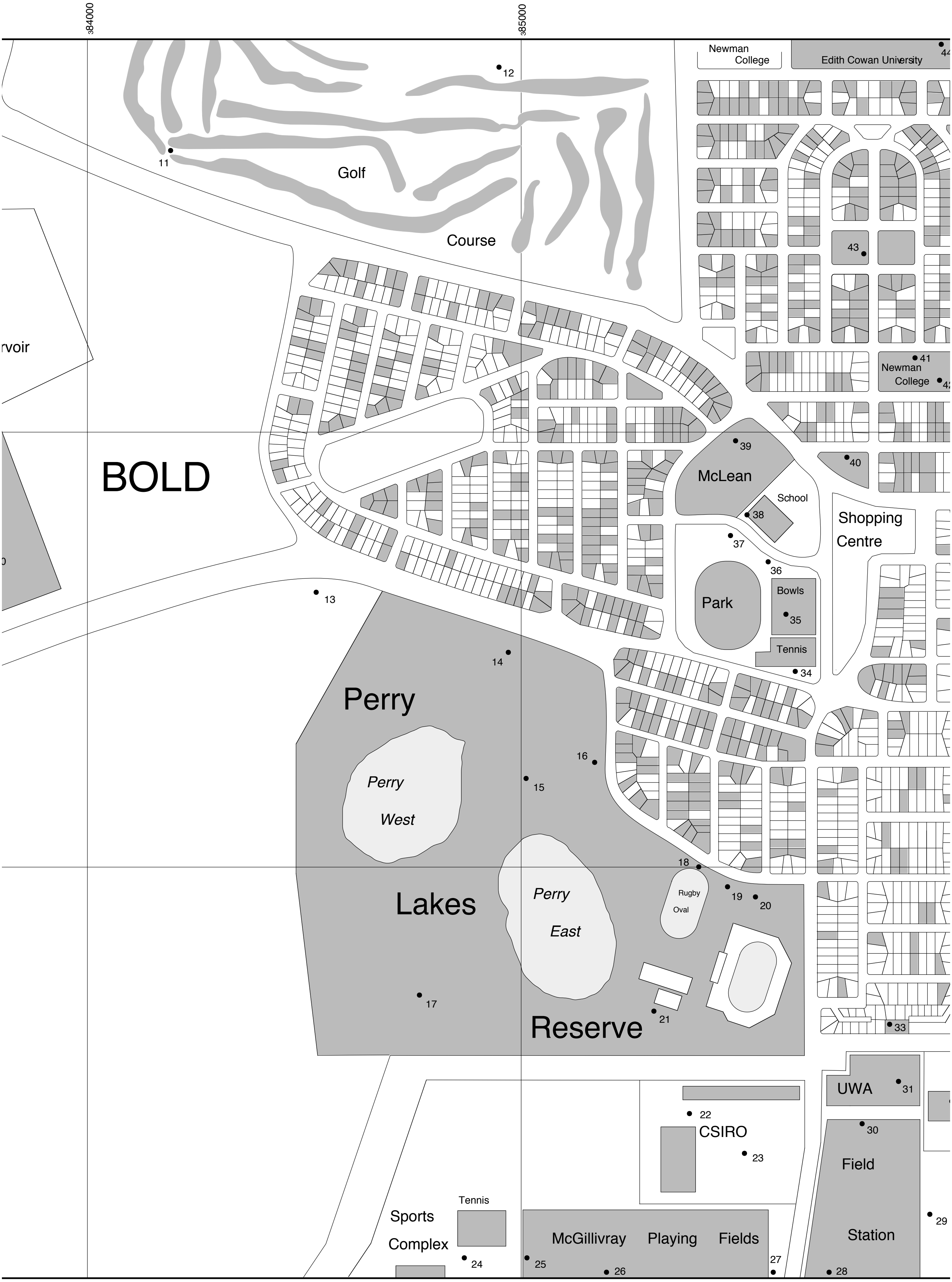
PARK


384000
385000
Newman College
Edith Cowan University
44
12
11
Golf
Course
rvoir
BOLD
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Newman College
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McLean
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School
38
Shopping Centre
37
36
Park
Bowls
35
Tennis
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13
14
Perry
Perry West
16
15
Lakes
Perry East
18
Rugby Oval
19
20
17
21
Reserve
33
UWA
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CSIRO
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Field
Station
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Sports Complex
Tennis
24
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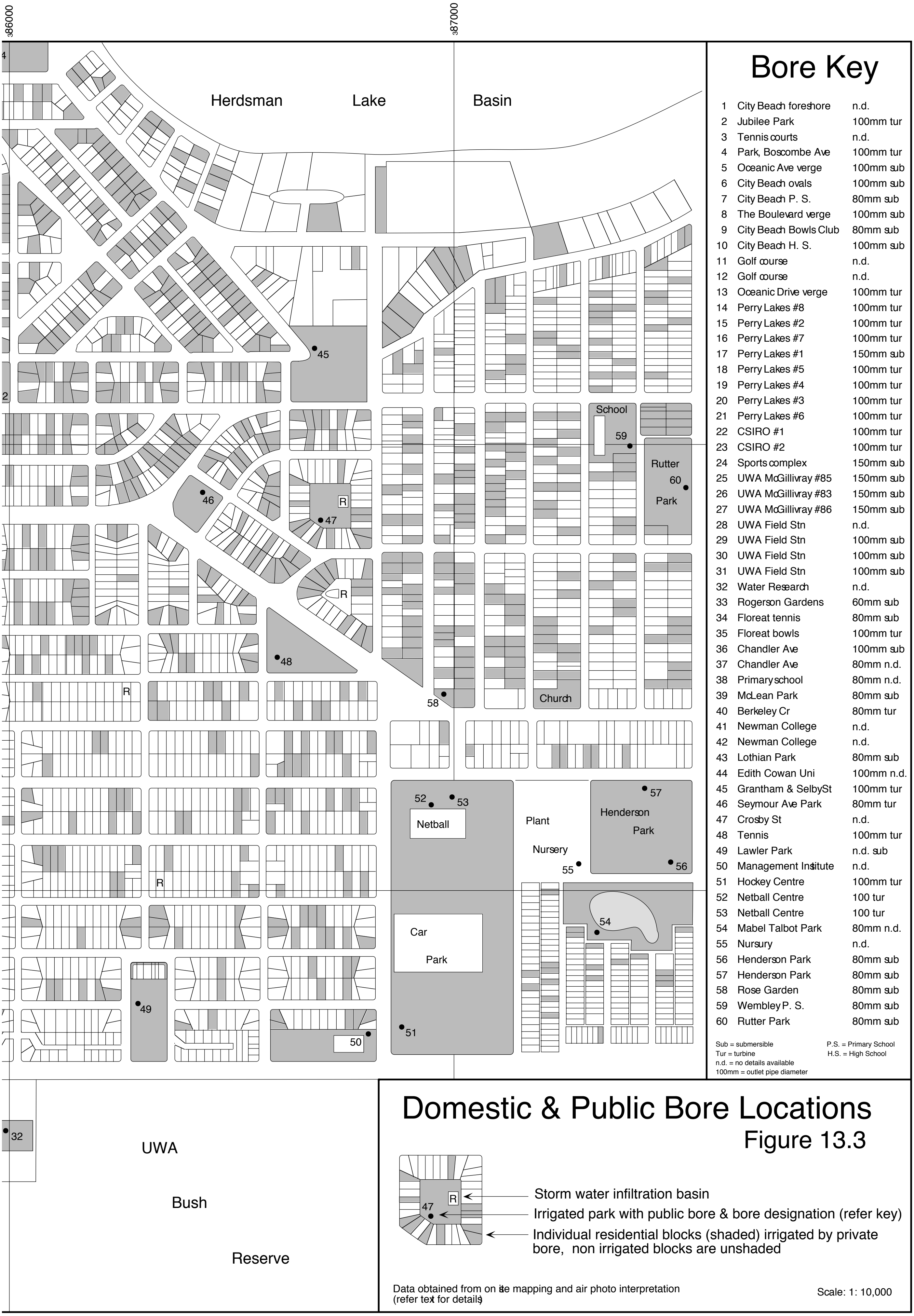
McGillivray Playing Fields
26
27
28



Bore Key

1	City Beach foreshore	n.d.
2	Jubilee Park	100mm tur
3	Tennis courts	n.d.
4	Park, Boscombe Ave	100mm tur
5	Oceanic Ave verge	100mm sub
6	City Beach ovals	100mm sub
7	City Beach P. S.	80mm sub
8	The Boulevard verge	100mm sub
9	City Beach Bowls Club	80mm sub
10	City Beach H. S.	100mm sub
11	Golf course	n.d.
12	Golf course	n.d.
13	Oceanic Drive verge	100mm tur
14	Perry Lakes #8	100mm tur
15	Perry Lakes #2	100mm tur
16	Perry Lakes #7	100mm tur
17	Perry Lakes #1	150mm sub
18	Perry Lakes #5	100mm tur
19	Perry Lakes #4	100mm tur
20	Perry Lakes #3	100mm tur
21	Perry Lakes #6	100mm tur
22	CSIRO #1	100mm tur
23	CSIRO #2	100mm tur
24	Sports complex	150mm sub
25	UWA McGillivray #85	150mm sub
26	UWA McGillivray #83	150mm sub
27	UWA McGillivray #86	150mm sub
28	UWA Field Stn	n.d.
29	UWA Field Stn	100mm sub
30	UWA Field Stn	100mm sub
31	UWA Field Stn	100mm sub
32	Water Research	n.d.
33	Rogerson Gardens	60mm sub
34	Floreat tennis	80mm sub
35	Floreat bowls	100mm tur
36	Chandler Ave	100mm sub
37	Chandler Ave	80mm n.d.
38	Primary school	80mm n.d.
39	McLean Park	80mm sub
40	Berkeley Cr	80mm tur
41	Newman College	n.d.
42	Newman College	n.d.
43	Lothian Park	80mm sub
44	Edith Cowan Uni	100mm n.d.
45	Grantham & Selby St	100mm tur
46	Seymour Ave Park	80mm tur
47	Crosby St	n.d.
48	Tennis	100mm tur
49	Lawler Park	n.d. sub
50	Management Institute	n.d.
51	Hockey Centre	100mm tur
52	Netball Centre	100 tur
53	Netball Centre	100 tur
54	Mabel Talbot Park	80mm n.d.
55	Nursury	n.d.
56	Henderson Park	80mm sub
57	Henderson Park	80mm sub
58	Rose Garden	80mm sub
59	Wembley P. S.	80mm sub
60	Rutter Park	80mm sub

Sub = submersible
Tur = turbine
n.d. = no details available
100mm = outlet pipe diameter
P.S. = Primary School
H.S. = High School

Domestic & Public Bore Locations

Figure 13.3

Data obtained from on site mapping and air photo interpretation
(refer text for details)

records show that regardless of the number of bores operated, maximum top up output is about 235m^3/hr. This limiting value (described in detail in Chapter 7) reflects increased pressure in the ring main with all water forced to exit through the 100mm (south) and 75mm (north) top up outlets.

Table 13.3 Pump specifications, Perry Lakes Reserve

Pump	Type	Rating (hp)	Irrigation Rate (m^3/hr)	Top Up Rate (m^3/hr)	Watt-hour meter	Hour meter	Amp meter
1	submersible	30	37.4	120	X	X	X
2	turbine	40	55.1		X		X
3	'	20	34.9	72			X
4	'	25	37.4				
5	'	25	37.4				
6	'	25	37.4	72			
7	'	25	37.4		X		
8	'	25	37.4		X		
9	'	25	37.4				

Total groundwater extraction is irrigation plus top up. Top up water was metered, irrigation water was not. Townley *et al* (1995) estimated lawn irrigation and lake maintenance over summer 1992-93 from grounds staff records of bore usage and irrigation application rates. Over 1996-97 irrigation usage was estimated from a combination of watt-hour meter, amp meter and hour meter data[3] from bores 1, 2, 7 and 8. Bores 3, 4, 5 and 6 are not metered separately (power is drawn via the stadium complex), bore 9 was ignored. In general rated horsepower (hp) where 1hp = 746 watts was used to estimate hours of pump operation, checked by amp meter data (where current x voltage = watts) and direct hour meter data. Data was corrected for other power use (principally flood lighting) by measuring daily lighting usage over winter when pumps were off. Hours used for top up were back calculated from the flow meter data assuming average input of 235m^3/hr. Bores 3, 4, 5 and 6 were assumed to run similar hours to bore 2 (but always with one bore off). Total groundwater extraction estimates appear as Table 13.4.

Table 13.4 Groundwater extraction, Perry Lakes Reserve

Period	Top Up (m^3)	Irrigation (m^3)	Sub Total	Seasonal Total
Dec 26 1992-May 16 1993	42875			
Dec 4 1993-May 28 1994	60226			
March 2-May 2 1993		100578		
Sept 15-Dec 31 1996	34783	123958	158741	Summer 1996-97
Jan 1-June 15 1997	145968	266569	412537	571278
Oct 21-Dec 21 1997	NIL	163628		

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[3] Detailed irrigation and top up records were also kept by grounds staff for this study. These records were lost when the maintenance vehicle (along with irrigation log book) was stolen.

Therefore over summer 1996-97 approximately 571,000m^3 of groundwater was extracted within Perry Lakes Reserve. Lawn irrigation totalled about 390,000m^3. Lake maintenance totalled about 180,700m^3 and about 210,000m^3 was returned to the aquifer as measured recharge in water balance calculations (combined recharge plus rainfall and storm drain inputs). During the period December 10, 1996 to May 15, 1997 (Balance periods 19-32) when there was nil groundwater discharge to East Lake (*i.e.* constant recharge conditions with nil flow-through), 154,700m^3 were added as top up of which 136,700m^3 were recharged to the aquifer. Intense lawn irrigation occurs for about 180 days each summer. The 1996-97 irrigation therefore averaged about 2160m^3/day. The total irrigated area is about 400,000m^2 suggesting an application average of about 5mm/day. Agriculture WA recommends 4mm/day to maintain an adequate lawn (Cargeeg *et al* 1987 p39) and CSIRO (1979) 16mm/week (average 2.3mm/day). This suggests that the lawns are over watered.

Recharge is difficult to measure. In Perth recharge estimates over natural vegetation vary from 5.5 to 13% of annual rainfall (refer Chapter 11). Recharge over lawns and playing fields is considerably greater (nil canopy effect and shallow root systems). McFarlane (1984) monitored soil water profiles under an urban lawn in Dalkeith (5km southeast of Perry Lakes) where summer irrigation was 40-50% of potential evapotranspiration (PET). These data estimate percent total input (rain + irrigation) becoming recharge at differing depths. McFarlane's field results confirm the suggestion made by Carbon (1975) that deep drainage becomes significant in Perth soils only when water input exceeds 60% PET. In Perry Lakes Reserve, depth to water table varies from about 2.5m over most of the reserve, rising to about 8m at piezometer nest N5. These data, summarised in Figure 13.4, allow recharge to be estimated.

The PET of lawn was considered never to exceed open water evaporation as measured at adjacent East Lake. Table 13.5 provides estimates of monthly irrigation, distributed over 180 days, with the most intensive irrigation occurring between December -February. These daily average irrigation rates are approximately equal to PET and suggest that significant recharge occurs from summer irrigation.

Table 13.5 Recharge Estimates to 3m water table, Perry Lakes Reserve 1997

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rain (mm)	<1	2	70	31	86	109	98	104	118	30	7	0	653
Irrigation (mm)	213	138	143	56						57	158	209	975
Total	214	140	212	87	86	109	98	104	118	87	164	209	1628
PET (mm)	209	135	139	82	65	42	53	70	87	145	154	205	1385
Inputs:PET (%)	102	104	152	105	132	261	184	149	135	60	107	102	
Recharge (%)	35	37	85	38	75	85	85	85	80	0	42	35	
Recharge (mm)	73	50	118	31	49	35	45	59	70	65	72	93	667

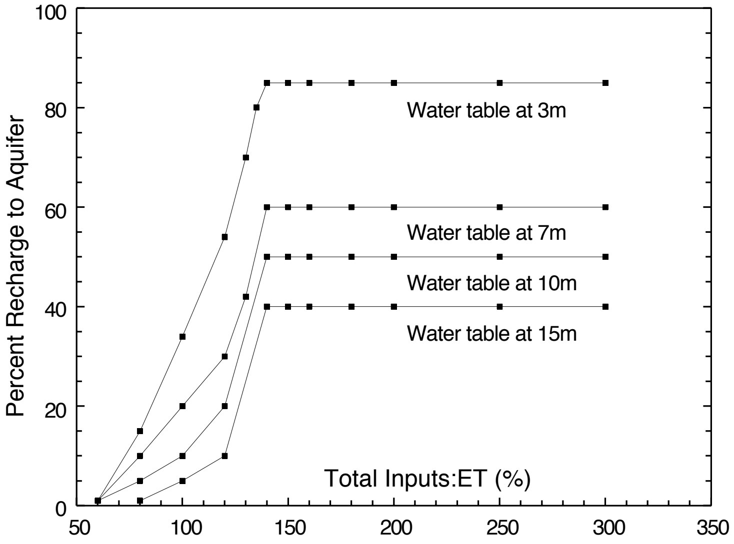

Figure 13.4 Recharge from lawns in Perth, data adapted from McFarlane (1984, p195)

Total annual input to irrigated lawns is estimated at 1628mm of which 667mm is recharged to groundwater. This is significantly greater that the 80 or so mm recharged below native coastal vegetation. It approximates the annual amplitude of the local water table cycle.

13.7.3 Regional Water Balance Estimates

A simple mass balance model was computed for an area of 9 km^2 comprising all areas east of AMG 384 500 in Figure 13.3. This is a square 3x3 km comprising approximately 2 km^2 of parks, reserves and native bush and 7 km^2 of low density residential housing. Table 13.6 shows estimates of bore extraction (low to high) within this area.

Table 13.6 Estimates of bore extraction in $9km^2$ area (m^3x1000)

		Public	Bores		
Extraction (m^3 yr^{-1})	*10,000*	*20,000*	*30,000*	*40,000*	*50,000*
Domestic Bores					
750	1,352	1,842	2,332	2,022	3,312
1,000	1,640	2,130	2,620	2,310	3,600
1,250	1,927	2,417	2,907	2,597	3,887

Domestic bores were calculated using a range of 750 to 1250 m^3 per year based on an estimated mean annual extraction of $1000m^3$ (Cargeeg *et al* 1987, p39) to $1100m^3$ (Farrell 1981). Within the model area there were 1150 domestic bores and 49 public bores mapped. Average public bore extraction is more difficult to estimate. An annual rate of

10,000m^3 to 50,000m^3 per bore was used. This range is based on the average 1997 extraction for lawn irrigation at Perry Lakes of approximately 430,000m^3 from eight bores (average 53,750m^3). Perry Lakes is almost certainly at the high end of average public extraction. Within adjacent residential areas McFarlane (1984) found that impervious shedding surfaces (ISS) on private blocks (roofs, paths and driveways) comprised 21.7 to 28.8% of the surface area while public roads and car parks comprised 9.6 to 13.1%. Assuming roughly median values of 25.2% roofs and 11.3% roads yielded 36.5% impervious shedding surfaces within the 7 km^2 of residential land. These shedding surfaces were assumed to shed 75% of their intercepted rain back to the aquifer either via soak wells or storm drains into public infiltration basins or wetlands. This figure is based on roof and other estimates made by McFarlane (1984). All other areas (residential gardens, lawns, parks and native bush reserves), recharge was estimated to be 10% of rainfall. Table 13.7 shows the estimated total recharge for seven values of average rainfall.

Table 13.7 Total recharge for model area of 9km^2 area (m^3x1000)

	Area (km)	850mm	800mm	750mm	700mm	650mm	600mm	550mm
ISS (R=75%)	2.5	1,594	1,500	1,406	1,312	1,219	1,125	1,031
Non ISS urban (R=10%)	4.5	382	360	337	315	292	270	247
Non urban (R=10%)	2.0	170	160	150	140	130	120	110
Total	9.0	2,146	2,020	1,894	1,767	1,641	1,515	1,389

Table 13.8 is the results of the simple regional water balance model. The data is an amalgamation of the extraction and recharge data, calculated as net annual change in the water table in mm. Boundary conditions assume flow in equal to flow out.

Table 13.8 Annual water table change (mm), typical recharge and extraction regimes

Rain (mm)	850mm	800mm	750mm	700mm	650mm	600mm	550mm
E&R* (m^3x1000)	2,146	2,020	1,894	1,767	1,641	1,515	1,389
1,352	88	74	60	46	32	18	4
1,640	56	42	28	14	0	-14	-28
1,842	34	20	6	-8	-22	-36	-50
1,927	24	10	-4	-18	-32	-46	-60
2,022	14	0	-14	-28	-42	-56	-70
2,130	2	-12	-26	-40	-54	-68	-82
2,310	-18	-32	-46	-60	-74	-88	-102
2,332	-21	-35	-49	-63	-77	-91	-105
2,417	-30	-44	-58	-72	-86	-100	-114
2,597	-50	-64	-78	-92	-106	-120	-134
2,620	-53	-67	-81	-95	-109	-123	-137
2,907	-85	-99	-113	-127	-141	-155	-169
3,312	-130	-144	-158	-172	-186	-200	-214
3,600	-162	-176	-190	-204	-218	-232	-246
3,887	-193	-208	-222	-236	-250	-264	-278

* E&R is extraction and recharge from Tables 13.6 and 13.7

A study of this type is at best an estimate however it does provide valuable insights into the likely importance played by bore extraction in the regional water balance. It must be remembered that urbanisation has had two major (and partially counterbalancing) effects. Huge amounts of water are now extracted via bores while at the same time recharge has been enhanced through impermeable shedding surfaces. Such models should account for the average 40 to 50mm decline in the water table measured at Perry Lakes over the forty years (Chapter 2). A comprehensive regional water balance is well outside the scope of this study. The bore mapping has provided reasonable estimates of annual groundwater extraction. Most importantly extraction appears to be equal to or greater than the likely recharge, indicating that it is a significant factor in the local and regional water table decline. Many combinations of extraction and recharge (highlighted in Table 13.8) model the observed groundwater decline. The simple fact that bore extraction appears to approximately equal or exceed recharge suggests that hydrologically we are already operating at a net groundwater deficit.

13.8 AQUIFER GEOLOGY

Changes in aquifer hydrogeology within the Perry Lakes sector are also likely factors in long term water table decline.

Damming effects within the Superficial Aquifer

Regional water table contours (Figure 13.5) show a distinct steepening of the gradient west of Lake Monger. This corresponds roughly with the appearance of limestone within the aquifer section. Drillers in the Herdsman-Jackadder Lake area report a widespread clay layer at the sand-limestone contact. Bores screened within residual Tamala sands and limestone have low residual yields. Haselgrove (1981) describes similar hydrogeology on the Kwinana coastal strip where the aquifer comprises highly permeable Tamala Limestone, and displays a nearly horizontal water table. The eastern boundary of this zone is defined by a pronounced steepening of the water table gradient coincident with an eastward dipping clayey sand unit defining the contact between Bassendean sands and limestone. These widely reported 'damming' effects are co-incident with the chain of lakes running from Lake Joondalup to Thompsons Lake, including Herdsman Lake and Lake Monger. Positive piezometric heads have been reported by cable tool drillers in residual Tamala limestone sands around both Herdsman and Jackadder Lakes (K. Wintergreen[4] pers com) suggesting that some lakes may be in part maintained by discharge from upward flowing groundwater driven by both this damming effect and normal flow-through induced positive piezometric heads. This zone effectively acts as a barrier, impeding the westward flow of groundwater into coastal areas.

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[4] cable tool drilling contractor, Perth

Variation in Aquifer Geology

Consider a transect from Herdsman Lake southwest through Perry Lakes to the coast at Swanbourne. The aquifer stratigraphy here undergoes a transition from 100% sand to mixed sand-limestone to predominantly Tamala limestone along the coast (Figure 13.6a). The coastal limestone generally has a high hydraulic conductivity (Davidson 1995). This is reflected in the generally lower slope of the water table (Figure 13.5). In the mixed sand-limestone zone however effective porosity of the limestone is highly variable (refer Appendix 3.4). At Perry Lakes bailing recovery in piezometers screened within the limestone was significantly less than those screened in the upper sand. Similarly around Jackadder and Herdsman Lake drillers frequently report low yields (about 300-400m^3 d^{-1}) from limestone and near surface residual sands derived from it. Where these sediments form a significant proportion of the aquifer, hydraulic conductivity and thus transmissivity is reduced. Therefore as a general rule, transmissivity increases close to the coast, decreasing eastward towards the 'barrier' described above.

Relationship to Constant Head Boundaries

The shape of the water table contours in Figure 13.5 reflects the constant head boundaries of the Indian Ocean and the Swan Estuary. Flow net analysis shows how water recharging the aquifer from Lake Monger rapidly becomes widely dispersed. An initial aquifer section of about 1000x30m or 30,000m^2 at Lake Monger expands to about 300,000m^2 along the constant head boundaries. The volume of groundwater entering this sector is initially impeded by the damming effect. Once past this low transmissivity bottle neck groundwater enters the Perry Lakes Sector of the Gnangara Mound. This is a much larger volume of aquifer sediment comprising predominantly highly transmissive coastal limestone. Much of it (such as Bold Park and the suburb of City Beach) are topographically elevated with low to nil annual recharge. Hydrologically the Perry Lakes Sector is partially isolated or detached from the Gnangara Mound. The water balance models confirm that current extraction exceeds recharge (which includes water entering through the eastern barrier sediments). The net effect is that extraction exceeds recharge resulting in a long term lowering of the water table.

The Cottesloe Peninsula (the northern portion of which is visible in Figure 13.5) is an extreme extension of the same phenomenon. It is almost completely surrounded by constant head boundaries and is almost hydrologically isolated from the Gnangara Mound. It is now completely underlain by salt water wedges with the maximum thickness of fresh water midway between the Indian Ocean and the Swan River being less than 15m. It represents a more extreme example of an area where extraction exceeds

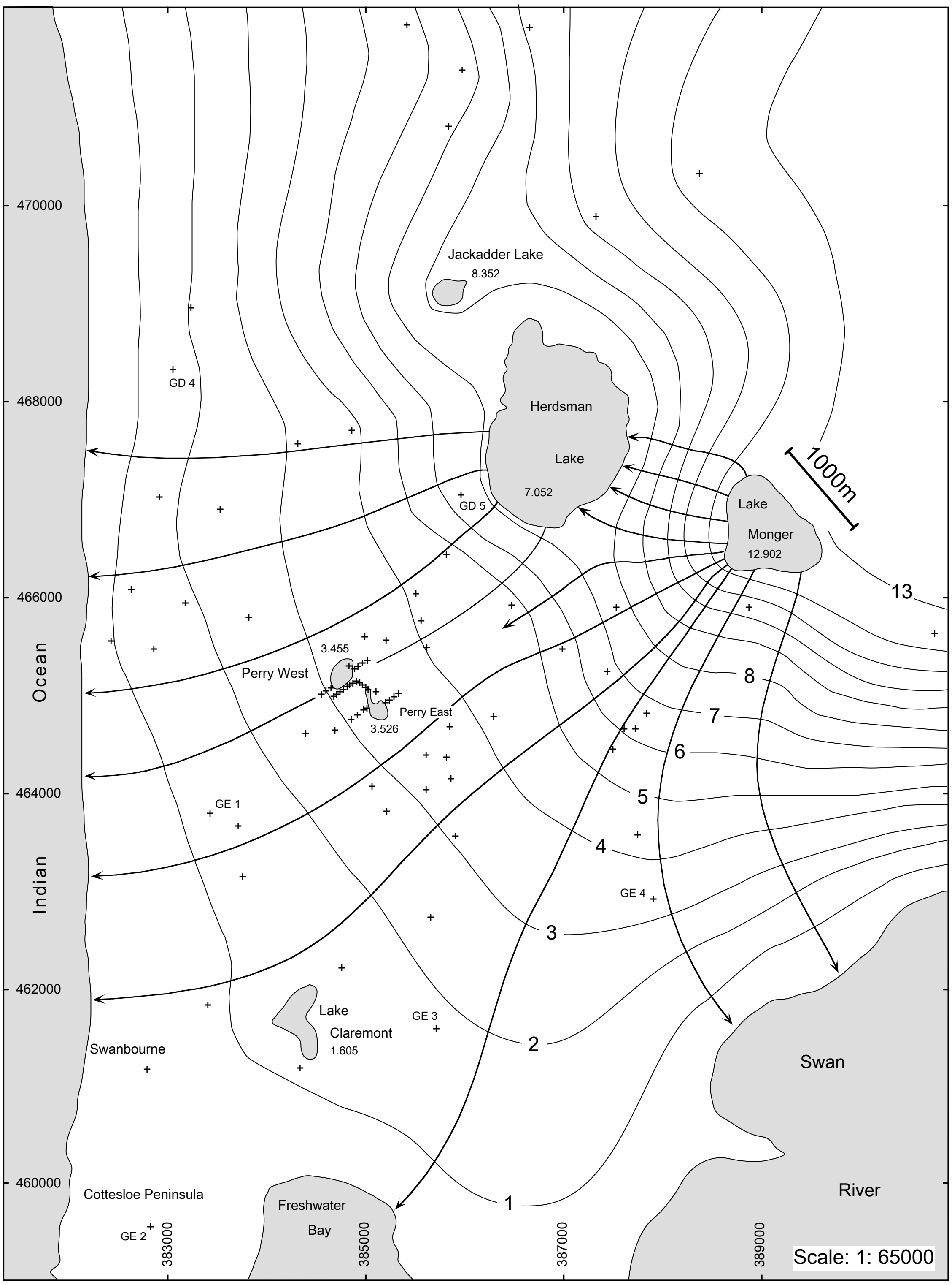

Figure 13.5 Groundwater Flow in the Perry Lakes Sector

Flownet showing pattern of groundwater flow for water recharging the aquifer from Lake Monger in flow through conditions. Lake Monger represents an aquifer section approximately 1000m in width. Water within this section spreads out into a massive fan discharging into the Swan River and Indan Ocean. In so doing it must suffer a decrease in velocity. The flow net also demonstrates that groundwater discharging to Perry Lakes may have passed through Lake Monger or both Lake Monger and Herdsman Lake, thereby explaining the large variations in groundwater isotope and chloride chemistry within Perry Lakes Reserve (refer Chapter 6).

Water table data compiled September 10-15, 1997
Lake stands are approximate maxima during survey period, all data metres AHD
Indian Ocean and Swan River set as constant head boundaries at 0.000m
Contours created in SURFER on 100x100m kriged grid

+ Monitoring well used as water table data point (refer Chapter 2)

← Groundwater flow line

recharge. In recent years many domestic bores have turned salty as extraction of fresh water has allowed the salt water wedges to expand (Cargeeg *et al* 1987, Davidson 1995). Again it represents a simple water balance problem where extraction exceeds recharge.

Variation in Aquifer Thickness

The thickness of the saturated section in the superficial aquifer is not constant but is a function of both the water table elevation and the surface of the Tertiary and Cretaceous units forming the basal aquiclude. Figures 13.6 b&c show aquifer isopachs and aquiclude geology. The aquifer section thickens over the Mullaloo sandstone by 10-20% further contributing to an expanded aquifer volume within the Perry Lakes sector.

Interaction with Underlying Tertiary and Cretaceous Formations

Northeast of Herdsman Lake the unconfined aquifer rests on Molecap greensand (Figure 13.6c) which is host to the Mirrabooka aquifer. In the Perth region, Davidson (1995) describes the Molecap as a glauconitic, fine to medium grained silty sandstone. The Perry Lakes area is underlain by early Tertiary age Kings Park Fm, comprising shallow marine to estuarine sediments (siltstone and shale) possibly deposited in the drowned valley of the ancestral Swan River (Playford *et al* 1976 p201). The Mullaloo sandstone member is incised into the Kings Park Fm. It consists of poorly sorted, fine to very coarse grained slightly glauconitic sandy clay. The Mullaloo Sandstone was deposited within deep marine channels incised into the Kings Park Fm and is considered to be a locally important semi-confined to confined aquifer (Davidson 1995).

Northeast of Herdsman Lake the unconfined aquifer receives water discharged from the underlying Mirrabooka aquifer. In the Perry Lakes area however scanty data suggests that while piezometric heads within the Mullaloo sandstone are positive, the bulk of the discharge occurs off shore close to the coast (Davidson pers com). Therefore northeast of Perry Lakes (and the Herdsman-Lake Monger barrier zone) there is recharge to the superficial aquifer which is absent within the Perry Lakes sector.

Rainfall Recharge

Northeast of Herdsman Lake the superficial aquifer comprises Bassendean sands with a predominantly shallow water table. Here natural recharge is estimated to be 15-20% of total rainfall (Davidson 1995) whereas to the southwest through Perry Lakes to the ocean, recharge estimates decrease to 10-15% (Figure 13.6d). Leaving aside the effects of urbanisation, the Perry Lakes sector receives reduced recharge. This is particularly so in elevated natural bush areas such as Bold Park where the distance from land surface

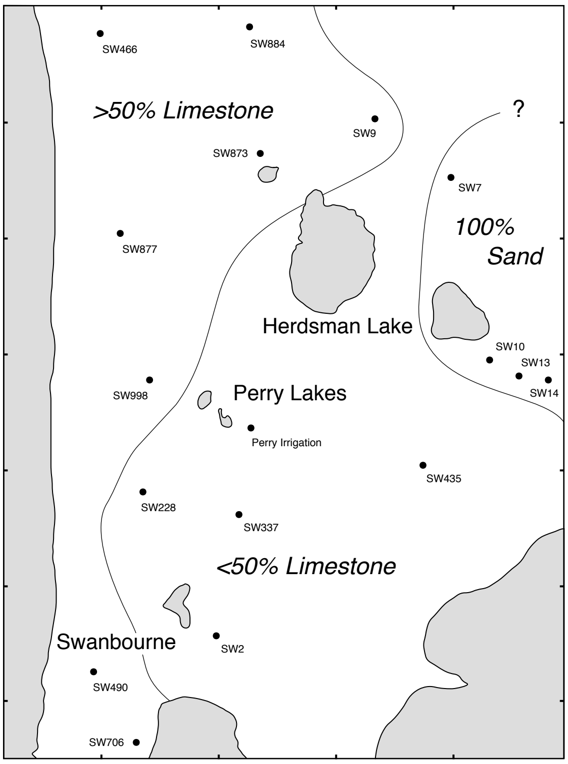

Figure 13.6A Variation in Aquifer Geology

Proportion of limestone estimated from drillers logs. Bore designations from Waters & Rivers Commision records

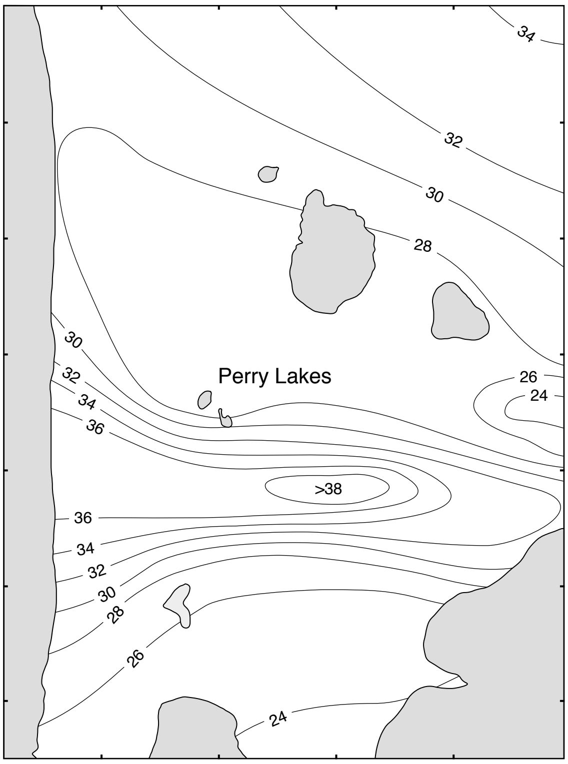

Figure 13.6B Variation in Aquifer Thickness

Unconfined aquifer isopachs in metres computed from basal aquiclude contour surface (Davidson 1995 p221) and water table levels September 1997

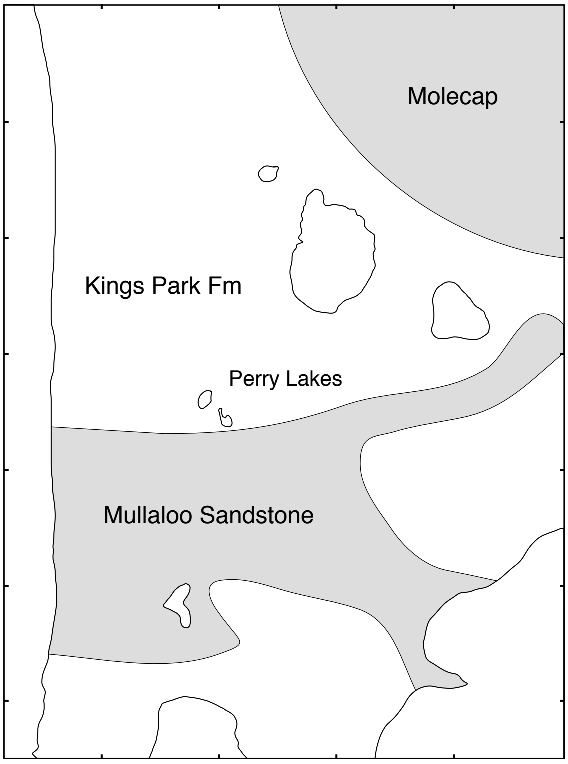

Figure 13.6C Geology at Aquifer Base

▨ Mullaloo Sandstone member

□ Kings Park Fm (Tertiary)

▨ Molecap Greensand (Cretaceous)
(area of discharge from Mirrabooka aquifer to unconfined aquifer)

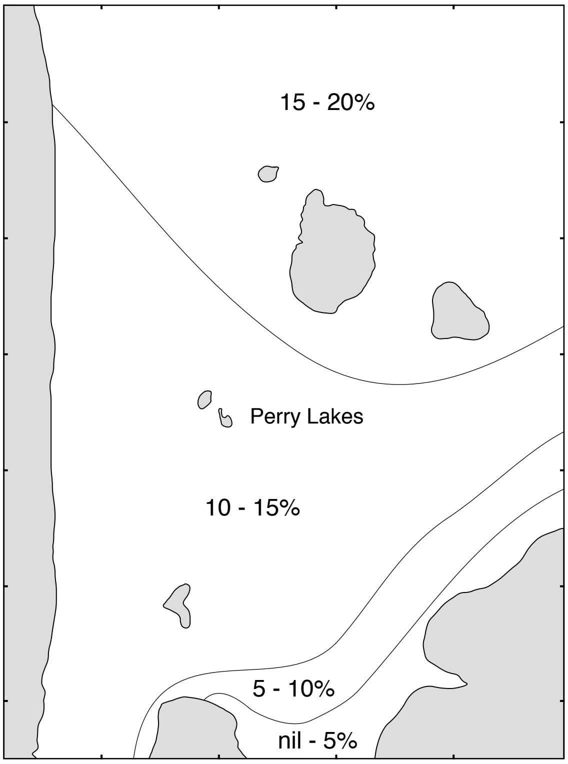

Figure 13.6D Variation in Recharge

Percentage of annual rainfall recharged to the unconfined aquifer (after Davidson 1995 p251)

Aquifer Geology

Figure 13.6

to water table is up to 80m. Vegetation here is non phreatic and therefore utilises a great proportion of vadose water.

In summary, natural factors have a substantial influence on the observed water table decline at Perry Lakes, in particular the damming effect to the east coupled with aquifer geometry which results in partial hydrologic isolation of the Perry Lakes sector from the Gnangara Mound, expanded aquifer volume terminating in constant head boundaries and reduced rainfall recharge. Aquifer geometry is not, in itself, the cause of the water table decline. Rather, its importance lies in the exaggerating effect it exerts on both natural and non natural factors. In particular, under the current regime of reduced rainfall and recharge:

- the effects on water table levels from bore extraction are increased because the damming effect impedes groundwater entering the area from the east
- the effects on water table levels from natural evaporative pumping around wetlands are similarly enhanced

13.9 SUMMARY

Wetlands are a fundamental feature of the Perth urban environment (Sadler *et al* 1988). When the climate that ultimately sustains them is significantly altered wetland managers are faced with difficult decisions. Which aspects (or even which wetlands) can or should be preserved become key questions. For example should West Lake simply be allowed to revert to sumpland as has already happened with South Lake and Camel Lake or should significant expense and effort be expended to rid it of invasive weed species and maintain more water in it over summer? Alternatively should all efforts go into maintaining East Lake as a permanent wetland? Should the whole lot simply be allowed to disappear?

Decreasing rainfall is a present fact and a future expectation. As Sadler *et al* (1988) point out history has shown that timely decisions on difficult resource management problems are difficult to achieve. Action is often precipitated only after the problem reaches crisis proportions. Concern over declining water levels in Perry Lakes has been on going for at least 30 years (Chapter 2). Unfortunately because any climate prediction includes uncertainties, decisions are likely to be incremental rather than pivotal. Easy (and we might add inexpensive) decisions are likely to predominate over difficult (and most likely more expensive) ones. In the case of wetlands, any realistic hope of preservation may be long lost by the time the problem reaches crisis point.

CHAPTER
14

FUTURE MANAGEMENT

14.1 INTRODUCTION

The Perth Urban Water Balance (Cargeeg *et al* 1987) identified the maintenance of groundwater levels as being the 'fundamental issue in managing the unconfined groundwater system'. This study also predicted the currently observed declines based on continued below average rainfall, increased groundwater extraction and continued urban development. The predicted decline in net vertical flux under these conditions was estimated at 20mm yr^{-1}, about half of the currently observed decline (Chapter 13). The degradation or complete elimination of wetlands is probably the single most obvious feature of a groundwater system under stress. The best (and simplest) solution would be a persistent period of increased rainfall. The Perth Urban Water Balance models suggested that a decade of 'average' rain (about 869mm annually) would result in a water table rise in the Perry Lakes area of less than 0.5m. In order for Perry Lakes and Camel Lake to be rejuvenated a rise of at least 1.5m is required. If Perry Lakes (and possibly even Camel Lake as well) are to be rejuvenated, complementary management strategies will have to be implemented. These become even more important if the current low rainfall trends continue and may at best provide only partial solutions. Again the Perth Urban Water Balance models predict that with below average rainfall, even a 50% reduction in domestic bore extraction coupled with a 30% reduction in local authority and potable water extraction would result in a rise of well less than 1m at Perry Lakes over 10 years. These models assumed reductions over the entire Perth metropolitan area.

14.2 REDUCING GROUNDWATER EXTRACTION

14.2.1 Modelling

Management strategies, particularly where they involve expensive infrastructure (such as waste water recycling) or major changes in social behaviour or preference (such as three minute showers and shifts from European to native gardens) must be based on sound science and predictive modelling. Mathematical models allow planners and water managers to understand and make informed decisions about water resources. More importantly they allow the consequences of proposed actions (such as engineered solutions) or theoretical changes (such as climate change) to be analysed and predicted (Anderson & Woessner 1992). A principal objective would be to differentiate natural and anthropologic cause and effect. Modelling and water balance studies of the Perry Lakes sector could provide insights and allow analysis of significant questions pertinent to the ultimate management of Perry Lakes (Turner & Rich 1999). These include:

Climate Change

- If rainfall and groundwater extraction within the Perry Lakes sector persist at their present rates, what are the long term trends and predicted levels for groundwater at Perry Lakes?
- What average annual increase in rainfall (and associated recharge) would be required to cause a natural rise in the water table? How much would be required to ensure lake basins remain flooded over most summers?

Bores & Groundwater Extraction

- To what extent are public and private bores in the Perry Lakes Sector contributing to the regional decline in groundwater levels?
- In particular what is the effect of the high level of groundwater extraction occurring within Perry Lakes Reserve? If pumping just within the reserve was reduced (or ceased) what effect (if any) would this have on lake levels?
- What would be the effect on groundwater levels if the bore usage in the Perry Lakes Sector was reduced by 10%, 30%, 50% etc under differing rainfall regimes?

Conservation & Public Education

- What is an 'optimum' water level regime for Perry Lakes consistent with its multi-purpose role as a wildlife reserve and recreation amenity? What combination of hydrological and/or engineered strategies could be used to achieve this outcome?
- If a reduction in bore usage was predicted to bring about a substantial groundwater rise, would the state government consider proclaiming the Perry Lakes sector to be a groundwater management zone, banning new bores and limiting the use of existing bores? If so what would be the effect?
- Would a comprehensive public education program achieve the same ends?

14.2.2 Bore Licensing

Water law in Australia operates on the premise that groundwater, as a common resource belongs to the crown and is only available to private users under rights or license given by a managing authority (Banyard 1989). Western Australia operates on a system of 'Proclaimed' areas (where bore licenses are required) and 'Non proclaimed' areas where anyone has the common law right to sink a private bore and extract groundwater with no license, and no requirement to notify any government authority. Landowners are free to take water for any purpose and in such quantities as they see fit (Cargeeg *et al* 1987).

Within the Perth metropolitan area there are a number of proclaimed areas such as Gwelup, Jandakot, Mirrabooka, Swan and Wanneroo (where groundwater is drawn for public supplies) however the bulk of the area is non proclaimed. The number of bores within this area is unknown but is estimated (1998) to be well over 130,000 (Water and Rivers Commission 1998b).

Society has for some time been moving towards a 'user pays' principle. There is a justification for applying this to groundwater management such that all users, both direct and indirect, shoulder a portion of management costs. There is also the view that groundwater is a grossly undervalued resource and that free access leads to over exploitation and wasteful irrigation practices. Given that there is a limit to the amount of groundwater which can be extracted and that such extraction is already contributing to significant environmental damage to some wetlands, licensing would have the principal benefit of controlling the further expansion of domestic extraction and (if bores were metered) controlling extraction in some areas.

Licensing users would require that all the Perth metropolitan area be proclaimed. Pope (1989) and Banyard (1989) have explored the considerable policy difficulties in setting up groundwater license and usage pricing policy and the logistical problems of bore metering. Possibly the simplest solution would be to proclaim the entire area but with licensing and monitoring only in those areas such as Wembley and Floreat where extraction is clearly contributing to environmental damage. Within these areas all bores would be registered and a permit required for any new or replacement bores. There is an argument that a blanket 'usage fee' might simply encourage continued high usage. Probably the best option would be to metre all bores in these areas and apply a nominal yearly license fee plus incremental water usage fees. This might include an initial 'free' allocation. This would allow total extraction to be measured (thereby allowing meaningful management and modelling) and actively encourage reduced usage and water efficient gardens. This would apply to both domestic and public users such as local councils. The policy objective would be to reduce usage, not raise revenue. There would be a general ban on new bore construction but there is no reason why licenses could not be transferable so that if a resident decommissioned a bore someone else could then acquire the license and construct one.

Historically the general connection between urbanisation and water table rise is one of the principal reasons private domestic bores have been allowed to proliferate unchecked in Perth. Water Corporation and its predecessor have actively encouraged bores as an convenient means of taking pressure off treated domestic water supplies. Currently garden irrigation consumes 47% of all treated domestic water, rising to 70% in summer months (Water Corporation 2002a). Bore licensing and extraction regulation is a contentious issue. If the current rainfall trends persist however it could form part of a management strategy for endangered wetlands such as Perry Lakes.

To date there has been not only a reluctance towards additional regulation but continued active encouragement of private groundwater exploitation. Following another year of below average rainfall in 2002, Water Corporation began offering a $500 rebate on domestic bore construction. Their on line maps continued to show the Perry Lakes sector as being suitable for bore construction.

Many of the ideas presented here are not new. Recommendations in the Perth Urban Water Balance Study (Cargeeg *et al* 1987) included:

- Proclaiming all of metropolitan Perth as a Groundwater Area
  (Recommendation 2)
- Licensing of all non domestic bores along with groundwater allocations
  (Recommendation 2)
- Implementing specific management strategies to reduce abstraction and increased recharge in the inner western suburbs around Wembley and Floreat
  (Recommendation 7)
- Determine the need for local management strategies in risk areas
  (Recommendation 8)

Sadly (or perhaps predictably) these recommendations have been largely ignored. It is worth noting again the comments of Sadler *et al* (1988). History shows that timely decisions on difficult resource management problems are difficult to achieve and action is often precipitated only after the problem reaches crisis proportions.

14.2.3 Public Education

Any scheme to supplement water to Perry Lakes must be accompanied by public education to cut profligate water use and water waste. Perth has a Mediterranean climate but continues to indulge in European style temperate gardens and huge amounts of lawn. Despite increasing water restrictions and other warnings, the average resident continues to undervalue water. Attempts by water utilities at demand management have largely failed. The preferred option has been to reduce pressure on the reticulated domestic supply by actively encouraging the use of bore water. During the 1977-79 drought, there was a 50% increase in the number of private bores (Water Authority of Western Australia 1995). This document also notes that education is seen as the most cost effective and publicly acceptable water management tool, however it can be argued that in 'special case' areas such as Perry Lakes public education pertinent to the local area and problems has been lacking.

Demand for water in Perth continues to increase. There has been a 20% rise in domestic (treated) water use per capita over the past two decades, accounted for mostly by water used outside the home on lawns and gardens . The average household consumes 920 litres per day with gardens (47%), showers (16%), laundry (13%) and toilets (10%) being the biggest users (Water Corporation 2002a). Promoting Mediterranean gardens, reducing or eliminating lawns and mandating water efficient appliances such as dual flush toilets, high efficiency shower roses, more efficient washing machines is a start. In some ways we perhaps need to go back to the ethos which still prevails in many parts of rural Australia where water is truly considered a precious commodity. Water wise and water wasting consumers should be rewarded and penalised respectively with appropriate domestic water pricing policies which have as their overriding priority water conservation.

14.2.4 Better Urban Design

Modifications to urban design, both existing and future, could have significant impacts on groundwater levels. The overriding consideration should be towards enhancing widespread groundwater recharge and limiting groundwater extraction. Block sizes should be reduced, limiting lawn and garden area and all water caught on impervious shedding surfaces should be routed directly into the soil as recharge. Roof drains should go directly to soak wells located below the grass root zone. Driveways and paths should be constructed to channel water off into adjacent soil rather than into streets and gutters and ultimately wetlands. Similarly storm drain networks should where ever possible terminate in infiltration basins rather than wetlands. Ultimately the aim should be twofold:

- reduce direct inputs to wetlands (which forces them to become recharge lakes)
- allow the groundwater system around wetlands to rise through increased recharge and reduced abstraction

All waste water from sewage treatment plants should be recycled via a second reticulation system to domestic users for toilet flushing and (careful!) garden use, and to high usage commercial users for industrial purposes. Urban design needs to promote higher density housing with less or no lawn, smaller gardens and drought tolerant plants.

14.2.5 Limiting Urban Expansion

Western Australia has the highest rate of growth in Australia, and Perth is the focus of that growth with over 70% of the total state population (Graetz *et al* 1998). The Swan Coastal Plain, bounded by the ocean and the Darling Range offers absolutely no constraint to north-south expansion. Perth is and shows every indication of continuing to be a low density city. Only 20% of urban housing is classed as medium density. Suburbs are 80% detached housing, one per allotment surrounded by a garden (Graetz *et al* 1998). The state population is expected to rise from 1.8 million to 3 million by 2029, when Perth's population will reach 2 million. As long as this 'Los Angeles' style of expansion continues, Perth will increasingly place inordinate demands on its groundwater. The style and extent of Perth's expansion needs to be reigned in but to date 'planning' seems aimed simply at accommodating accelerating low density urban sprawl.

14.3 ENGINEERED SOLUTIONS

14.3.1 Diversion from Herdsman Lake

Herdsman Lake was drained for agricultural purposes in 1924 by constructing a tunnelled drain to the ocean. This drain still operates. Water volumes drained for 1998 are summarised in Table 14.1:

Table 14.1 Water Volumes to Herdsman Drain 1998

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily m^3/s	0.140	0.121	0.128	0.134	0.170	0.341	0.433	0.498	0.519	0.287	0.207	0.188
Daily m^3	12100	10450	11060	11580	14690	29460	37410	43030	44840	24800	17890	16240

Data from Water Corporation WA (1999)

Total water drained for 1998 was approximately 8,340,000m^3 while the total water used to maintain East Lake over 1996/97 was about 180 000m^3. It is believed that a similar proposal along with some engineering and planning was put to the Perth City Council in the 1960's. The proposal involved a purpose built gravity drain, with the final section utilising the existing storm drains into West Lake.

Perry Lakes would become an artificial groundwater recharge area. A small proportion of surplus Herdsman Lake water would be directed into the lakes both summer and winter, effectively creating a local, permanent groundwater mound. Water would be constantly entering the lakes. Water losses would comprise evapotranspiration and seepage through the lake bottoms. Computer modelling would be able to predict the extent of this local mound and the amount of imported water required to maintain it. There is even a possibility that local levels might rise sufficiently to create winter inundation at Camel Lake. There is equally the possibility that the former South Lake (now the children's play area adjacent to the toilet block) might also re-flood, allowing a third lake to be created effectively re-establishing the lake system which existed in the 1950's (Chapter 2).

The maximum water requirement would be in summer when the water table is below the lake bottoms and evapotranspirative losses are greatest. There would be significant on going seepage losses maintaining a local groundwater mound. Under current summer level maintenance maximum seepage losses are about 100mm per day. Possible daily requirements taking into account seepage and evaporation are summarised in Table 14.2. These proposed levels would ensure a minimum of about 30cm depth over the entire basin floor.

Table 14.2 Possible Daily Water Requirements

	Stage	Wetted Area	Volume	Daily Losses m^3
East Lake	3.9m AHD	$70350m^2$	$50400m^3$	$7035m^3$
West Lake	3.8m AHD	$63200m^2$	$44550m^3$	$6320m^3$
Total				$13355m^3$

These estimates suggest that over the summer, there would be sufficient water available from Herdsman Lake to maintain an artificial recharge program at Perry Lakes. During summer any shortfall could be supplied from tertiary treated sewage (refer below).

Importing water whether natural or recycled risks upsetting the nutrient balance in wetlands. In Swan Coastal Plain wetlands, nutrients entering a lake tend to accumulate, largely in the sediments. Under certain water chemistry conditions, this nutrient reservoir can be released back into the water column, leading to algal blooms. Water quality data for Herdsman Lake (Table 14.3) shows nitrogen and phosphorous levels in the Herdsman drain.

Table 14.3 Nitrogen & Phosphorous Levels, Herdsman Drain

	May 97	Jun 97	Jul 97	Aug 97	Sep 97	May 98	Jun 98	Jul 98	Sep 98	Oct 98
Total N (mg/l)	4.20	3.30	4.08	3.42	4.76	3.64	4.22	3.30	3.37	3.84
Total P (mg/l)	0.35	0.14	0.09	0.07	0.08	0.08	0.23	0.06	0.09	0.05

Data from Water Corporation WA 1999

Compared to other Swan Coastal Plain wetlands, these levels are on the high side (Davis *et al* 1993). The proposed water quality objectives to ensure aquatic ecosystem integrity at Herdsman Lake (Clarke *et al* 1990) recommended total N<2.0mg/l and total P<0.10mg/l. Nutrient stripping might be required to keep nutrient levels within acceptable limits. Certainly tertiary treated waste water would require nutrient stripping.

14.3.2 Treated Waste Water

Tertiary treated sewage re-use is a proven technology, common in arid regions where sewage and grey water is utilised for irrigation or artificial recharge to aquifers (Wright & Parsons 1994). The water is rendered useable by treating it for pathogenic organisms, nutrients and trace metals (Asano 1994). Tertiary treated water has high initial infrastructure costs and on going treatment costs but with the advantage that once operating it provides a constant and assured water supply (Water Authority of Western Australia 1995).

The Subiaco waste water treatment plant is located 1.2km from East Lake (Figure 1.1). Output from this facility represents a huge resource which currently is disposed of by ocean outfall. Total output from the Subiaco plant is about 19,800 megalitres (19.8 million m^3) per year. Only a small portion of this would be required to maintain summer levels in both East and West Lakes (East Lake top up summer 1996/97 was 180,000 m^3). Viewed from an engineering perspective much of the pipe work is already in place. The rising main which feeds water from the Perry East flood remediation pumping station (Figure 5.1a) could be used to gravity feed waste water back into East Lake. The single biggest problem which would have to be overcome is excess nutrient levels in the water. Current nutrient load from the plant is around 450kg phosphorous and 1300kg nitrogen per day (Water Corporation 2001). Waste water typically contains phosphorous and nitrogen in the range 2.3 to 9.0 and 6.1 to 44.2 mg l^{-1} (Scatena & Williamson 1999). Waste water is currently treated to the point where it is already widely used in country towns throughout Western Australia for park irrigation (Water Corporation 2000). In this application some nutrient load is seen as an advantage, reducing the need for artificial fertilisers. A pilot project is under way to use waste water to irrigate McGillivray playing fields (Figure 1.1). This will reduce groundwater extraction by about 350,000 m^3 per year (Water Corporation 2002b). There is no reason why this could not be extended to include Perry Lakes Reserve where current lawn irrigation consumes about 430,000 m^3 of groundwater per year. Removal of nutrient is technically feasible (Scatena & Williamson 1999) and has been considered by Water Corporation for other waste water reuse projects including groundwater recharge and remediation of salt water intrusion in the Cottesloe and Mosman Park area (Water Corporation 2000). Possibly the biggest initial impediment is cost. Water Corporation would prefer to recoup some of the costs of tertiary treatment by selling water to industrial users. This is feasible for water from the Woodman Point waste water plant which can be used by industry in Kwinana. The Subiaco water however would be used only for wetland conservation purposes and would require financial assistance in order to be viable.

14.3.3 Groundwater Recharge

Groundwater recharge is a proven technology and one which has been considered as a technique to take some pressure off Perth's groundwater supplies (Peters 1998, Scatena & Williamson 1999, Bekele 2001). Scatena & Williamson (1999) have identified areas, including Perry Lakes, within the Perth metropolitan area in which physical characteristics of the unconfined aquifer are likely to be suitable for artificial recharge. Modelling would be required to ascertain if recharge of waste water would raise groundwater levels sufficiently to flood the lakes to the required level. Based on cost and engineering complexity, piping waste water directly into the lakes remains the simplest option. In this case the lakes would become permanent infiltration basins. Schemes such as this are at odds with the recommendations in Section 14.2 which advocate reduced direct inputs to wetlands but in the end it can be argued that a wetland (operating permanently as a recharge lake) is better than no wetland at all.

14.3.4 Dual Water Supplies

Dual water supplies are a feature of many cities in arid climates. The Los Angeles area has over 1000 reuse areas where about a million m^3 per day are used for agricultural and landscape irrigation, groundwater recharge and industrial reuse (Water Corporation 2000). Typically dual water supplies have two reticulation systems carrying potable and non potable recycled water. The recycled water is used for toilet flushing and garden irrigation. In the Wembley-Floreat area a dual supply would provide maximum benefit as a substitute for domestic bores. The single biggest impediment to schemes of this sort is that the cost of reused water is often similar to the mean cost for potable water and so few authorities are willing to subsidise waste water reuse projects (N. Martyn, e-mail posted to 'WaterForum' January 4, 2001).

14.4 CONCLUSIONS

The Perth Metropolitan Area and satellite developments will continue to grow on current predictions to at least 2030. In the absence of any definitive policy to limit expansion on the Perth Coastal Plain, urban sprawl will continue and with it an increasing demand for water. This coupled with the likelihood of continued low rainfall will place an ever increasing pressure on easily extracted groundwater. It appears inevitable that overall groundwater levels will decline. Perry Lakes and other wetland systems will be threatened with total extinction. The elaborate engineered solutions which may save Perry Lakes are not a panacea which can easily be applied elsewhere. Most of our wetlands are water table 'windows'. Under pre urban episodes of climate change they expanded and contracted or disappeared altogether in response to small changes in water table levels.

Urbanisation and its seemingly insatiable demand for water and climate change are now placing all wetlands under threat.

One of the important values that society places on wetlands is their ability to convey a sense of the natural environment as it was before urbanisation. Public attitude towards wetlands (and indeed the environment generally) has changed remarkably over the past few decades. Up to the 1960's wetlands were systematically drained, filled (often with rubbish) and developed. These destructive activities are now at variance with the views of the vast majority of the population who see wetlands and urban bushland as important and essential components of the urban landscape. This is reflected in the extensive legislation which exists to protect them. Unfortunately the threat is not now from bulldozers and developers but collectively from all of us. Urbanisation and an insatiable demand for water will continue to place wetlands under threat. Only a huge paradigm shift in our collective attitudes to water conservation, a major reversal to a wetter climate or innovative technical solutions (importing water from the Ord River or desalinisation, for example) which reduce our dependence on groundwater, will save Perth's wetlands.

Many of the recommendations made in the Perth Urban Water Balance, if implemented when first published in 1987 might now be having a significant effect on reducing groundwater abstraction. They would have been politically unpopular then, as now, and it appears that in the longer term wetlands will ultimately be sacrificed as the price of political expediency. For Perry Lakes it may already be too late and engineered solutions may be the only hope (in the short term at least) for preserving Joseph Perry's swamps.

CHAPTER
15
CONCLUDING SUMMARY

15.0 INTRODUCTION

This study has been a very detailed and holistic examination of one wetland system. The principal conclusions and observations therefore cover a wide range of topics. Some are specific to Perry Lakes while others are more general and have application to other wetlands, in particular those on the Swan Coastal Plain. Following are the principal conclusions or observations made in Chapters 6-14 followed by the principal recommendations for future study and wetland management.

15.1 CONCLUSIONS

Chapter 6 Water Balance Integration

Integrated mass, solute (chloride) and isotopic (deuterium) balances confirm that East Lake operates as a flow-through lake in late winter and a recharge lake the rest of the year when it receives substantial imported water via storm drains and artificial summer 'top up'. Levels in the surrounding aquifer have been declining for about 40 years. West Lake is now dry for about 6 months of each year (apart from an artificially deepened 'sump' dug around the staff gauge). East Lake would be dry for a similar period without artificial maintenance.

In their original state such wetlands probably functioned as flow-through lakes for most if not all of the year. Under natural conditions they were maintained solely by direct rainfall and groundwater discharge. They had no riparian inputs. Most wetlands on the Swan Coastal Plain now operate as storm water infiltration basins. Groundwater discharge is reduced and replaced by 'non natural' inputs. The most significant result of the integrated balances was the non symmetrical nature of East Lake under flow-through conditions. It was assumed that in winter at least groundwater discharge and recharge would more or less balance each other. The storm drain inputs however are so large that even under flow-through conditions the lake always tends towards a recharge state. The dividing streamline tends towards the up gradient shore and groundwater discharge is significantly diminished. Table 15.1 shows the principal mass balance components for 1997.

Table 15.1 Mass balance components East Lake 1997

	GW Recharge	Top Up	Drains	Evaporation	Rain	GW Discharge	Total 1997
Mass (m^3)	-205,289	+155,017	+56,398	-49,299	+29,468	+11,957	507,428
Percent	40.5	30.5	11.1	9.7	5.8	2.4	100.0

Signs indicate water added to (+) or lost (-) from the lake

Non natural inputs (drains and summer top up) accounted for 41.7% of the annual mass budget. The annual ratio of groundwater discharge:recharge was 1:17, whereas under pre urban natural conditions it probably approached 1:1. In 1997 groundwater discharge comprised just 2.4% of the annual mass budget.

Chapter 7 Lake-Aquifer Interaction

Mini piezometer studies confirmed that in winter when East Lake is in flow-through status, the dividing stream line lies close to the up gradient shore. Storm water inputs constantly force the lake towards recharge status. There is an oscillation between flow-through and recharge flow states during storm events. During summer the water table now lies below the deepest point of both lakes. Allowing East Lake to shrink and approach dryness confirmed that flow-through (or potential flow-through) is maintained as the lake shrinks and becomes confined to the clay lining. Where sections of the lake became detached as separate ponds during the drying process, transitory discharge regimes become established.

In summer East Lake is maintained against a falling water table by filling it with locally derived groundwater. The lake becomes a local mound surrounded by a water table further depressed by pumping both to maintain water in East Lake and irrigate lawns. The water table gradient west of the lake steepens and the gradient east of the lake is frequently depressed to the point where significant ‘reverse flow’ zones occur with water flowing against the regional trend from a mounded East Lake into pumping depressions around the major bore fields. Despite being strongly mounded East Lake never ‘detaches’ from the aquifer. Pump spikes are evident in hydrographs throughout the summer.

When viewed over a year East and West Lake present a highly dynamic, highly modified wetland system. A typical summer pattern comprises East Lake artificially maintained as a local groundwater mound. The lake is in permanent recharge flow state. There is a steep gradient between East and West Lakes resulting in a strong flow towards West Lake. West Lake becomes a small residual pond which maintains a flow-through regime throughout the summer. The strong gradient from East Lake serves to enhance groundwater discharge into West Lake. Late summer storms can fill both lakes in a matter of hours. Both then become recharge lakes with a large shared release zone.

Flow-through is established in both lakes over winter. Initially the lakes function as separate systems however as winter progresses shared capture and release zones are established. As summer approaches the lakes shrink and separate capture and release zones re-establish. Generally in October or November the wetland managers commence pumping groundwater for summer lake maintenance and the typical summer flow pattern returns. East Lake becomes a recharge lake with local groundwater mound while West Lake shrinks almost to dryness while maintaining flow-through status.

Historic hydrograph data from the Wembley-Floreat area confirms that regionally, groundwater levels everywhere have declined in response to decreased rainfall and recharge and increased extraction. At Perry Lakes however, the absolute amount of decline has been greater. Indeed the rate of decline has increased in recent years whereas regionally it has been constant. This strongly suggests that at Perry Lakes, groundwater extraction has had a disproportionately greater effect than elsewhere.

Wetland managers are now at the limit of what is possible in terms of artificially maintaining East Lake through pumping local groundwater. The lake is the visible top of a local groundwater mound which pumping attempts to maintain against a falling regional water table, locally depressed further by irrigation extraction, increased transpiration and open water evaporation. The rate of mound decay is further enhanced by reduced water viscosity and higher effective lake lining hydraulic conductivity.

Chapter 8 Thermal Balance

As far as we are aware this represents the first thermal balance to be completed on a Swan Coastal Plain wetland. Table 15.2 shows the relative scale of all thermal terms on an annual basis. It is important to remember that seasonally some terms such as the sediment heat flux (Qse) and the heat energy stored in the lake (Qx) change sign, tending to almost cancel on an annual basis.

The sediment heat flux term (Qse), which has often been ignored in other studies, is a significant component of the thermal balance in shallow coastal wetlands. In East Lake evaporation (1997) calculated by thermal balance without considering Qse was 1468.4mm compared to the floating pan benchmark of 1378.8mm (a 6.5% over estimate). Over a year much of the error cancels out because the thermal balance both over and under estimates evaporation however within individual balance periods very large errors can occur. Greatest over estimate was 50.9% (June 1997, balance period 34). Greatest under estimate was –53.1% (August 1997, balance period 38).

Table 15.2 Thermal balance summary 1997

Term	Explanation	Heat W m^{-2}
Qbs	Long wave radiation emitted from the water	-151272
Qa	Incoming long wave radiation	124647
Qs	Incoming short wave radiation	84877
Qe	Energy used for evaporation	-39109
Qrc	Heat in lake water recharged to the aquifer	-6588
Qsr	Reflected short wave radiation	-5945
Qh	Energy conducted from the water as sensible heat	-5539
Qtu	Heat in top up water	4646
Qar	Reflected long wave radiation	-3739
Qse	Heat conducted into and out of the lake sediments	-2466
Qw	Energy advected from the water body via evaporated water	-1553
Qsd	Heat in storm water	962
Qrn	Heat in rain falling directly on the lake	441
Qx	Change in heat energy stored in the lake (T_m at final lake volume)	-283
Qdc	Heat in groundwater discharged to the lake	227

Positive terms are heat gained, negative terms are heat lost.

Chapter 9 Thermal Regimes in Wetland Sediments

When viewed seasonally the sediment heat flux term becomes much more important than might first be ascertained from Table 15.2. In extremely shallow wetlands such as East Lake, heat moves into and out of the sediments both diurnally and seasonally. In summer there is a net negative flux (heat moves from the water column into the sediments). In winter this reverses with a net flux from the sediments into the water column. The sediments act as a seasonal heat sink, storing substantial amounts of summer heat and returning it to the water column over winter. In East Lake positive winter sediment heat fluxes averaged 46.3 W m^{-2} over one 12 day period in early September.

Within the aquifer below a water table lake, heat is both conducted and advected. Close to the up gradient shore, during winter flow-through regimes heat is both advected and conducted from the sediments into the water column. In summer the situation is reversed. The lake is now in recharge and heat is both conducted and advected from the water column into the sediments. Therefore on the up gradient shore heat conduction and advection are additive both summer and winter. On the opposite shore summer heat is similarly conducted and advected into the sediments however in winter advection and conduction are opposed. Therefore flow-through lakes such as East Lake display very different thermal patterns below their up gradient and down gradient shores reflecting seasonal changes in both flow and thermal regimes.

Chapter 10 Evaporation

Class A pan coefficients were derived for Perry Lakes and the Bureau of Meteorology pan at Perth airport. Workers investigating Swan Coastal Plain wetlands within 3-4km of the coast should use the coefficients in Table 15.3.

Table 15.3 Pan coefficients for wetlands within 4km of the coast

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av
Pan	0.73	0.65	0.71	0.81	0.85	0.70	0.84	0.87	0.91	0.82	0.82	0.76	0.79
BoM	0.54	0.48	0.54	0.56	0.66	0.71	0.69	0.81	0.86	0.78	0.74	0.67	0.67

'Pan' refers to a class A pan operated adjacent to the wetland under study. 'BoM' refers to the Bureau of Meteorology pan at Perth airport.

Ten empirical equations for evaporation were calibrated against the East Lake evaporation as determined by floating Class A pan. Best performer was the Makkink equation which tracked the floating pan data closely throughout all seasons. The poorest performers were the Penman, DeBruin-Keijman, Priestley-Taylor and Brutsaert-Stricker methods all of which grossly over estimated late winter (August and September) evaporation.

Chapter 11 Transpiration

Experimental determination of annual transpiration from *Typha orientalis* was 27.6% of open water evaporation from East Lake. Typha dies back over winter. In summer (January to March) *Typha* transpiration rose to 43.2% of open water evaporation. *Baumea articulata* transpiration calculated for February through March only was 19.5% of open water evaporation. All data was calculated under non flooded conditions.

The results suggest that for East Lake the evapotranspiration from *Baumea* meadows was less than from a similar area of open water. The evaporation figures taken from the floating pan and used in the water balances are therefore slight over estimates.

Chapter 12 Isotope Experiments

Many natural water bodies undergoing evaporation, approach a limiting or isotopic steady state. This value will vary seasonally. Using pans evaporated to dryness and pans evaporated at constant volume, the limiting values can be used to determine $\delta_{E(lake)}$, the isotopic value of evaporate from the water surface. Knowing $\delta_{E(lake)}$ is a requirement for completing an isotopic balance. The meteorological conditions at the lake and pans should be similar. The most important requirement is identical thermal regimes in the pans and the lake. At Perry Lakes daily average $\delta_{E(lake)}$ was determined independently for East and West Lake using three methods:

- Equation 23 of Craig & Gordon (1965), critical parameters humidity, $\delta_{(lake)}$, δ_A with daily estimated average δ_A computed by interpolating weekly atmospheric sampling

- Equation 12 of Welhan & Fritz (1977), critical parameters humidity (as *m*), $\delta_{(lake)}$ and δ_S calculated from pans evaporated to dryness

- Equation 12 of Allison & Leaney (1982), critical parameters humidity (as *m*), $\delta_{(lake)}$ and δ_K calculated from pans evaporated at constant volume

The results obtained from all three approaches are different. The Craig and Gordon (1965) equation and the use of δ_K produced similar results although the mean daily and annual values of $\delta_{E(lake)}$ were about 40‰ greater using δ_K . The results using δ_S were much 'noisier' but with a gross similar annual pattern and difference of only about 11‰.

Isotopic balances were computed using:

- experimentally derived values of $\delta_{E(lake)}$ developed from constant volume pan δ_K

- empirically derived $\delta_{E(lake)}$ using the Craig and Gordon equation.

The resulting balances varied, on average, by less that 1%. This probably reflects the fact that in East Lake evaporation represents a small (<10%) component of the annual mass balance.

Chapter 13 Climate, Urbanization & Wetlands

The only consistent feature of climate is change. Natural variability is a normal feature of climate anywhere. Perth rainfall has exhibited extreme variability over the past 125 years and has been steadily decreasing for the past 40 years. Natural variability and anthropologically induced climate change are both operative but the relative role of each is difficult to gauge. The IOCI modelling however suggests that natural rainfall reductions of the magnitude affecting Perth over the past 40 years are rare. Greenhouse (increased atmospheric CO_2) modelling however can account for such changes. The models suggest a prolonged (possibly 100 to 150 year) decline in rainfall. Perth rainfall also exhibits well defined cyclicity with a frequency of 20 to 21 years. Suggested links with sunspot cycles remain speculative.

Simple water balance models of the Floreat, Wembley and City Beach areas suggest that groundwater extraction already exceeds recharge despite the enhanced recharge effects associated with urbanisation. Further reduced rainfall and increased extraction appear likely.

Wetland managers must take into account:

- decreasing rainfall trends over the past 40 years
- long range IOCI greenhouse modelling of further reduced rainfall
- on going urban sprawl and its increasing relative and absolute reliance on groundwater
- the likelihood that water conservation will continue to receive lip service only

These trends strongly suggest that groundwater levels in the Perry Lakes area are likely to continue declining and engineered solutions may represent the only viable option for preservation of these wetlands.

Chapter 14 Future Management

The state government needs to look seriously at reducing both the absolute and per capita amounts of groundwater it extracts in metropolitan Perth. It needs to seriously formulate and implement strategies to reduce groundwater extraction. These might include (but are not limited to) proclaiming all of metropolitan Perth as a *Groundwater Area*, capping the drilling of new domestic bores, licensing existing bores (with possible sliding scales of water usage fees), public education with a ‘rural ethos’ regarding water conservation, revised domestic (reticulated) water pricing which rewards ‘water wise’ and penalises ‘water wasting’ customers, better urban design which minimises European style lawn and gardens and maximises recharge, and reticulation of waste water from sewage treatment plants for toilet flushing and garden use. Possibly the single most important consideration would be serious regional planning which is proactive rather than reactive and which places a non negotiable limit on Perth’s urban sprawl.

Perth appears likely to continue expanding and extracting greater absolute and per capita amounts of groundwater from the unconfined aquifer. This coupled with decreased rainfall and recharge will cause the water table to continue declining both within and outside the urban area. Wetlands which once contained permanent water will either shrink or become dry for part of each year. Permanent wetlands will become sumplands and sumplands will become damplands.

15.2 RECOMMENDATIONS

Perry Lakes

The detailed water balances provide the basis for further wetland modelling, in particular an extension of the work by Townley *et al* (1993 a&b) and Nield *et al* (1994), applying real data to the theoretical models.

The Town of Cambridge as wetland managers should initiate discussions with the state to examine the feasibility of artificially maintaining Perry Lakes using either surplus water from Herdsman Lake and/or tertiary treated waste water from the Subiaco treatment plant. The natural rejuvenation of the lakes requires a long term increase in rain. Even then potential increases in recharge may be off set by increased extraction elsewhere in the system. In other words it is highly unlikely that Perry Lakes will be rejuvenated naturally in the foreseeable future. Unlike other Perth wetlands there are two readily available sources of water nearby which could see the lakes maintained artificially indefinitely.

Further Research

The central theme of this study has been detailed water balances of two wetlands. This needs to be extended regionally to detailed balances and computer modelling of the Perry Lakes sector of the Gnangara Mound and ultimately to the entire Gnangara Mound. The simplistic modelling completed in this study suggests (but does not prove conclusively) that groundwater extraction and reduced rainfall are the principal factors in the groundwater decline at Perry Lakes. The Perry Lakes sector cannot really be treated in isolation from the remainder of the Perth metropolitan area or the Gnangara Mound. The modelling would take into account present and anticipated urban expansion and in particular look at present and anticipated extraction from public and private bores. It would also consider long term reductions in rainfall and recharge. The ultimate purpose would be to ensure that Perth’s wetlands are not sacrificed at the alter of political expediency, endless urban expansion and an insatiable public demand for water.

In Perth truly sustainable yield is possible only from that additional recharge which comes about from increased impermeable shedding surfaces within the urban landscape. Extraction beyond that amount comes with a price, in this case degradation and ultimately the disappearance of wetland systems.

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Computer Software

Program	Source	Version(s)	System
Canvas	Deneba Software	3.5.5 and 7.0	Macintosh
DFT (Discreet Fourier Transform)	Astronomy, Swinburn University	1.0	Macintosh
Equation Editor	Design Science Inc	1.0b	Macintosh
Excel	Microsoft	5.0a	Macintosh
FlowThru	CSIRO	1.1	Macintosh
Kaleidagraph	Abelbeck Software	2.1.3	Macintosh
Microcom II Study	Microcom	2.35	DOS
PmpTst	Earthware (Hall & Chen 1994)	n/a	DOS
Surfer	Golden Software	6.01	Windows
Word	Microsoft	5.1a	Macintosh

CHAPTER
2
APPENDICES

Appendix 2.1

Figure 1 is a map of the Perry Lakes sector of the Gnangara Mound showing all monitoring wells, research bores and piezometers and natural water bodies used to compile summer and winter water table minimum and maximum levels in 1997. The accompanying Table 1 includes each well location in Australian Map Grid (AMG) coordinates and standing water levels (SWL) in metres above AHD. Wells drilled for this project within Perry Lakes reserve are included in the table but not labelled separately on the map. Refer to Figure 3.3 for well locations within Perry Lakes Reserve.

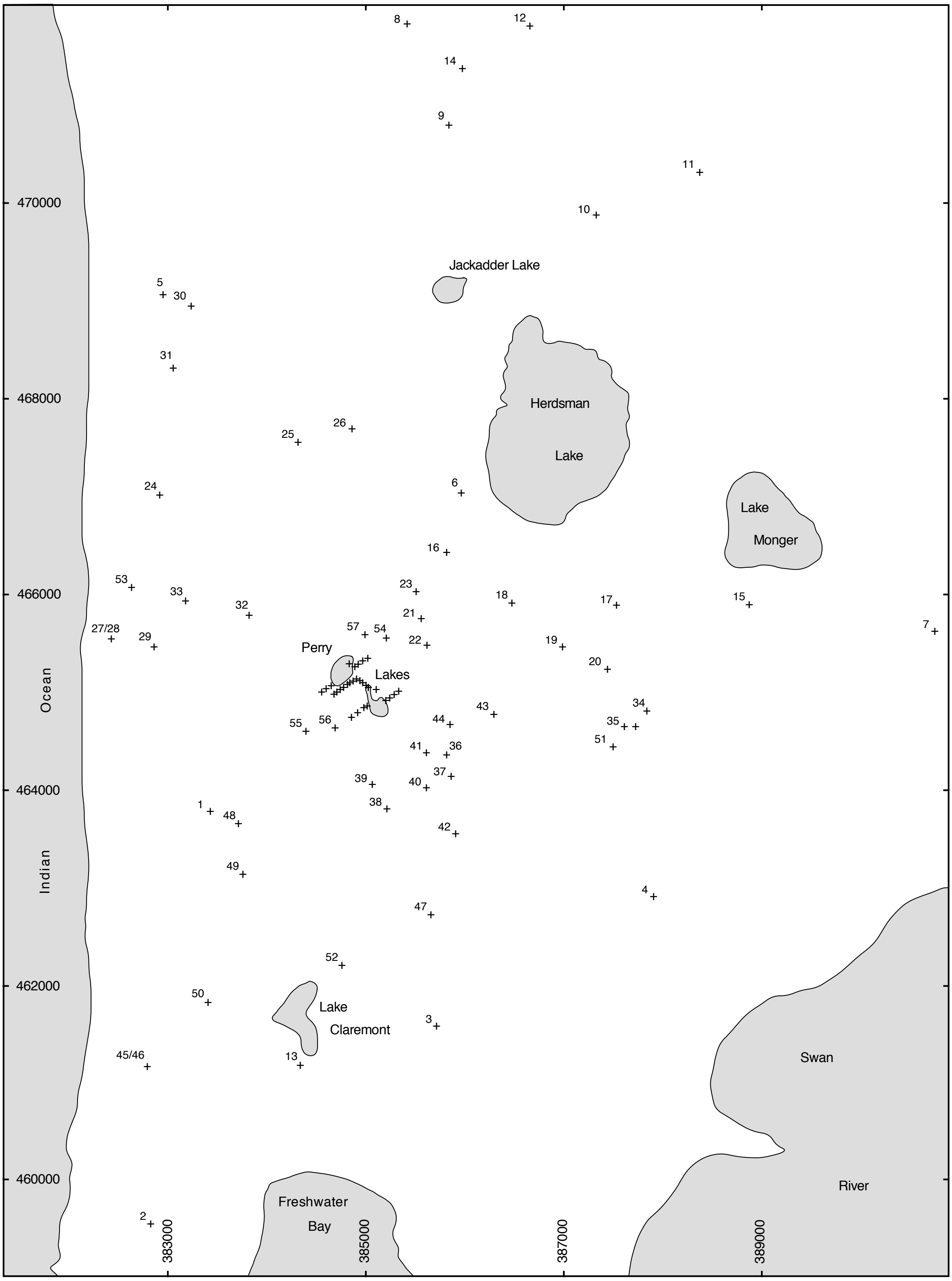
Perth is literally peppered with public and private irrigation bores. Within the survey area however there were only 14 dedicated monitoring wells (ID 1-14 in the table). Their distribution and density was insufficient to provide the detail required. In particular we thought a very detailed survey might reveal local perturbations in the water table around areas of very high extraction areas such as Perry Lakes. Such features do occur at a detailed scale during and immediately following pumping (Chapter 7) but were not observed regionally. The requirement that the end of summer readings be taken 2-3 weeks after irrigation bores were shut off for the winter probably meant that any such features had long disappeared. End of winter measurements were taken in September at around the time of peak water levels in Perry Lakes Reserve and well before the commencement of lawn irrigation. Depending on the depth to the water table the date of maximum winter recharge SWL will vary slightly from place to place occurring earlier close to wetlands and later under high ground where winter recharge takes much longer to infiltrate.

The survey proved to be technically and logistically difficult. Public irrigation bores are fitted with either turbine or submersible pumps. Only submersible equipped wells could be monitored. Turbine pumps have no access to the well casing. Submersible equipped wells are of variable construction. Many have a small 3/4 inch (18mm) threaded bung in the top plate. This allows a standard water level probe to be lowered down the well. Entanglement with the electrical cables feeding the submersible were a constant problem.

One probe entangled in the Wollaston College bore had to be cut off and abandoned. Many other wells had no bung but access was possible by removing the access plate for the electrical junction box. The cable access to the well casing was seldom large enough to allow access for the standard water level probe and were often off set from the top of the casing. A custom made water level sensor was constructed of thin (2.5mm) brass and thin 'figure 8' electrical cable. This was flexible enough to be fed through tight spaces and cheap enough that if it got jammed it could be abandoned at no great cost.

The second (and greatest) logistical problem was the requirement that every well be tied to a surveyed bench mark. All SWL were read to an accuracy of +/- 1mm. Similar surveyed height accuracy was required for the height datum at each well. In Perth there is generally a primary or secondary bench mark within about 500m of any point. The reality is that many secondary points end up hidden by gardens, under brick paving and so on. The Department of Land Administration (DOLA) provide very detailed maps of the location of each mark but despite this many could not be located. Optical levelling over distances of up to 2km was sometimes required to tie bores to the closest bench mark.

The bores surveyed were situated within five different municipal areas (City of Stirling, City of Subiaco, City of Nedlands, Town of Cambridge and Town of Claremont). Thanks to all of them for their cooperation and assistance with the survey.



Appendix 2.1 Figure 1 Scale 1:65 000

^{3}+ Bore or piezometer location and identfier (ID number in Table 1)

Monitoring wells, irrigation bores, research wells and water bodies used to compile summer and winter water table levels 1997. Refer to Figure 3.3 for designation of research wells around Perry Lakes.

Surface water levels in lakes read from Water and Rivers Commission staff gauges except Jackadder Lake which has no gauge and was levelled from a bench mark specifically for this survey.

Regional Water Levels 1997 Appendix 2.1 Table 1

Bore or Water Body		AMG mE	AMG mN	SWL May	SWL Sept	Seasonal Change
Water and Rivers Commission Monitoring Bores						
ID	Name					
1	GE-1	383405	6463761	1.165	1.376	0.211
2	GE-2	382867	6459546	0.046	0.087	0.041
3	GE-3	385682	6461550	1.292	1.758	0.466
4	GE-4	387874	6462874	3.074	3.541	0.467
5	GD-4	382893	6467000	1.492	1.760	0.268
6	GD-5	385942	6467014	6.732	6.970	0.238
7	GD-6	390720	6465580	NR	12.947	
8	GM-17	385396	6471802	5.202	5.721	0.519
9	GM-22	385821	6470754	6.225	6.833	0.608
10	GM-26	387308	6469851	9.613	10.414	0.801
11	GM-27	388358	6470269	12.259	12.610	0.351
12	GM-30	386628	6471760	8.170	9.268	1.098
13	142	384321	6461154	NR	1.067	
14	8525	385970	6471330	6.150	6.325	0.175
Irrigation Bores in Parks and Reserves (including CSIRO Research Wells)						
15	Tara Vista Park	388840	6465850	9.466	9.818	0.352
16	Park, Lothian & Brookdale St.	385790	6466400	3.711	4.403	0.692
17	Rutter Park	387510	6465860	7.096	7.626	0.530
18	Park, Seymour & The Boulevard	386450	6465880	3.903	4.530	0.627
19	Rose Garden	386960	6465420	4.797	5.396	0.599
20	Henderson Park	387420	6465200	6.292	6.922	0.630
21	Floreat Oval, Chandler Ave.	385540	6465720	3.387	4.067	0.680
22	Floreat Oval Tennis Courts	385590	6465450	3.419	4.059	0.640
23	McLean Park	385480	6466000	3.387	4.084	0.697
24	The Boulevard & Landra Gdns.	383500	6466860	2.034	2.502	0.468
25	Empire Ave Reserve	384290	6467540	2.557	3.080	0.523
26	Luketina Reserve	384830	6467670	2.952	3.555	0.603
27	Jubilee Park abandonned bore casing	382420	6465520	1.098	NR	
28	Jubilee Park submersible	382430	6465520	NR	1.128	0.030
29	Oceanic Drive & West Coast Hwy	382830	6465450	1.330	1.567	0.237
30	Drabble Reserve	383190	6468930	1.660	2.032	0.372
31	Hale-Brompton Park	383020	6468300	NR	NR	
32	City Beach High School	383800	6465760	1.977	2.402	0.425
33	City Beach Primary School	383150	6465920	1.530	1.865	0.335
34	CSIRO BOC 1	387810	6464765	6.198	6.740	0.542
35	CSIRO BOC 6	387580	6464615	5.614	6.108	0.494
36	UWA Field Station, Wx station abd. bore	385790	6464330	3.065	3.533	0.468
37	UWA Field Station, Sheep paddock well	385840	6464100	3.070	3.486	0.416
38	UWA McGillivray #84	385180	6463780	2.010	2.507	0.497
39	UWA McGillivray #85	385040	6464020	2.076	2.561	0.485
40	UWA McGillivray #86	385590	6464000	2.632	3.146	0.514
41	CSIRO 'PF' well	385580	6464360	2.874	3.349	0.475
42	Lemnos St.	385890	6463530	2.624	3.114	0.490
43	Lawler Park	386270	6464740	3.590	4.053	0.463
44	Rogerson Gardens	385820	6464640	3.300	3.765	0.465
45	Allen Park (submersible)	382770	6461140	0.380	0.436	0.056
46	Allen Park (adjacent well)	382780	6461140	0.387	0.442	0.055
47	Graylands Hospital, depot bore	385620	6462700	1.645	2.133	0.488
48	Wollaston College	383680	6463640	1.326	1.501	0.175
49	Christchurch Grammar McClements Rd.	383730	6463110	1.104	1.366	0.262
50	Swanbourne High School	383380	6461800	0.495	0.608	0.113
51	CSIRO J6 Jolimont Primary School	387470	6464400	5.030	5.548	0.518
52	Town of Claremont, Alfred & Davies Rd.	384730	6462180	1.282	1.753	0.471
53	West Coast Highway	382600	6466065	NR	1.588	

Bore or Water Body	AMG mE	AMG mN	SWL May	SWL Sept	Seasonal Change
Perry Lakes Research Wells					
54 PL1	385170	6465525	3.029	3.722	0.693
WL1	384990	6465325	2.960	3.645	0.685
WL2	384930	6465275	2.922	3.602	0.680
WL3	384890	6465250	2.883	3.546	0.663
N1a	384870	6465240	2.862	3.506	0.644
N2a	384610	6465045	2.461	3.119	0.658
WL4	384595	6465035	2.401	3.013	0.612
WL5	384545	6465000	2.285	2.817	0.532
WL6	384845	6465090	2.773	3.447	0.674
WL7	384828	6465080	2.753	3.442	0.689
WL8	384810	6465065	2.733	3.436	0.703
WL9	384730	6465010	2.673	3.395	0.722
WL10	384710	6464998	2.631	3.334	0.703
WL11	384700	6464985	2.601	3.295	0.694
WL12	384680	6464972	2.546	3.230	0.684
PL2	384860	6465102	2.795	3.477	0.682
WL13	384885	6465091	2.820	3.510	0.690
WL14	384910	6465080	2.841	3.530	0.689
WL15	384935	6465068	2.853	3.545	0.692
WL16	384960	6465055	2.875	3.562	0.687
WL17	384982	6465045	2.899	3.577	0.678
WL18	385290	6464968	3.107	3.797	0.690
WL19	385250	6464935	3.043	3.721	0.678
WL20	385228	6464922	3.004	3.661	0.657
N3a	385205	6464905	2.964	3.620	0.656
N4a	384975	6464822	2.798	3.463	0.665
WL21	384962	6464815	2.768	3.431	0.663
WL22	384950	6464802	2.728	3.390	0.662
WL23	384890	6464762	2.603	3.263	0.660
WL24	384820	6464715	2.512	3.187	0.675
55 WL25	384360	6464568	1.956	2.346	0.390
56 N5a	384655	6464600	2.114	2.584	0.470
W26A	385077	6464988	NR	3.598	
57 Abd#8	384965	6465560	2.956	3.622	0.666
Surface Water					
Indian Ocean			0.000	0.000	0.000
Swan River/Freshwater Bay			0.000	0.000	0.000
Lake Monger			12.665	12.902	0.237
Jackadder Lake			8.000	8.352	0.352
Herdsman Lake			6.530	7.052	0.522
Perry Lake East			3.006	3.526	0.520
Perry Lake West			2.687	3.455	0.768
Lake Claremont			1.090	1.605	0.515

Notes

All values in metres, SWL are m AHD

NR = not read

#27 Jubilee Park, May reading in abandonned bore, September reading in adjacent submersible well #28

CHAPTER
3

APPENDICES

Appendix 3.1 Geological Logs

Geological logs were obtained from the Geological Survey of Western Australia, (GSWA) Hydrogeology Branch (now incorporated into Water and Rivers Commission). The GSWA compiled drillers logs for much of the drilling on the Swan Coastal Plain in the 1960's and 1970's. In many cases GSWA geologists attended drilling sites and logged the cuttings themselves. These logs are all believed to have been logged by GSWA personnel and represent the only deep sub surface information on the hydrogeology of the unconfined aquifer below Perry Lakes. Data here has been transcribed from the original logs and stratigraphic columns. The 'Irrigation' number refers to the current bore designations within Perry Lakes Reserve (refer Figure 3.3).

Appendix 3.2 Grain Size Analysis and Determination of Hydraulic Conductivity

Text summarises the theory and general approaches taken by various workers to provide estimates of hydraulic conductivity using grain size methods. Notes on the preparation and sieving of samples are included.

Table 1 Hydraulic Conductivity Calculations

Data calculated on a sample (metre by metre) basis. Averages are calculated for the wetted section of the aquifer only.

Table 2 Grain Size Distribution

This is the data derived from cumulative frequency curves, reported as percent per weight and as Phi units. Table includes sedimentary statistics (sorting, skewness and kurtosis). Refer Appendix text for details. Data from Table 2 is also reported graphically as histograms. Included are the sedimentary statistics, hydraulic conductivity data and the geological logs for all samples compiled at the time of drilling. The histograms include the raw percent by weight data for each size class. The data in Appendix 3.2 taken as a whole, represents a very detailed sedimentary analysis of the Upper Sand unit at Perry Lakes.

Appendix 3.3 a&b Lake Lining Isopach Survey Station Locations.

Maps show every station where the lake was probed or augered to determine the thickness of the lake lining clays. As indicated by the station distributions, most of the detailed surveying was done around the perimeter of each lake. Each lake is rimmed by a trough, now filled with recent (post 1960) sediment. This trough which varies in depth and width is an artefact of the bank reforming which appears to have been done with a mechanical digger.

Appendix 3.4 Geology and Hydrogeology of the Tamala Limestone

This is a general summary of the literature pertaining to the Tamala Limestone in the Perth Metropolitan area. At Perry Lakes the only information on the limestone unit are the irrigation bore geological logs (Appendix 3.1). Both cable tool and rotary percussion drilling breaks the limestone up. The sample returned to the surface and logged by the geologist bears little resemblance to the consolidated parent rock. Drill logs almost certainly under report the amount of limestone present because weakly cemented limestone is completely disaggregated by the drilling process and returns to the surface as sand.

Appendix 3.5 Hydraulic Conductivity of East Lake Lining Sediments

These permeameter experiments were attempts to directly measure the hydraulic conductivity of lake lining sands and clays. Unlike most permeameter experiments the samples were inserted into the permeameter as in situ undisturbed sedimentary columns. The resulting estimates of hydraulic conductivity are therefore considered much more representative than would have been the case if samples were disturbed and repacked. The real eye opener in this experiment was the relationship between water viscosity (as a function of temperature) and hydraulic conductivity. It is obvious that in clay sediments with their inherent low permeability, the rate at which water moves through them is highly influenced by water temperature.

Appendix 3.6 Determination of Specific Yield of Lake Sediments

Specific yield was required for field experiments to estimate evapotranspiration from water table fluctuations. Sands were found to drain almost completely within 10 hours. Complete draining of the clay lining however is an extremely slow process. The experiment was allowed to run 58 days at which time total water drained was only 2.4% of total sediment volume.

Appendix 3.7 a&b Lake Basin Topography Survey Station Locations

Maps show all stations optically levelled to compute basin topography and volume. Just as with the lake lining surveys, detailed work tended to be concentrated around the basin margin. West Lake was surveyed in 1995 when the lake was dry apart from a small residual pool around the staff gauge. In East Lake work was completed in January 1998. The Town of Cambridge agreed to limit lake maintenance top up during the survey period so that water was maintained only in the South Basin. The remainder of the lake was dry and could be traversed on foot. In the South Basin lake bottom was taken to be the water - false bottom contact.

Appendix 3.8 a&b Depth - Area - Volume Data

Data is tabulated at the following levels of resolution for both lakes:

Lake dry to 3.6m (stage m AHD):	1mm
Stage 3.6 to 4.0m	5mm
Stage 4.0 to 5.0m	10mm

Appendix 3.1: Geological Logs

Irrigation 1

0	6.1	sand
	27.4	limestone
	39.6	c.g. sand
	42.7	clayey sand and shale

Irrigation 2 (GSWA 0396)

0	9.1	f.g. yellow and white sand
	11.3	coarse white sand
	12.8	fine white sand
	15.2	m.g.-c.g. white sand
	25.0	limestone & c.g. white sand
	26.2	c.g. white sand
	28.7	f.g. yellow sand
	29.9	c.g. white sand & limestone
	39.3	c.g. white sand

Irrigation 6 (GSWA 1712)

0	8.5	yellow sand
	12.0	limestone
	13.0	open hole, little water
	14.0	limestone & f.g. sand
	15.0	thick f.g. to very c.g. green to grey sand with layers of clay and c.g. clean sand
	17.5	grey f.g. to c.g. sand w/limestone rubble
	18.0	brown m.g. to c.g. dirty sand and limestone
	21.0	limestone, open hole from 19, no water
	23.0	limestone & c.g. light brown to white sand, some f.g. sand
	26.0	white limestone, & mucky white sand with minor f.g. sand & loose lst
	30.0	solid limestone, open hole
	31.0	limestone rubble and water

Irrigation 7 (GSWA 1711)

0	11.6	yellow sand
	14.0	m.g. sand, bluish, little clay
	14.3	decomposed limestone
	15.8	limestone with f.g. white sand
	19.2	limestone, decomposed, minor yellow clay
	20.4	m.g.-c.g. sand
	21.0	limestone, hard
	22.3	c.g. white sand
	22.9	limestone, hard
	25.0	m.g. sand
	26.5	limestone with c.g. sand
	27.1	hard, quartz cemented w/ c.g. sand
	28.7	limestone, decomposed
	29.9	c.g. sand and quartz
	36.0	f.g. sand

Irrigation 7 (GSWA 1713)

0	10.5	f.g. yellow sand
	15.0	grey m.g. sand
	21.0	hard limestone, brown
	21.5	limestone & f.g. white sand
	22.5	hard limestone, brown
	25.7	limestone & c.g. white sand
	26.3	m.g. gravel
	27.0	f.g. gravel and c.g. sand
	31.0	limestone & c.g. sand
	36.7	m.g. to f.g. sand
	37.0	brown clay

Abandonned (GSWA 1691)

0	13.7	soil and white sand
	14.6	m.g. brown sand
	15.8	m.g. light brown sand
	17.1	c.g. sand, minor limestone
	18.3	m.g.-c.g. sand
	20.4	c.g. sand (good water source)
	23.8	m.g.-f.g. sand
	27.4	limestone with shells and c.g. sand
	30.5	grey clay

Irrigation 8 (GSWA 0151)

0	2.1	sand
	9.5	f.g. sand with clay
	13.1	c.g. white sand with stones
	19.2	limestone with f.g. sand
	30.2	limestone
	36.3	c.g. clean sand

Appendix 3.2
Grain Size Analysis and Hydraulic Conductivity of Upper Sand Unit

Grain size analysis serves three purposes as outlined by Kresic (1997):

- determine the range of grain size present *i.e.* its degree of uniformity
- determine the effective grain size
- estimate the hydraulic conductivity

Numerous empirical formulas have been devised to estimate hydraulic conductivity from grain size. These fall in to two principal types. The majority are non dimensionally homogeneous. They employ either:

- the grain size which principally determines the rate of groundwater flow in the porous medium, the *effective grain size*, usually taken to be d_{10}
- the range of grain sizes present, defined by the slope of the cumulative frequency curve, and usually defined by the uniformity coefficient U where:

$$U = \frac{d_{60}}{d_{10}}$$

Equations relating the grain size of porous media to hydraulic conductivity take the general form defined by Bear (1972):

$$K = f_1(s) f_2(n) d^2$$

Where $f_1(s)$ is a dimensionless parameter which expresses the effect of the shape of the grains, $f_2(n)$ is the porosity factor and *d* is the effective or mean diameter of the grains. This forms the basis of the *Kozeny-Carmen equation* (Bear 1972) and the *Fair-Hatch equation*, as reported by Freeze & Cherry (1979). Combining the product of $f_1(s)$ and $f_2(n)$ as a single dimensionless coefficient leads directly to the simple relation developed by Hazen (1893) cited Freeze & Cherry (1979) where K is defined by the power-law relation:

$$K = Cd_{10}^2$$

with d_{10} defined as the grain size diameter at which 10% of the sediment by weight is finer and 90% coarser. For *K* in cm/s and *d* in mm, *C* is approximately equal to unity.

Refinements of Hazen's method include Harleman *et al* (1963), Beyer (1964) cited Ptak & Teutsch (1994), and Uma *et al* (1989). The basis of all these equations is experimental observation which suggests that a direct power law relationship exists between *K* and a representative size of the sediment. Formulas for the first three are as follows for *K* in cm/s:

Harleman *et al* (1963)	$K = 0.641d_{10}^2$	for water at 20° C, *d* in mm
Beyer (1964) cited Ptak & Teutsch (1994)	$K = c(u)d_{10}^2$	where *c(u)* is an empirical constant defined as d_{60}/d_{10}
Uma *et al* (1989)	$K = Cd_{10}^2$	where *C* varies from 2 (cemented) to 6 (unconsolidated) sediments

At Perry Lakes, the method of Beyer (1964) produced unreasonably large values of *K*. Using the method of Uma *et al* (1989), *C* was taken as 6.

Dimensionally correct methods attempt to take into account the overall grain size distribution. A sediment with a wide range of grain sizes will have lower porosity and hydraulic conductivity. These methods may provide useful results for more heterogeneous, poorly sorted sediments.

Masch & Denny (1966) investigated measures of average grain size, dispersion around the median diameter (in other words the standard deviation or degree of sorting in the sediment), skewness, kurtosis and modality of sample distributions. Their method uses d_{50} grain size and the inclusive standard deviation s_I calculated using phi values after the method of Folk & Ward (1957) where:

$$\sigma_I = \frac{d_{16} - d_{84}}{4} + \frac{d_5 - d_{95}}{6.6}$$

They argue that the inclusive standard deviation, as a measure of dispersion or spread, reflects the range of grain size variability within the sample.

The Breyer equation (Kresic 1997) is:

$$K = \frac{g}{v} C_b d_e^2$$

where

$$C_b = 6 \text{x} 10^{-4} \log \frac{500}{U}$$

The method was developed for poorly sorted material where $1 < U < 20$ and where $1 < d_{10} < 0.6$mm. This includes the majority of the material from piezometers N1-N4.

Reyes (1966) carried out experiments on the applicability of the basic $K = cd^n$ equation to particle size and distribution within sands and gravels. For homogeneous sands he found $K = 9034 d_{50}^{1.93}$ with units of US gallons day^{-1} ft^{-2}.

Shepherd (1989) expanding on Reyes (1966), used regression of 19 sets of published data comprising both grain size and laboratory permeability measurements on unconsolidated sediments ranging from uniform glass spheres to poorly sorted natural sediments and cemented sandstone. Shepherd found that in the basic formula $K = cd^n$ values of *c* and the exponent both generally decrease with decreased textural maturity and increased induration. Shepherd produced 6 variants of the basic equation that relate hydraulic conductivity to the mean grain diameters of different sediment types, using the d_{50} percentile for grain size (again with units of US gallons day^{-1} ft^{-2}.):

Glass spheres	$K = 300{,}000 d_{50}^{2}$
Dune sands	$K = 40{,}000 d_{50}^{1.85}$
Beach sands	$K = 12{,}000 d_{50}^{1.75}$
Channel sands	$K = 3{,}500 d_{50}^{1.65}$
Consolidated sediments	$K = 800 d_{50}^{1.50}$

Values of hydraulic conductivity presented in Chapter 3 (Table 3.2) were calculated using the equation for channel sands only. This provides values which most closely approximate those derived from pump test data and other grain size methods. The beach and dune sand equations produced unrealistically high values of *K*.

Alyamani & Sen (1993) propose an alternate procedure. Rather than using a representative grain size distribution parameter such as diameter or standard deviation, they relate hydraulic conductivity to the initial slope and intercept of the grain size distribution curves. The method involves computing a cumulative frequency plot with grain size plotted arithmetically. The straight line portion of the curve is extrapolated to the x axis. The steeper the slope, the greater the overall amount of fine material in the sample and the smaller the x intercept value, designated I_0. The final equation, for *K* in m/day, based on empirical studies is:

$$K = 1300\left[I_0 + 0.025\left(d_{50} - d_{10}\right)\right]^2$$

At Perry Lakes this method was found to be problematic where distributions are bi modal. There are two straight sections of the curve and, depending on which one is used, the resulting K values are either very large or very small.

Where estimates of porosity from long time specific yield tests were available, hydraulic conductivity was also estimated using the *Fair Hatch equation.* This method utilises porosity (which provides an integrated measure of the packing arrangement) to calculate hydraulic conductivity and also characteristics of the fluid. The hydraulic conductivity of a porous medium consisting of uniform spheres of diameter *d* is given by:

$$K = \left[\frac{\rho g}{\mu}\right] C d^2$$

where ρ is the fluid density and μ is the viscosity. This basic equation evolves to:

$$K = \left[\frac{\rho g}{\mu}\right]\left[\frac{n^3}{(1-n)^2}\right]\left[\frac{1}{m\left(\frac{\theta}{100}\sum\frac{P}{d_m}\right)^2}\right]$$

where m is a packing factor, found experimentally to be about 5, θ is a grain shape factor which varies from 6.0 for spherical grains to 7.7 for angular grains, *P* is the percentage of material retained between adjacent sieves and d_m is the geometric mean of the rated aperture sizes of adjacent sieves. The results fell within the range of other methods tested and have not been reported. An extensive analysis of the *Fair-Hatch equation* is provided in Fraser (1935).

It is important to remember that all of these methods are empirical, based on experimental data from a variety of natural and artificial material. They can provide, at best, only an *approximation* of hydraulic conductivity.

Notes on Sample Preparation

Samples were dried for a minimum 24 hours at 105˚C. Dried samples were disaggregated by mortar and pestle and then sieved using techniques modified from Allman & Lawrence (1972). Each sieve plus bottom receiving pan was weighed empty along with pre-sieved sample weight. Samples were shaken mechanically for 10 minutes. Sieves were then reweighed and sample size fraction weights calculated by difference.

Sieve Aperture Data

Aperture	2.000	1.000	0.500	0.355	0.250	0.180	0.125	0.090	0.063	<.063
phi ș	-1.0	0.0	1.0	1.5	2.0	2.5	3.0	3.5	4.0	<4.0
	granule pebbles	v. coarse sand	course sand	medium sand	medium sand	fine sand	fine sand	v. fine sand	v. fine sand	silts & clays

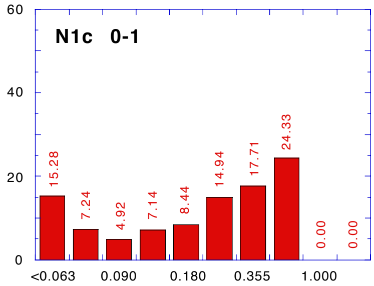
Material retained on a screen was assumed to have a size value equal to the screen aperture diameter. No attempt was made to correct for true weight mid points. Merely assigning a midpoint phi value of the class interval is not valid because for each class interval, the true weight midpoint diameter is different. Folk (1966) p79 provides a more detailed discussion of this problem.

The size distributions within the <.063mm material was not investigated for any of the samples. As a result the sedimentary size distributions are 'open ended' in that they contain a large (up to 5%) proportion of unanalysed fine material. The cumulative frequency curves and inclusive standard deviation, skewness and kurtosis determinations require the entire distribution. Folk (1966) discusses this problem and advocates that where fines are not analysed, that an arbitrary assumption of their mean size be used. In these computations the under size material was arbitrarily assigned a phi value of 5 (.031mm, medium silt).

Cumulative frequency plots were generated using KALEIDAGRAPH and grain diameters at 05, 10, 16, 25, 50, 60, 75, 84 & 95 percent weight calculated. Percentile grain diameters were entered in EXCEL. Diameters were recalculated as phi units (-$\log_2$) and inclusive standard deviation, skewness and kurtosis calculated (Table 2) using the method of Folk & Ward (1957). These are included with the grain size histograms.

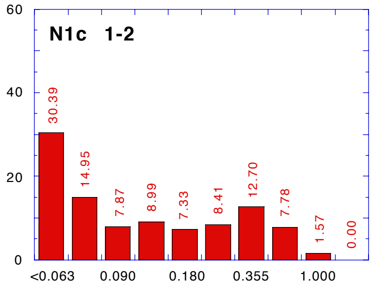
Refer last page for notes and key

Piezometer N1c



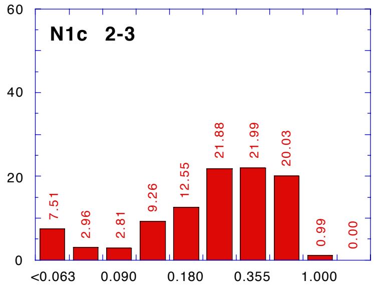
Sorting	1.89	K_1	0.1	K_2	0.08
Skewness	0.56	K_3	3.4	K_4	0.07
Kurtosis	1.19	K_5	10.6	K_6	0.04
				K_7	0.09

Sand, m-c.g.,brown, with organics, silt and minor clay possibly as thin bands, distinctly bi-modal suggesting distinct sand-silt layers



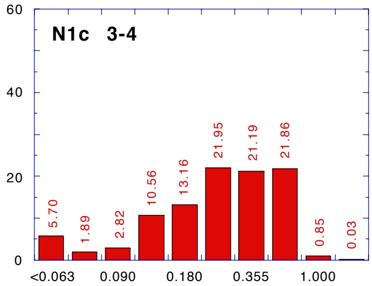
Sorting	2.55	K_1	0.01	K_2	0.01
Skewness	0.35	K_3	2.7	K_4	0.01
Kurtosis	1.09	K_5	2.3	K_6	0.01
				K_7	0.01

Silt and clay bands, brown, organic with poorly sorted very fine to medium sand interbeds
Winter max water table approximately 1.5m



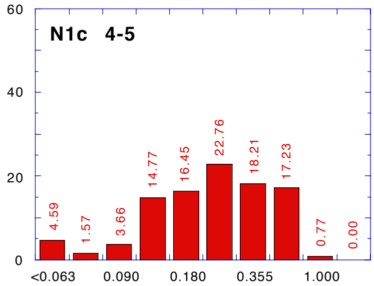
Sorting	1.33	K_1	2.9	K_2	1.9
Skewness	0.41	K_3	5.6	K_4	1.7
Kurtosis	1.73	K_5	12.1	K_6	3.0
				K_7	3.1

Sand, fine-coarse grained, light brown-beige
Summer min water table approximately 2.2m



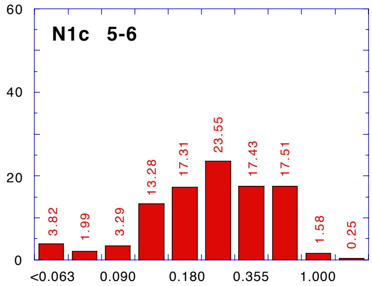
Sorting	1.24	K_1	6.1	K_2	3.9
Skewness	0.37	K_3	6.1	K_4	3.7
Kurtosis	1.59	K_5	12.4	K_6	3.9
				K_7	6.9

Sand, fine-coarse grained, light brown-beige



Sorting	1.01	K_1	7.2	K_2	4.6
Skewness	0.22	K_3	6.1	K_4	4.3
Kurtosis	1.13	K_5	10.5	K_6	3.6
				K_7	8.4

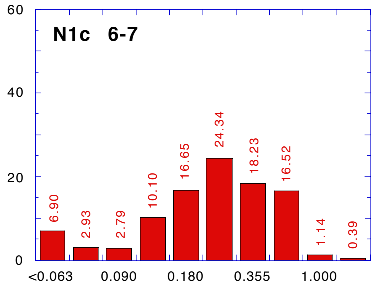
Sand, fine-medium grained, light brown-beige



Sorting	0.96	K_1	7.2	K_2	4.6
Skewness	0.18	K_3	6.3	K_4	4.3
Kurtosis	1.06	K_5	10.7	K_6	5.3
				K_7	8.4

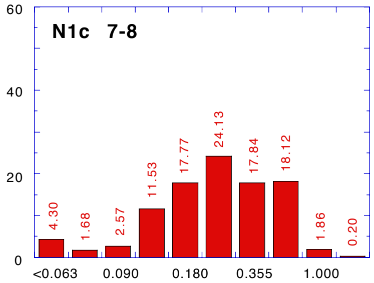
Sand, fine-medium grained, light brown-beige

Piezometer N1c



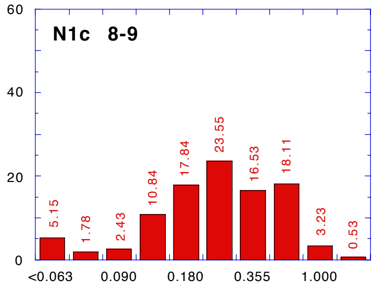
Sorting	1.31	K_1	3.5	K_2	2.3
Skewness	0.35	K_3	5.4	K_4	2.1
Kurtosis	1.84	K_5	10.7	K_6	4.2
				K_7	3.9

Sand, fine-medium grained, light brown-beige



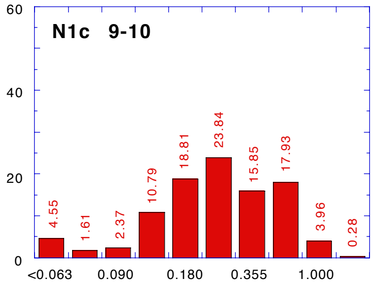
Sorting	0.99	K_1	7.5	K_2	4.8
Skewness	0.19	K_3	6.3	K_4	4.5
Kurtosis	1.17	K_5	11.0	K_6	5.7
				K_7	8.8

Sand, fine-medium grained, brown



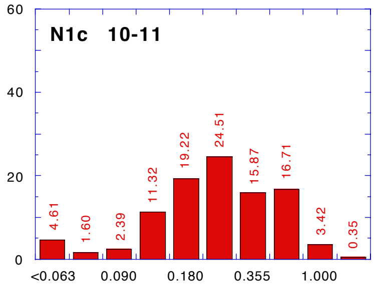
Sorting	1.09	K_1	7.2	K_2	4.6
Skewness	0.23	K_3	6.1	K_4	4.3
Kurtosis	1.31	K_5	11.1	K_6	5.5
				K_7	8.4

Sand, fine-medium grained, light brown-beige
minor coarse fraction



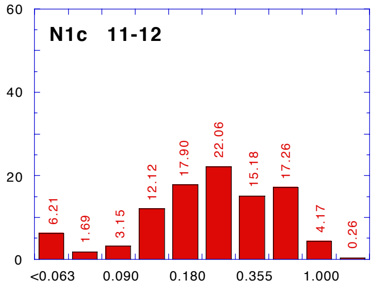
Sorting	1.02	K_1	7.5	K_2	4.8
Skewness	0.17	K_3	6.3	K_4	4.5
Kurtosis	1.20	K_5	11.0	K_6	6.4
				K_7	8.8

Sand, fine-medium grained, light brown-beige
minor coarse fraction, possibly as distinct beds



Sorting	1.02	K_1	7.5	K_2	4.8
Skewness	0.17	K_3	6.2	K_4	4.5
Kurtosis	1.24	K_5	10.7	K_6	6.4
				K_7	8.8

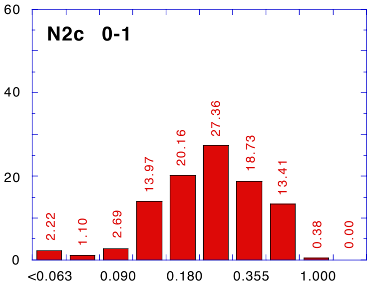
Sand, fine-medium grained, light brown-beige
minor coarse fraction, possibly as distinct beds



Sorting	1.34	K_1	5.4	K_2	3.5
Skewness	0.30	K_3	5.1	K_4	3.2
Kurtosis	1.70	K_5	10.7	K_6	4.0
				K_7	6.2

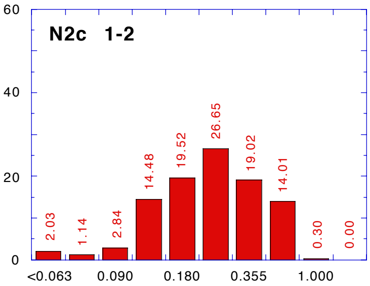
Sand, fine-medium grained, light brown-beige
minor coarse fraction, possibly as distinct beds

Piezometer N2c



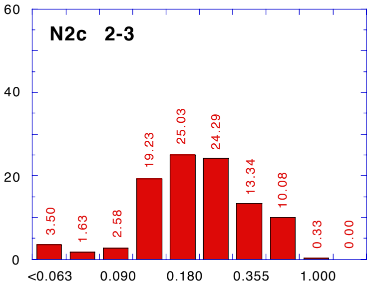
Sorting	0.78	K1	8.3	K2	5.3
Skewness	0.08	K3	6.9	K4	5.0
Kurtosis	0.96	K5	10.2	K6	7.4
				K7	10.0

Sand, fine-medium grained, light grey



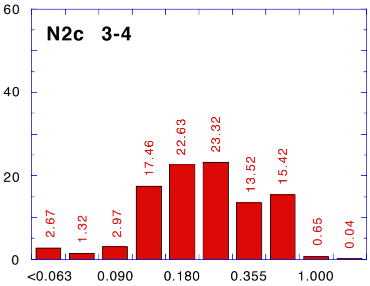
Sorting	0.78	K1	8.3	K2	5.3
Skewness	0.07	K3	6.9	K4	5.0
Kurtosis	0.93	K5	10.2	K6	7.0
				K7	10.0

Sand, fine-medium grained, light grey
Winter water table max approximately 2.0m



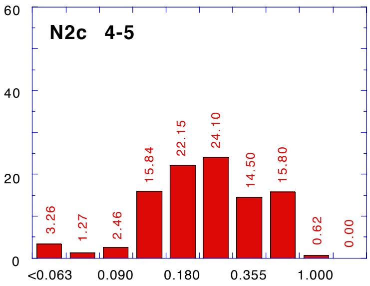
Sorting	0.82	K1	7.5	K2	4.8
Skewness	0.02	K3	5.9	K4	4.5
Kurtosis	1.13	K5	7.9	K6	6.7
				K7	9.1

Sand, fine-medium grained, light grey
Summer min water table approximately 2.8m



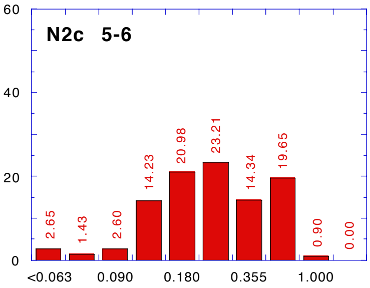
Sorting	0.84	K1	7.8	K2	5.0
Skewness	-0.01	K3	6.3	K4	4.7
Kurtosis	0.97	K5	9.0	K6	7.6
				K7	9.4

Sand, fine-coarse grained, weakly bi-modal
suggesting distinct fine-coarse beds, light grey



Sorting	0.85	K1	8.0	K2	5.1
Skewness	0.03	K3	6.3	K4	4.8
Kurtosis	0.98	K5	9.4	K6	7.2
				K7	9.6

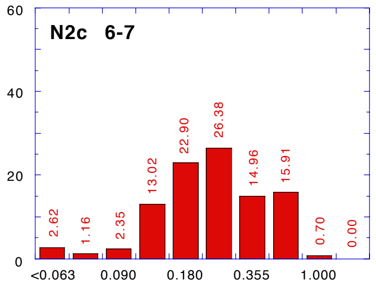
Sand, fine-coarse grained, weakly bi-modal
suggesting distinct fine-coarse beds, light grey



Sorting	0.86	K1	8.1	K2	5.2
Skewness	0.04	K3	6.6	K4	4.9
Kurtosis	0.89	K5	10.2	K6	7.2
				K7	9.7

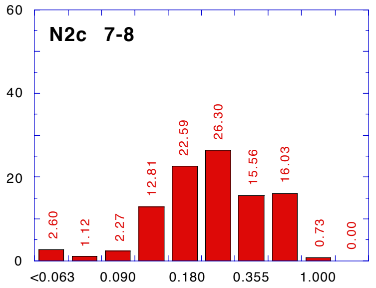
Sand, fine-coarse grained, bi-modal
suggesting distinct fine-coarse beds, beige

Piezometer N2c



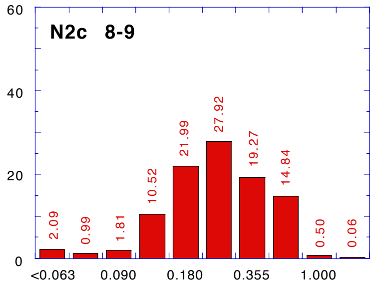
Sorting	0.80	K_1	8.3	K_2	5.3
Skewness	0.01	K_3	6.7	K_4	5.0
Kurtosis	0.99	K_5	9.9	K_6	7.8
				K_7	10.0

Sand, fine-coarse grained, weakly bi-modal suggesting distinct fine-coarse beds, beige



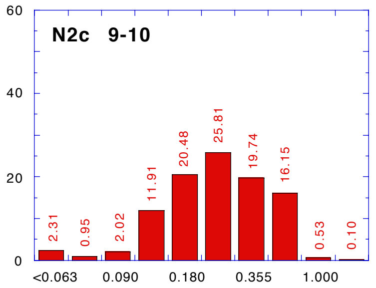
Sorting	0.79	K_1	8.6	K_2	5.5
Skewness	0.02	K_3	6.7	K_4	5.2
Kurtosis	0.97	K_5	10.0	K_6	8.4
				K_7	10.5

Sand, fine-coarse grained, weakly bi-modal suggesting distinct fine-coarse beds, beige



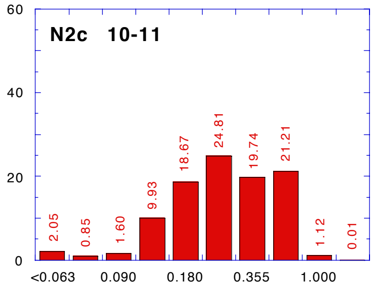
Sorting	0.72	K_1	9.5	K_2	6.1
Skewness	0.01	K_3	7.3	K_4	5.7
Kurtosis	0.94	K_5	10.7	K_6	10.0
				K_7	11.6

Sand, fine-medium grained, light beige to brown



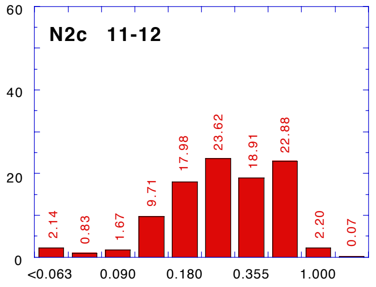
Sorting	0.76	K_1	9.0	K_2	5.8
Skewness	0.04	K_3	7.2	K_4	5.4
Kurtosis	0.91	K_5	10.9	K_6	7.9
				K_7	10.8

Sand, fine-medium grained, light beige to brown



Sorting	0.77	K_1	10.1	K_2	6.5
Skewness	0.05	K_3	7.8	K_4	6.1
Kurtosis	0.84	K_5	12.1	K_6	9.2
				K_7	12.1

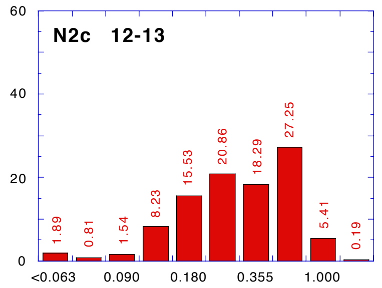
Sand, fine-coarse grained, weakly bi-modal suggesting distinct fine-coarse beds, beige



Sorting	0.78	K_1	10.1	K_2	6.5
Skewness	0.05	K_3	8.0	K_4	6.1
Kurtosis	0.82	K_5	12.5	K_6	9.4
				K_7	12.0

Sand, fine-coarse grained, bi-modal suggesting distinct fine-coarse beds, beige

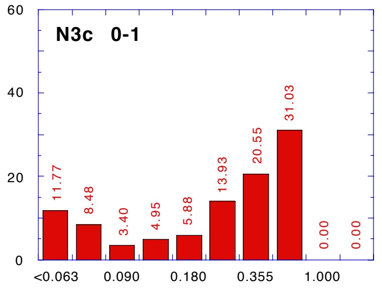
Piezometer N2c



Sorting	0.80	K_1	11.0	K_2	7.1
Skewness	0.13	K_3	8.6	K_4	6.6
Kurtosis	0.82	K_5	14.7	K_6	9.5
				K_7	12.9

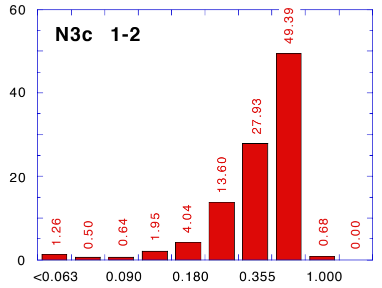
Sand, medium-coarse grained, bi-modal, beige

Piezometer N3c



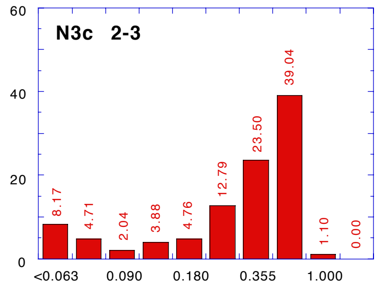
Sorting	1.66	K_1	0.5	K_2	0.3
Skewness	0.62	K_3	4.7	K_4	0.3
Kurtosis	1.16	K_5	15.0	K_6	0.2
				K_7	0.4

Sand, bimodal with silt and medium-coarse grained beds, black-brown, organic, possible dredging spoil and sand fill



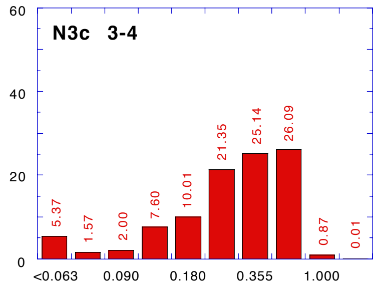
Sorting	0.55	K_1	30.2	K_2	19.4
Skewness	0.45	K_3	18.4	K_4	18.1
Kurtosis	1.09	K_5	26.0	K_6	39.5
				K_7	37.3

Sand, medium-coarse grained, brown with organic material, original surface sands(?)
Water table winter max approximately 1.6m



Sorting	1.39	K_1	1.4	K_2	0.9
Skewness	0.64	K_3	6.3	K_4	0.8
Kurtosis	2.02	K_5	20.1	K_6	12.4
				K_7	1.3

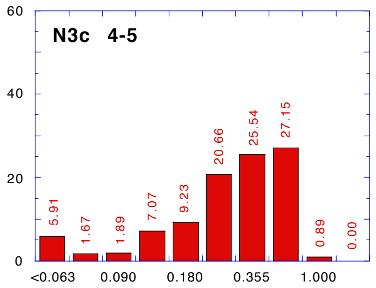
Sand, medium-coarse grained, carbonaceous black, 20-30cm black clay/silt unit 2.0-2.3m
Water table summer min approximately 2.4m



Sorting	1.11	K_1	7.5	K_2	4.8
Skewness	0.41	K_3	7.1	K_4	4.5
Kurtosis	1.63	K_5	15.0	K_6	12.0
				K_7	8.5

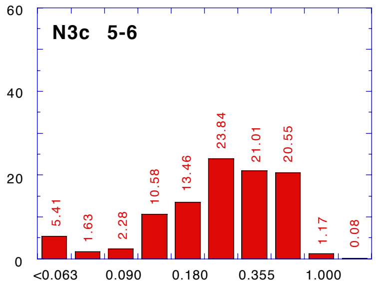
Sand, medium-coarse grained, carbonaceous, black-brown, silty

Piezometer N3c



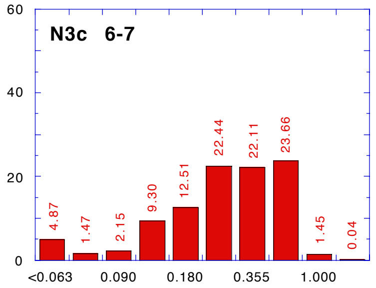
Sorting	1.24	K_1	7.3	K_2	4.7
Skewness	0.47	K_3	6.8	K_4	4.4
Kurtosis	2.01	K_5	15.6	K_6	12.0
				K_7	8.2

Sand, medium-coarse grained, dark brown, silty



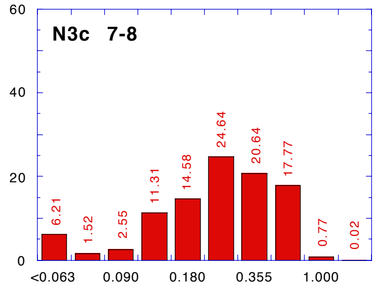
Sorting	1.14	K_1	7.2	K_2	4.6
Skewness	0.33	K_3	6.3	K_4	4.3
Kurtosis	1.48	K_5	12.2	K_6	5.2
				K_7	8.3

Sand, fine-coarse grained, brown, silty



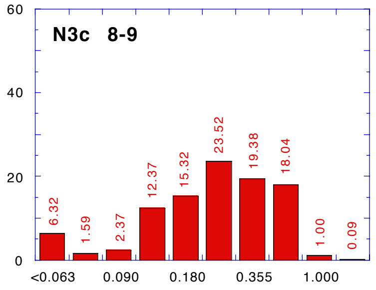
Sorting	1.03	K_1	7.8	K_2	5.0
Skewness	0.32	K_3	7.1	K_4	4.7
Kurtosis	1.31	K_5	13.5	K_6	5.6
				K_7	9.0

Sand, fine-coarse grained, brown, silty



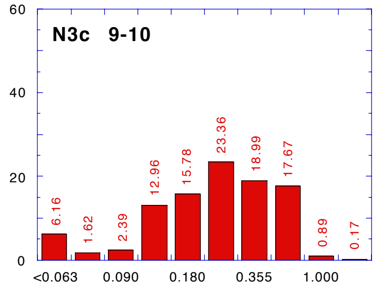
Sorting	1.29	K_1	6.2	K_2	4.0
Skewness	0.37	K_3	5.7	K_4	3.8
Kurtosis	1.85	K_5	11.4	K_6	4.7
				K_7	7.2

Sand, fine-coarse grained, brown, silty



Sorting	1.30	K_1	6.1	K_2	3.9
Skewness	0.36	K_3	5.5	K_4	3.7
Kurtosis	1.79	K_5	11.1	K_6	4.6
				K_7	7.0

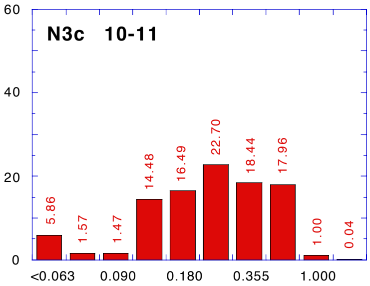
Sand, fine-coarse grained, brown, silty



Sorting	1.30	K_1	6.4	K_2	4.1
Skewness	0.34	K_3	5.5	K_4	3.8
Kurtosis	1.79	K_5	10.9	K_6	4.7
				K_7	7.4

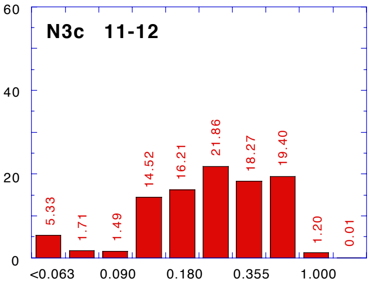
Sand, fine-coarse grained, brown, silty

Piezometer N3c



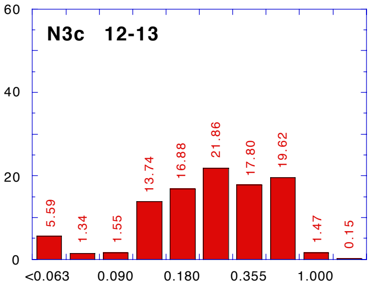
Sorting	1.21	K_1	7.3	K_2	4.7
Skewness	0.30	K_3	5.8	K_4	4.4
Kurtosis	1.57	K_5	10.7	K_6	4.1
				K_7	8.6

Sand, fine-coarse grained, brown, silty



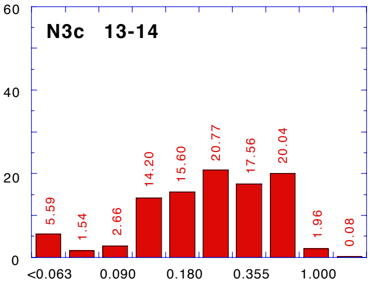
Sorting	1.12	K_1	7.3	K_2	4.7
Skewness	0.26	K_3	5.9	K_4	4.4
Kurtosis	1.36	K_5	10.9	K_6	4.2
				K_7	8.6

Sand, fine-coarse grained, brown, silty



Sorting	1.23	K_1	7.5	K_2	4.8
Skewness	0.30	K_3	5.7	K_4	4.5
Kurtosis	1.57	K_5	11.1	K_6	3.9
				K_7	8.8

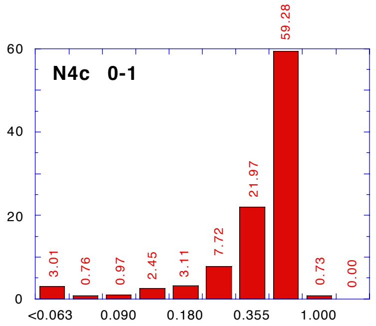
Sand, fine-coarse grained, brown, silty



Sorting	1.24	K_1	7.0	K_2	4.5
Skewness	0.29	K_3	5.7	K_4	4.2
Kurtosis	1.46	K_5	10.9	K_6	4.1
				K_7	8.2

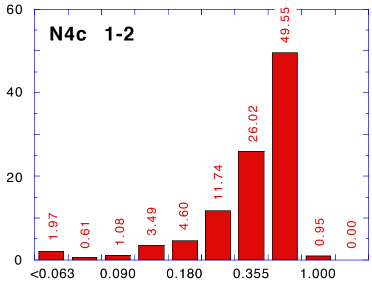
Sand, fine-coarse grained, brown, silty

Piezometer N4c



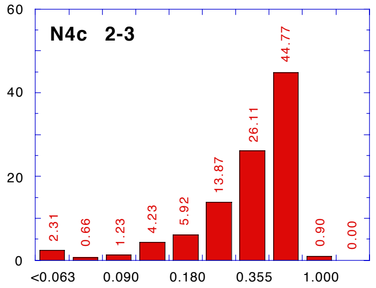
Sorting	0.61	K_1	25.9	K_2	16.6
Skewness	0.57	K_3	18.2	K_4	15.5
Kurtosis	1.55	K_5	28.3	K_6	38.5
				K_7	31.1

Sand, coarse grained, black



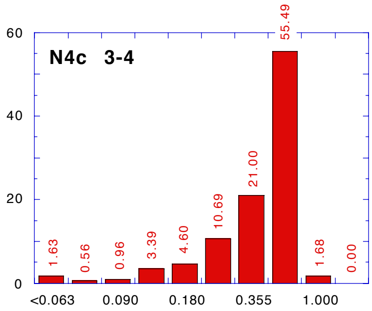
Sorting	0.63	K_1	21.0	K_2	13.5
Skewness	0.51	K_3	16.9	K_4	12.6
Kurtosis	1.27	K_5	26.0	K_6	35.0
				K_7	25.1

Sand, coarse grained, light grey-beige
Water table winter max approximately 1.5m



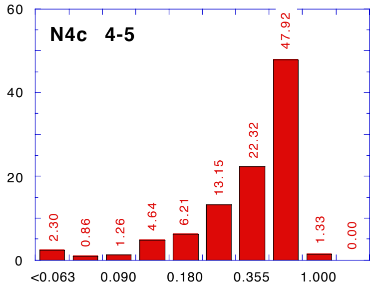
Sorting	0.67	K_1	16.5	K_2	10.6
Skewness	0.45	K_3	14.7	K_4	9.9
Kurtosis	1.12	K_5	23.5	K_6	26.2
				K_7	19.3

Sand, coarse grained, light grey-brown
Summer water table mini approximately 2.2m



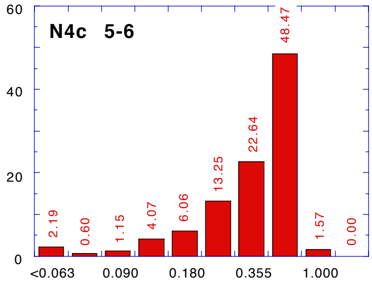
Sorting	0.62	K_1	23.5	K_2	15.1
Skewness	0.55	K_3	17.9	K_4	14.1
Kurtosis	1.25	K_5	27.7	K_6	21.7
				K_7	28.2

Sand, coarse grained, light grey-brown



Sorting	0.69	K_1	15.1	K_2	9.7
Skewness	0.55	K_3	15.1	K_4	9.0
Kurtosis	1.12	K_5	25.7	K_6	17.1
				K_7	17.4

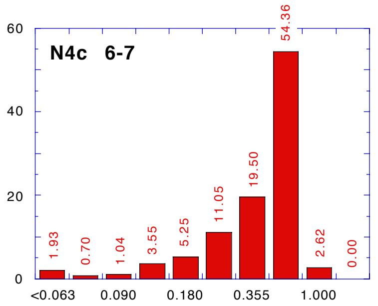
Sand, coarse grained, light grey-brown



Sorting	0.67	K_1	17.2	K_2	11.0
Skewness	0.53	K_3	15.7	K_4	10.3
Kurtosis	1.14	K_5	25.9	K_6	18.2
				K_7	20.1

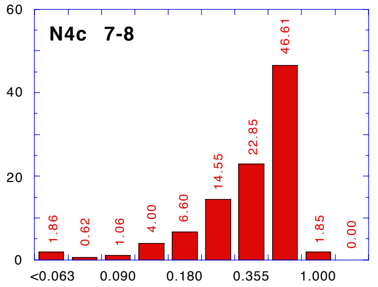
Sand, coarse grained, light grey

Piezometer N4c



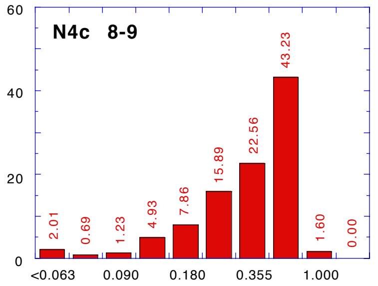
Sorting	0.64	K_1	19.4	K_2	12.5
Skewness	0.58	K_3	17.3	K_4	11.7
Kurtosis	1.23	K_5	27.9	K_6	18.0
				K_7	22.9

Sand, coarse grained, light grey



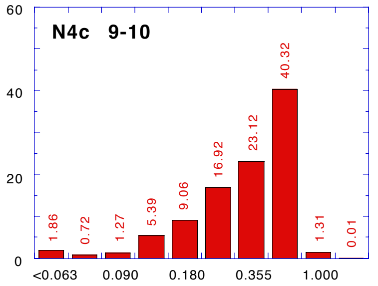
Sorting	0.66	K_1	17.7	K_2	11.3
Skewness	0.48	K_3	15.5	K_4	10.6
Kurtosis	1.06	K_5	24.8	K_6	19.1
				K_7	20.8

Sand, coarse grained, light grey



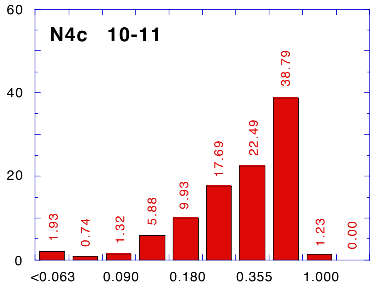
Sorting	0.69	K_1	14.6	K_2	9.4
Skewness	0.44	K_3	13.7	K_4	8.8
Kurtosis	1.00	K_5	22.6	K_6	15.4
				K_7	16.9

Sand, coarse grained, light grey



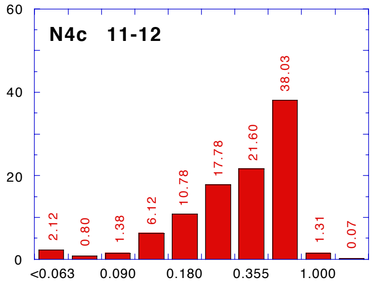
Sorting	0.71	K_1	14.4	K_2	9.2
Skewness	0.39	K_3	12.6	K_4	8.6
Kurtosis	0.97	K_5	21.0	K_6	13.4
				K_7	16.7

Sand, coarse grained, light grey



Sorting	0.73	K_1	13.3	K_2	8.5
Skewness	0.35	K_3	11.6	K_4	8.0
Kurtosis	0.92	K_5	19.7	K_6	11.8
				K_7	15.4

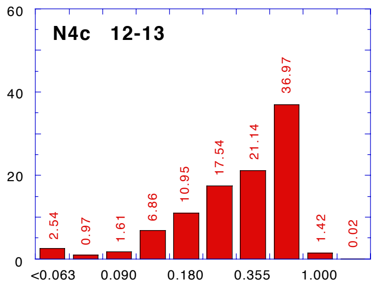
Sand, coarse grained, light grey



Sorting	0.75	K_1	12.9	K_2	8.2
Skewness	0.35	K_3	11.0	K_4	7.7
Kurtosis	0.90	K_5	19.4	K_6	9.3
				K_7	14.9

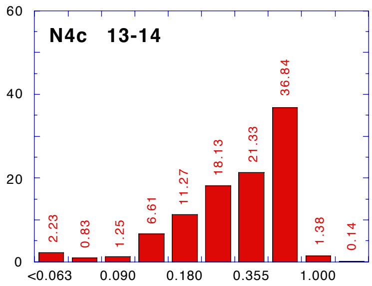
Sand, coarse grained, light grey

Piezometer N4c



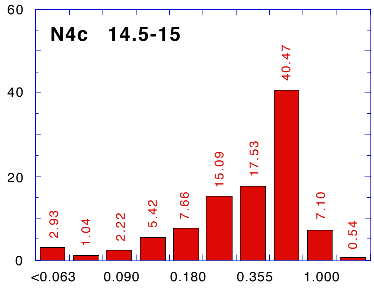
Sorting	0.78	K_1	11.0	K_2	7.1
Skewness	0.35	K_3	10.8	K_4	6.6
Kurtosis	0.91	K_5	18.7	K_6	7.2
				K_7	12.6

Sand, coarse grained, light grey



Sorting	0.75	K_1	12.2	K_2	7.8
Skewness	0.33	K_3	10.8	K_4	7.3
Kurtosis	0.90	K_5	18.7	K_6	8.2
				K_7	14.1

Sand, coarse grained, light grey



Sorting	0.87	K_1	11.0	K_2	7.1
Skewness	0.44	K_3	11.8	K_4	6.6
Kurtosis	1.18	K_5	24.4	K_6	8.7
				K_7	12.4

14.0-14.5 (no sample), possible dark green (glauconoitic(?) sand
14.5-15.0 Sand, coarse to very coarse grained, stained orange-brown

Key:

Sieve fractions represent oversize weight percent
Sieve stack apertures (mm): 0.063, 0.090, 0.125, 0.180, 0.250, 0.355, 0.500, 1.000 & 2.000
K_1-K_6: Hydraulic conductivity (m day^{-1}), calculated as follows: K_1 Hazen (1893),
K_2 Harleman et al (1963), K_3 Masch & Denny (1966) K_4 Uma (1989), K_5 Shepherd (1989),
K_6 Alyamani & Sen (1993), K7 Breyer cited Kresic (1997)

Hydraulic Conductivity from Grain Size Appendix 3.2 Table 1

Depth (m)	Hazen	Harleman	Masch & Denny	Uma	Shepherd[1]	Alyamani & Sen	Breyer
Nest N1c							
0-1	0.12	0.08	3.43	0.07	10.61	0.04	0.09
1-2	0.01	0.01	2.73	0.01	2.30	0.01	0.01
2-3	2.91	1.86	5.59	1.74	12.09	3.01	3.07
3-4	6.10	3.91	6.12	3.66	12.36	3.87	6.92
4-5	7.15	4.59	6.12	4.29	10.45	3.63	8.44
5-6	7.15	4.59	6.32	4.29	10.70	5.31	8.42
6-7	3.54	2.27	5.38	2.12	10.70	4.16	3.89
7-8	7.47	4.79	6.32	4.48	10.95	5.65	8.80
8-9	7.15	4.59	6.12	4.29	11.13	5.50	8.39
9-10	7.47	4.79	6.32	4.48	10.95	6.36	8.80
10-11	7.47	4.79	6.20	4.48	10.70	6.35	8.84
11-12	5.39	3.46	5.10	3.24	10.70	3.96	6.18
Av from 2m	6.18	3.96	5.96	3.71	11.07	4.78	7.18
Nest N2c							
0-1	8.30	5.32	6.93	4.98	10.19	7.43	9.99
1-2	8.30	5.32	6.85	4.98	10.19	7.04	9.97
2-3	7.47	4.79	5.91	4.48	7.89	6.74	9.12
3-4	7.80	5.00	6.32	4.68	8.98	7.57	9.42
4-5	7.96	5.10	6.32	4.78	9.37	7.20	9.62
5-6	8.13	5.21	6.61	4.88	10.19	7.24	9.74
6-7	8.30	5.32	6.73	4.98	9.86	7.81	10.01
7-8	8.64	5.54	6.73	5.18	10.03	8.42	10.45
8-9	9.53	6.11	7.34	5.72	10.70	9.97	11.56
9-10	8.99	5.76	7.18	5.39	10.87	7.85	10.82
10-11	10.08	6.46	7.75	6.05	12.09	9.15	12.06
11-12	10.08	6.46	7.95	6.05	12.45	9.39	11.98
12-13	11.03	7.07	8.56	6.62	14.68	9.50	12.89
Av from 2m	8.91	5.71	7.04	5.35	10.65	8.26	10.70
Nest N3c							
0-1	0.50	0.32	4.69	0.30	14.97	0.15	0.41
1-2	30.21	19.37	18.35	18.13	25.97	39.46	37.26
2-3	1.38	0.89	6.32	0.83	20.12	12.39	1.25
3-4	7.47	4.79	7.14	4.48	14.97	11.99	8.48
4-5	7.31	4.69	6.81	4.39	15.66	12.04	8.24
5-6	7.15	4.59	6.32	4.29	12.18	5.22	8.28
6-7	7.80	5.00	7.14	4.68	13.55	5.60	8.97
7-8	6.24	4.00	5.71	3.75	11.39	4.72	7.21
8-9	6.10	3.91	5.51	3.66	11.13	4.56	7.04
9-10	6.39	4.10	5.51	3.83	10.87	4.70	7.41
10-11	7.31	4.69	5.79	4.39	10.70	4.06	8.62
11-12	7.31	4.69	5.91	4.39	10.87	4.22	8.58
12-13	7.47	4.79	5.71	4.48	11.13	3.93	8.78
13-14	7.00	4.49	5.71	4.20	10.87	4.08	8.17
Av from 2m	6.58	4.22	6.13	3.95	12.79	6.46	7.59
Nest N4c							
0-1	25.86	16.58	18.15	15.52	28.29	38.48	31.14
1-2	21.03	13.48	16.92	12.62	25.97	34.96	25.08
2-3	16.45	10.55	14.68	9.87	23.49	26.19	19.27
3-4	23.52	15.08	17.94	14.11	27.67	21.68	28.15
4-5	15.05	9.65	15.09	9.03	25.73	17.06	17.39
5-6	17.18	11.01	15.70	10.31	25.85	18.21	20.10
6-7	19.44	12.46	17.33	11.66	27.92	17.96	22.85
7-8	17.67	11.33	15.50	10.60	24.77	19.06	20.76
8-9	14.60	9.36	13.66	8.76	22.57	15.42	16.93
9-10	14.38	9.22	12.64	8.63	21.00	13.42	16.72
10-11	13.28	8.52	11.62	7.97	19.69	11.84	15.37
11-12	12.86	8.24	11.01	7.72	19.36	9.26	14.85
12-13	11.03	7.07	10.81	6.62	18.72	7.21	12.59
13-14	12.24	7.84	10.81	7.34	18.72	8.18	14.10
14.5-15	11.03	7.07	11.83	6.62	24.42	8.69	12.36
Av from 2m	15.29	9.80	13.74	9.17	23.07	14.94	17.80

[1] Shepherd using formula for channel sands

Nested Piezometer Grain Size Distributions Calculated from Cumulative Frequency Curves

Appendix 3.2 Table 2

Depth (m)	Interval	Grain Size Diameter (mm)									Grain Size Diameter (Phi units)											
	(m)	d-05	d-10	d-16	d-25	d-50	d-60	d-75	d-84	d-95	ø5	ø10	ø16	ø25	ø50	ø60	ø75	ø84	ø95	Sorting	Skew	Kurtosis
Nest N1c																				(Std Dev)		
0-1	1.0	0.005	0.012	0.033	0.074	0.207	0.258	0.352	0.400	0.465	7.644	6.381	4.921	3.756	2.272	1.955	1.506	1.322	1.105	1.891	0.56	1.19
1-2	1.0	0.001	0.004	0.010	0.023	0.082	0.119	0.224	0.294	0.434	9.966	7.966	6.644	5.442	3.608	3.071	2.158	1.766	1.204	2.547	0.35	1.09
2-3	1.0	0.010	0.058	0.098	0.134	0.224	0.261	0.333	0.385	0.464	6.644	4.108	3.351	2.900	2.158	1.938	1.586	1.377	1.108	1.332	0.41	1.73
3-4	1.0	0.014	0.084	0.106	0.139	0.227	0.265	0.343	0.395	0.467	6.158	3.573	3.238	2.847	2.139	1.916	1.544	1.340	1.099	1.241	0.37	1.59
4-5	1.0	0.038	0.091	0.103	0.125	0.205	0.235	0.309	0.370	0.458	4.718	3.458	3.279	3.000	2.286	2.089	1.694	1.434	1.127	1.005	0.22	1.13
5-6	1.0	0.047	0.091	0.106	0.131	0.208	0.238	0.317	0.380	0.467	4.411	3.458	3.238	2.932	2.265	2.071	1.657	1.396	1.099	0.962	0.18	1.06
6-7	1.0	0.010	0.064	0.100	0.131	0.208	0.236	0.309	0.370	0.467	6.644	3.966	3.322	2.932	2.265	2.083	1.694	1.434	1.099	1.312	0.35	1.84
7-8	1.0	0.041	0.093	0.110	0.137	0.211	0.242	0.321	0.385	0.470	4.608	3.427	3.184	2.868	2.245	2.047	1.639	1.377	1.089	0.985	0.19	1.17
8-9	1.0	0.028	0.091	0.109	0.137	0.213	0.242	0.334	0.395	0.485	5.158	3.458	3.198	2.868	2.231	2.047	1.582	1.340	1.044	1.088	0.23	1.31
9-10	1.0	0.038	0.093	0.112	0.139	0.211	0.242	0.334	0.400	0.492	4.718	3.427	3.158	2.847	2.245	2.047	1.582	1.322	1.023	1.019	0.17	1.20
10-11	1.0	0.037	0.093	0.110	0.137	0.208	0.236	0.321	0.390	0.485	4.756	3.427	3.184	2.868	2.265	2.083	1.639	1.358	1.044	1.019	0.17	1.24
11-12	1.0	0.010	0.079	0.102	0.129	0.208	0.236	0.329	0.397	0.491	6.644	3.662	3.293	2.955	2.265	2.083	1.604	1.333	1.026	1.341	0.30	1.70
Nest N2c																						
0-1	1.0	0.078	0.098	0.113	0.136	0.202	0.227	0.286	0.338	0.444	3.680	3.351	3.146	2.878	2.308	2.139	1.806	1.565	1.171	0.775	0.08	0.96
1-2	1.0	0.079	0.098	0.112	0.136	0.202	0.230	0.290	0.343	0.443	3.662	3.351	3.158	2.878	2.308	2.120	1.786	1.544	1.175	0.781	0.07	0.93
2-3	1.0	0.060	0.093	0.104	0.121	0.173	0.200	0.245	0.305	0.423	4.059	3.427	3.265	3.047	2.531	2.322	2.029	1.713	1.241	0.815	0.02	1.13
3-4	1.0	0.071	0.095	0.107	0.126	0.187	0.216	0.275	0.356	0.449	3.816	3.396	3.224	2.989	2.419	2.211	1.862	1.490	1.155	0.837	-0.01	0.97
4-5	1.0	0.068	0.096	0.107	0.129	0.192	0.218	0.286	0.356	0.452	3.878	3.381	3.224	2.955	2.381	2.198	1.806	1.490	1.146	0.848	0.03	0.98
5-6	1.0	0.072	0.097	0.110	0.134	0.202	0.230	0.315	0.385	0.465	3.796	3.366	3.184	2.900	2.308	2.120	1.667	1.377	1.105	0.860	0.04	0.89
6-7	1.0	0.076	0.098	0.115	0.138	0.198	0.224	0.290	0.361	0.455	3.718	3.351	3.120	2.857	2.336	2.158	1.786	1.470	1.136	0.804	0.01	0.99
7-8	1.0	0.078	0.100	0.115	0.138	0.200	0.226	0.291	0.361	0.455	3.680	3.322	3.120	2.857	2.322	2.146	1.781	1.470	1.136	0.798	0.02	0.97
8-9	1.0	0.090	0.105	0.126	0.147	0.208	0.233	0.297	0.352	0.449	3.474	3.252	2.989	2.766	2.265	2.102	1.751	1.506	1.155	0.722	0.01	0.94
9-10	1.0	0.086	0.102	0.120	0.143	0.210	0.237	0.303	0.361	0.455	3.540	3.293	3.059	2.806	2.252	2.077	1.723	1.470	1.136	0.761	0.04	0.91
10-11	1.0	0.091	0.108	0.127	0.152	0.224	0.258	0.338	0.395	0.467	3.458	3.211	2.977	2.718	2.158	1.955	1.565	1.340	1.099	0.767	0.05	0.84
11-12	1.0	0.091	0.108	0.129	0.155	0.228	0.268	0.356	0.410	0.479	3.458	3.211	2.955	2.690	2.133	1.900	1.490	1.286	1.062	0.780	0.05	0.82
12-13	1.0	0.092	0.113	0.134	0.167	0.252	0.307	0.390	0.437	0.505	3.442	3.146	2.900	2.582	1.989	1.704	1.358	1.194	0.986	0.799	0.13	0.82

Notes:

Grain size distribution calculated from Cumulative Oversize Distribution Curves

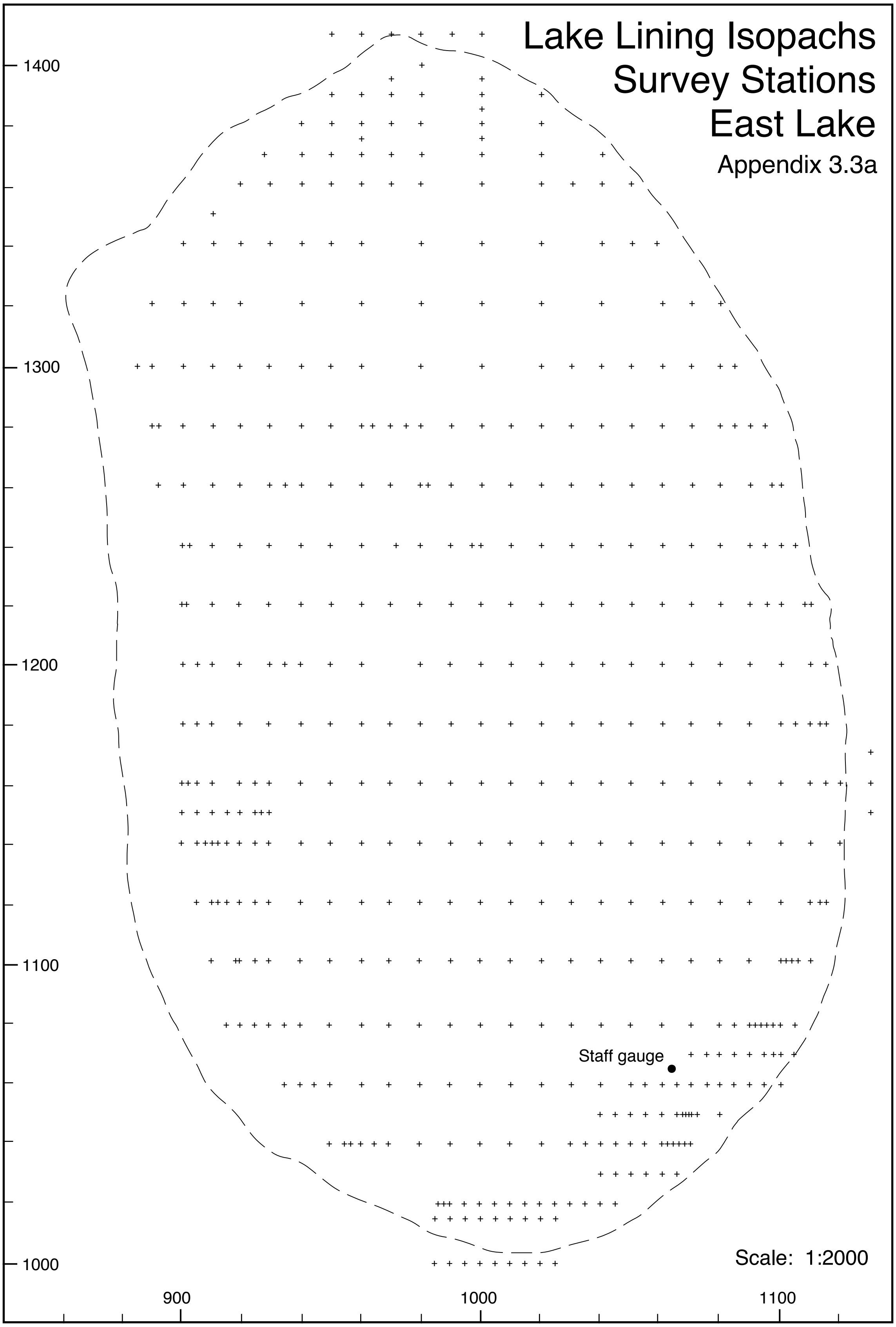
Sieve Stack Apertures: 2.00, 1.00, 0.500, 0.355, 0.250, 0.180, 0.125, 0.090, 0.063mm (-1.0, 0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 Phi units)

Grain Size d-05, d-10 etc is grain diameter such that 5%, 10% by weight of the sediment consists of smaller grains, as calculated from distribution curves

Phi units (ø): - log to base 2 of the grain diameter

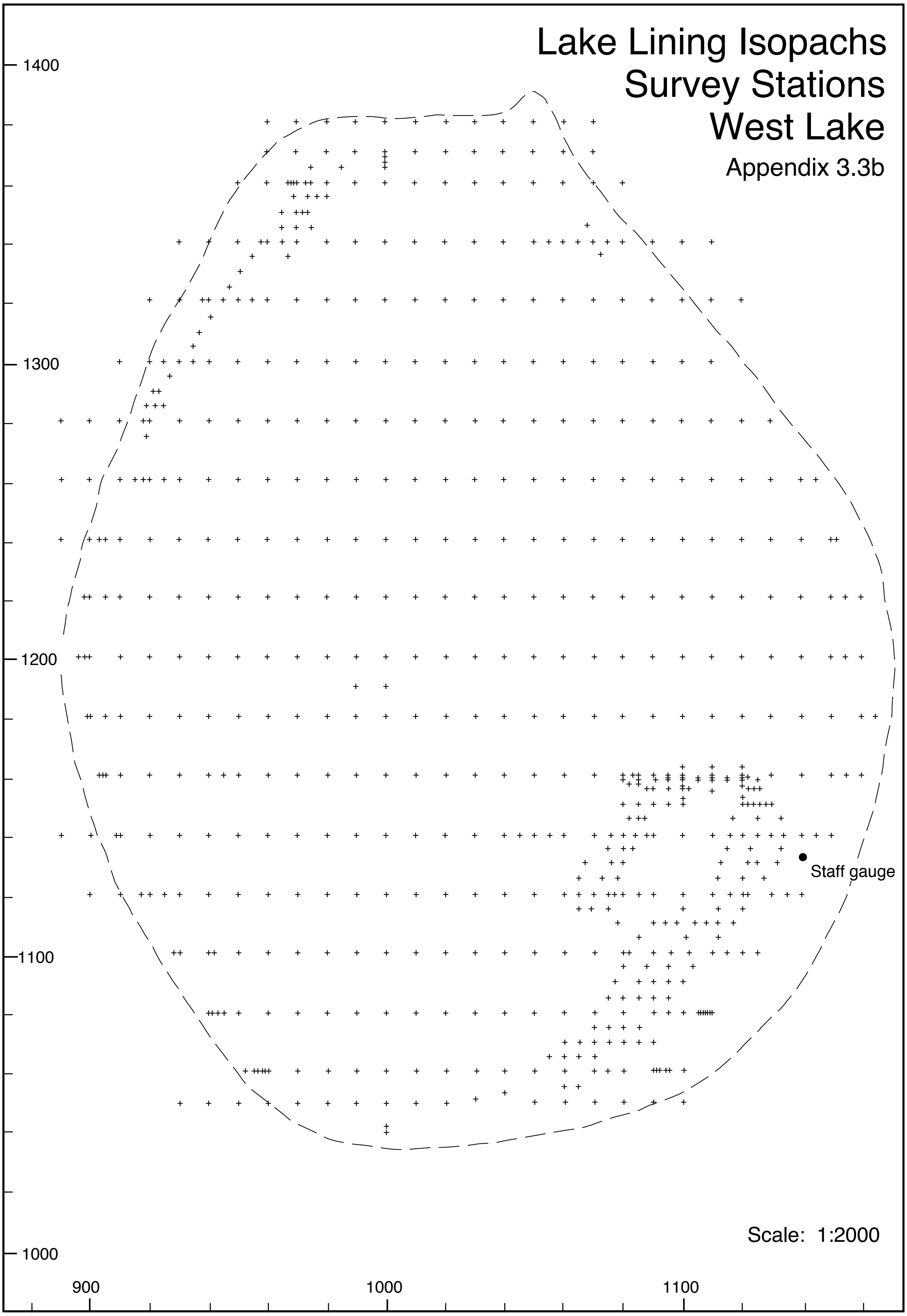
Sorting (standard deviation), Skewness, Kurtosis, all after Folk & Ward (1957)

Depth (m)	Interval	Grain Size Diameter (mm)									Grain Size Diameter (Phi units)											
	(m)	d-05	d-10	d-16	d-25	d-50	d-60	d-75	d-84	d-95	ø5	ø10	ø16	ø25	ø50	ø60	ø75	ø84	ø95	Sorting	Skewness	Kurtosis
Nest N3c																						
0-1	1.0	0.010	0.024	0.043	0.097	0.255	0.303	0.380	0.416	0.473	6.644	5.381	4.540	3.366	1.971	1.723	1.396	1.265	1.080	1.662	0.62	1.16
1-2	1.0	0.132	0.187	0.216	0.258	0.356	0.380	0.421	0.449	0.485	2.921	2.419	2.211	1.955	1.490	1.396	1.248	1.155	1.044	0.548	0.45	1.09
2-3	1.0	0.010	0.040	0.098	0.185	0.305	0.356	0.405	0.438	0.479	6.644	4.644	3.351	2.434	1.713	1.490	1.304	1.191	1.062	1.386	0.64	2.02
3-4	1.0	0.022	0.093	0.121	0.169	0.255	0.294	0.365	0.410	0.473	5.506	3.427	3.047	2.565	1.971	1.766	1.454	1.286	1.080	1.111	0.41	1.63
4-5	1.0	0.012	0.092	0.121	0.173	0.262	0.300	0.366	0.410	0.473	6.381	3.442	3.047	2.531	1.932	1.737	1.450	1.286	1.080	1.243	0.47	2.01
5-6	1.0	0.021	0.091	0.110	0.143	0.225	0.260	0.337	0.390	0.467	5.573	3.458	3.184	2.806	2.152	1.943	1.569	1.358	1.099	1.135	0.33	1.48
6-7	1.0	0.033	0.095	0.117	0.155	0.240	0.279	0.356	0.405	0.473	4.921	3.396	3.095	2.690	2.059	1.842	1.490	1.304	1.080	1.030	0.32	1.31
7-8	1.0	0.010	0.085	0.106	0.136	0.216	0.245	0.317	0.370	0.457	6.644	3.556	3.238	2.878	2.211	2.029	1.657	1.434	1.130	1.286	0.37	1.85
8-9	1.0	0.010	0.084	0.104	0.132	0.213	0.242	0.317	0.375	0.461	6.644	3.573	3.265	2.921	2.231	2.047	1.657	1.415	1.117	1.300	0.36	1.79
9-10	1.0	0.010	0.086	0.104	0.131	0.210	0.242	0.315	0.375	0.462	6.644	3.540	3.265	2.932	2.252	2.047	1.667	1.415	1.114	1.300	0.34	1.79
10-11	1.0	0.015	0.092	0.105	0.129	0.208	0.239	0.315	0.375	0.461	6.059	3.442	3.252	2.955	2.265	2.065	1.667	1.415	1.117	1.208	0.30	1.57
11-12	1.0	0.023	0.092	0.106	0.131	0.210	0.244	0.325	0.385	0.467	5.442	3.442	3.238	2.932	2.252	2.035	1.621	1.377	1.099	1.123	0.26	1.36
12-13	1.0	0.014	0.093	0.108	0.132	0.213	0.245	0.330	0.390	0.469	6.158	3.427	3.211	2.921	2.231	2.029	1.599	1.358	1.092	1.231	0.30	1.57
13-14	1.0	0.015	0.090	0.103	0.127	0.210	0.246	0.334	0.395	0.473	6.059	3.474	3.279	2.977	2.252	2.023	1.582	1.340	1.080	1.239	0.29	1.46
Nest N4c																						
0-1	1.0	0.093	0.173	0.227	0.279	0.375	0.400	0.432	0.455	0.485	3.427	2.531	2.139	1.842	1.415	1.322	1.211	1.136	1.044	0.612	0.57	1.55
1-2	1.0	0.102	0.156	0.202	0.255	0.356	0.380	0.421	0.449	0.485	3.293	2.680	2.308	1.971	1.490	1.396	1.248	1.155	1.044	0.629	0.51	1.27
2-3	1.0	0.096	0.138	0.187	0.230	0.335	0.370	0.416	0.443	0.485	3.381	2.857	2.419	2.120	1.578	1.434	1.265	1.175	1.044	0.665	0.45	1.12
3-4	1.0	0.107	0.165	0.208	0.262	0.370	0.395	0.432	0.455	0.490	3.224	2.599	2.265	1.932	1.434	1.340	1.211	1.136	1.029	0.615	0.55	1.25
4-5	1.0	0.093	0.132	0.182	0.230	0.354	0.380	0.421	0.449	0.485	3.427	2.921	2.458	2.120	1.498	1.396	1.248	1.155	1.044	0.687	0.55	1.12
5-6	1.0	0.097	0.141	0.190	0.236	0.355	0.380	0.422	0.451	0.488	3.366	2.826	2.396	2.083	1.494	1.396	1.245	1.149	1.035	0.665	0.53	1.14
6-7	1.0	0.101	0.150	0.200	0.255	0.372	0.395	0.432	0.456	0.491	3.308	2.737	2.322	1.971	1.427	1.340	1.211	1.133	1.026	0.643	0.58	1.23
7-8	1.0	0.101	0.143	0.187	0.230	0.346	0.377	0.422	0.449	0.488	3.308	2.806	2.419	2.120	1.531	1.407	1.245	1.155	1.035	0.660	0.48	1.06
8-9	1.0	0.096	0.130	0.173	0.213	0.327	0.367	0.412	0.443	0.483	3.381	2.943	2.531	2.231	1.613	1.446	1.279	1.175	1.050	0.692	0.44	1.00
9-10	1.0	0.096	0.129	0.164	0.205	0.313	0.359	0.406	0.440	0.484	3.381	2.955	2.608	2.286	1.676	1.478	1.300	1.184	1.047	0.710	0.39	0.97
10-11	1.0	0.095	0.124	0.156	0.197	0.301	0.354	0.405	0.438	0.480	3.396	3.012	2.680	2.344	1.732	1.498	1.304	1.191	1.059	0.726	0.35	0.92
11-12	1.0	0.093	0.122	0.150	0.192	0.298	0.352	0.405	0.438	0.479	3.427	3.035	2.737	2.381	1.747	1.506	1.304	1.191	1.062	0.745	0.35	0.90
12-13	1.0	0.088	0.113	0.142	0.187	0.292	0.347	0.400	0.438	0.479	3.506	3.146	2.816	2.419	1.776	1.527	1.322	1.191	1.062	0.777	0.35	0.91
13-14	1.0	0.093	0.119	0.147	0.190	0.292	0.347	0.402	0.438	0.480	3.427	3.071	2.766	2.396	1.776	1.527	1.315	1.191	1.059	0.753	0.33	0.90
14.5-15	0.5	0.074	0.113	0.154	0.202	0.343	0.380	0.429	0.461	0.652	3.756	3.146	2.699	2.308	1.544	1.396	1.221	1.117	0.617	0.871	0.44	1.18



East Lake lacustrine sediment isopach contours were generated from 497 soundings. These were made with a stiff 6mm diameter brass rod with a blunt end which penetrated the clays easily but not the basal sands. The rod was 3.5m long. In shallow areas results were checked with a 1.5m hand auger. Survey was completed in summer when the lake was dry apart from the South Basin. This was surveyed from a boat with the water depth subtracted.

Dashed line is 5m surface contour (approximate limit of lake basin)



West Lake lacustrine sediment isopach contours were generated from 646 soundings. These were made with a stiff 6mm diameter brass rod with a blunt end which penetrated the clays easily but not the basal sands. The rod was 3.5m long. In shallow areas results were checked with a 1.5m hand auger. Survey was completed in summer when the lake was dry apart from the residual pond around the staff gauge.

Dashed line is 5m surface contour (approximate limit of lake basin)

Appendix 3:4

Geology and Hydrogeology of the Tamala Limestone

Transmissivity within the Tamala Limestone is extremely variable. Both published and anecdotal data (mostly from local drillers) suggest highly variable aquifer characteristics. Some extremely high transmissivities have been reported. For example, pump tests at the Alcoa Refinery in Kwinana indicate transmissivities of up to 20,000m^2 d^{-1} (Layton Groundwater Consultants 1979). These high transmissivities are believed to reflect zones of karst development and cavernous flow conditions.

Drillers in the City Beach-Ocean Reef area frequently comment that the upper 20m of the aquifer contains thin hard silcrete bands, but is also the most porous zone and often the only zone producing reasonable yields. Below this level it is often difficult to obtain useable flows (M. Davies, W. Brandt pers com). At Jackadder Lake, drill contractors report poor yields in the near surface residual Tamala sands of only 300-400m^3 d^{-1}. In the underlying limestone there is frequently little improvement in yield (K. Wintergreen, pers com). Davidson (1995) notes that the eastern margin of the Tamala Limestone is characterised by finer grained sand and correspondingly lower hydraulic conductivity. The reasons for the extreme variability in flow velocities and aquifer characteristics reflect the geological history of this unit which is summarised below.

Tamala Limestone Geology

The Tamala Limestone is essentially an aeolian deposit, comprising dunes of calcarenite (Playford 1983) along with variable amounts of quartz sand and wind blown shell fragments. Included within it are marine carbonates and grainstones. These include near shore and beach deposits characterised by coarse grained quartz sand and abundant shell fragments, exhibiting varying degrees of carbonate cementation (Klenowski 1975). The Tamala was deposited over a period of at least 100 000 years (Teichert 1967, Playford 1983) and represents numerous periods of dune building under coastal aeolian conditions. Interruptions in the dune building process are marked by prominent soil horizons (Playford 1983) Yellow siliclastic sands overlying the Tamala Limestone have been generally interpreted to represent in situ decalcified limestone (Prider 1948, Lowry 1977) however recent research suggests an aeolian continental provenance representing extensive desert phases co-incident with periods of middle Pleistocene glaciation in higher latitudes (Glassford & Killigrew 1976, Semeniuk & Glassford 1987, Glassford & Semeniuk 1990).

From a hydrological point of view our interest in the Tamala Limestone as an aquifer host is primarily concerned with effective porosity. Drilling through the Tamala confirms numerous alternating hard and soft bands. The soft bands comprise quartz skeletal sands, unconsolidated to weakly cemented at the grain contacts with extensive intergranular porosity. This material is probably typical of Pleistocene aeolian sands world wide which tend to be well sorted (Scholle *et al* 1983). Well sorted sediments approach porosities of 40% obtained experimentally with spheres (Graton & Fraser 1935) and with clastic sediments (Fraser 1935). We would therefore expect that 'typical' limestone will exhibit both high porosity and transmissivity.

Hard bands take a number of forms:

- calcrete, massive to laminar with mm scale banding
- grainstones, in part vuggy comprising quartz and carbonate sand in a carbonate matrix
- vuggy massive limestone, vugs coated with mm scale rims of carbonate

In the Tamala Limestone, zones of reduced porosity and zones of significantly enhanced porosity result from at least three distinct processes:

- carbonate may be dissolved and re-precipitated as dense indurated crusts, a process commonly termed case hardening (Ford & Williams 1989)
- calcrete formation within the vadose zone
- development of distinctive karst topography

Case Hardening

Case hardening is a surface phenomena which imparts a 1-2m thick duricrust which follows the general surface of the ground (Klenowski 1975). Such duricrusts may have porosities as low as 5% (Ford & Williams 1989) while encasing virtually unaltered and still highly porous quartz and carbonate sands. In the Perth area this material contains up to 80% $CaCO_3$ and has been used for making cement and building lime (Playford *et al* 1976). Dune building is a dynamic process. Soil horizons marking interruptions in the dune building process are widespread (Playford 1983). It is likely that many of the hard bands encountered when drilling the Tamala are fossil duricrusts. Within the aquifer their irregular sheet like form and low porosity inhibit vertical groundwater movement. If located at or above the water table, recharge is impeded.

Vadose Zone Processes

The original Tamala calcarenite deposits are generally interpreted to have been decalcified in situ through leaching (Prider 1948, McArthur & Bettenay 1960, Lowry 1977). In this process carbonate is remobilised downwards forming carbonate cemented grainstones at depth and leaving residual quartz sands which may be subsequently reworked. Sub aerial diagenetic processes in calcarenites are highly influenced by climate with greater interstitial porosity resulting from early cementation under arid rather than humid conditions (Ward 1973). Semeniuk & Meagher (1981) describe a variety of calcrete forms which develop in the vadose zone in response to climatic (evaporative) and vegetative (evapotranspirative) processes. Both the water table and proximity to the land surface and vegetation control what sort of calcrete forms. Just as with duricrusts, numerous zones of calcrete may be preserved within the Tamala representing changes in water table level and surface morphology during numerous dune building events.

In the Tamala Park area dense, extremely hard limestone of low porosity is widespread as an undulating sheet up to 3m thick (Cody 1992). Cable tool drillers report extreme difficulties penetrating this material (E. Foley pers com).

Karsting

Karst features include vertical solution pipes, cavities and caves. Solution pipes occur on the scale of centimetres to metres. Where these reach the water table, cave systems may develop. During subsequent erosional cycles the solution pipes frequently become filled and re-cemented, forming pinnacles. Sub aerial weathering, solution and impregnation produces karren structures (Semeniuk & Glassford 1987) which are also referred to as 'pinnacles' by drillers on the Swan Coastal Plain. A buried pinnacle landscape occurs on the south side of Perry Lakes. This was revealed by engineering drilling to investigate the construction of open drains in the 1950's (E. J. Smith pers com).

Cave development in the Tamala Limestone occurred and continues to occur in a geologically youthful material where cementation has done little more than impart weak coherence to what is essentially a carbonate sand. This cementation is the result of dissolution and precipitation of carbonate within the vadose zone. Bastian (1967) describes cave development in the Tamala as a reversal of normal trends. Usually cave formation is initiated along joint planes within competent limestone. In the Tamala however cave development is contemporaneous with the earliest stages of cementation and results in the curious situation where cave development and consolidation of the enveloping rock are occurring simultaneously. Jennings (1968) proposed the concept of *syngenetic karst* development where the same agents are responsible for *simultaneous* lithification and karstification. It is likely that cave development under these conditions can be extremely rapid. In these poorly consolidated sediments, linear cave systems develop readily at the water table and migrate up and down in response to water table variations. Numerous caves and cave systems have been documented within the Perth metropolitan area with the base level of cave development generally lying at or close to the present water table (Playford *et al* 1976). Drillers frequently report cavernous ground well below the water table suggesting fossil karst features from earlier erosional cycles and water table levels. At Tamala Park, approximately 1.5m of dense calcrete coincides with the present water table overlying 6m of cavernous limestone (Cody 1992).

Hydrogeological Summary

Where the superficial aquifer is hosted by Tamala Limestone aquifer characteristics may take one of three general forms:

1: limestone comprising unconsolidated to weakly cemented carbonate and quartz sand will display aquifer characteristics similar to other sand units within the superficial formations but with generally greater hydraulic conductivity.

2: where initial porosity has been destroyed or reduced through duricrusting or vadose zone processes, the limestone may act as an aquitard, inhibiting vertical groundwater movement. Where such limestone comprises a significant portion of the aquifer section overall transmissivity of the aquifer will decrease.

3: limestone containing karst features may exhibit cavernous flow conditions and extremely high transmissivities.

Notes

Murray Davies, Wally Brandt, Kevin Wintergreen and Eddie Foley are all water well drillers operating primarily in the Perth metropolitan area

E. J. Smith was an engineer with the City of Perth

Appendix 3.5

Vertical Hydraulic Conductivity of East Lake Lining Sediments

Sample Collection

Samples were collected in nominal 100mm (107.2mm I.D.) Class 6 PVC storm water pipe. Pipe sections 110cm long were sharpened (bevel out) and driven into sediment using a wooden block and mallet. The clay section was driven until slight deformation was noted indicating commencement of compression in the sample. Driving even sharpened PVC into sand is difficult, 460mm was the maximum depth which could be achieved without shattering the top of the column. A hole was excavated beside each column down to the column base, allowing each column to be removed and fitted with Class 6 PVC pressure caps lined with 53 micron Nytal woven nylon screen and secured with PVC glue. The centre of each cap was threaded and fitted with a quarter inch BSP nipple. No upper caps were used. Instead permeameters were run at extremely small head pressure. Outlet drains consisting of threaded 3mm PVC tube were fitted immediately above the sediment surface. The resulting columns are considered to contain essentially undisturbed vertical sections of lake lining sediment. Details in Figure 1.

Sand Permeameter Methodology

The sand section was saturated slowly (over several hours) from below using de-aired water. It is essential that water is allowed to rise slowly, displacing all interstitial air. The column was run (also using de-aired water) as a falling head permeameter using the formula:

$$K = \frac{A_t L}{A_c t} ln \frac{h_0}{h}$$

where A_t is the reservoir cross sectional area, L is the length of sediment within the permeameter, A_c is the cross sectional area of the permeameter, t is time, and h_0, h the initial and final height of water in the reservoir (above the permeameter outlet). Results are shown in Table 1.

Table 1 Sand permeameter detailed results

Run	Hours	h_0 (cm)	h (cm)	K (m d^{-1})	Run	Hours	h_0 (cm)	h (cm)	K (m d^{-1})
1	2	28.0	24.0	7.16	5a	1	27.5	25.0	8.85
4	1	22.0	19.5	11.20	5b	1	25.0	22.0	11.87
5	3	27.5	19.8	10.17	5c	1	22.0	19.8	9.78
6	10	19.8	7.2	9.39					
			Mean	9.48				Mean	10.17

Clay Permeameter Methodology

The clay section was saturated slowly from below using de-aired water. Approximately 30cm at the base of the section was already saturated being below the standing water table when collected. Approximately 20 days were required for flow to be established using a fixed head of 36cm above the permeameter outlet. The column was run (using de-aired water) as a fixed head permeameter using the formula:

$$K = \frac{VL}{Ath}$$

where V is the volume of water discharging in time t, L is length of sediment section, A is the cross sectional area of the permeameter and h is the reservoir head.

Tests were run in an unheated building during June and July. Minimum run was 12 hours, with readings at 0700 and 1900 hr. The permeameter was run continuously for 27 days with 43 individual reading periods of typically 12 hours. Flows over night were up to 50% of day time flows due to differences in the absolute viscosity of water. Night time and day time data were averaged and corrected to 20˚C using the mean of the daily maximum-minimum air temperatures using the formula:

$$K_{20} = \frac{K_t u_t}{u_{20}}$$

where K_{20} is the hydraulic conductivity at 20˚C, K_t is the hydraulic conductivity at mean temperature *t*, and u_t, u_{20} are the absolute viscosity of water at mean temperature *t* and 20˚C. Data is summarised in Table 2.

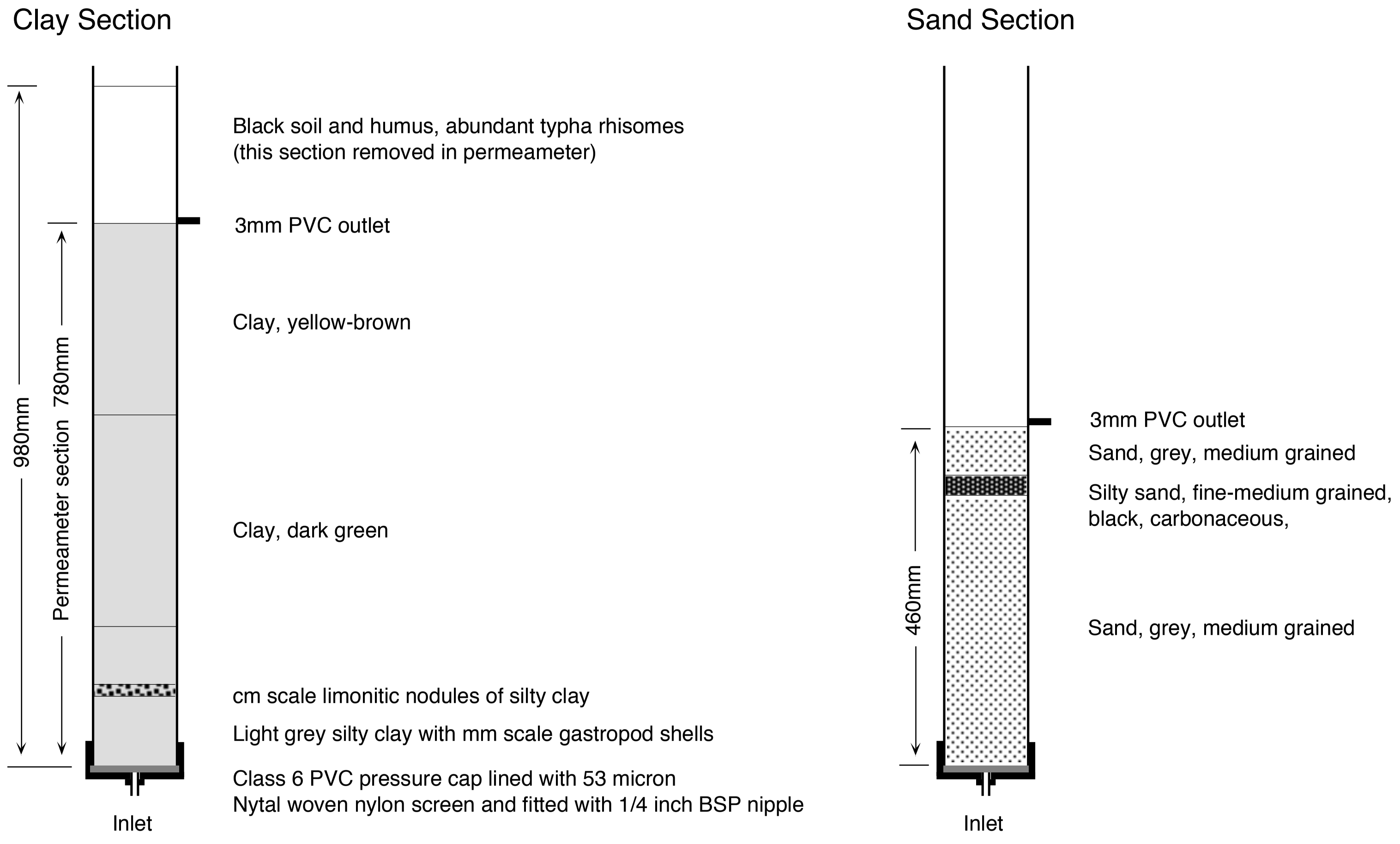
Table 2 East Lake clay lining permeameter test

Day	Time	Hr	Day	Air Min	Temp Max	°C Mean	Viscosity u_t (g cm^{-1} sec^{-1})	Water (cc)	raw K (cm d^{-1})	corr K (cm d^{-1})
June 23	0700	12	0.5	7.1		10.0	0.0001307	17.7	0.850	1.108
	1900	12	0.5					17.3	0.831	
24	0700	12	0.5	2.7	19.1	10.9	0.0001274	18.5	0.888	1.093
	1900	12	0.5					22.0	1.056	
25	0700	12	0.5	3.8	18.8	11.3	0.0001259	13.0	0.624	1.056
	1900	12	0.5					24.5	1.176	
26	0700	12	0.5	8.9	16.2	12.6	0.0001218	17.5	0.840	1.226
	1900	12	0.5					22.5	1.080	
27	0700	12	0.5	6.5	16.9	11.7	0.0001245	13.5	0.648	1.074
29	0700	48	2.0	3.3	16.8	10.1	0.0001303	74.5	0.894	1.163
	1900	12	0.5					20.0	0.960	
30	0700	12	0.5	7.6	14.2	10.9	0.0001274	13.0	0.624	1.007
	1900	12	0.5					25.0	1.200	
July 01	0700	12	0.5	8.8	14.3	11.6	0.0001249	17.0	0.816	1.257
	1900	12	0.5					19.0	0.912	
02	0700	12	0.5	9.8	13.7	11.8	0.0001242	19.5	0.936	1.146
	1900	12	0.5					22.0	1.056	
03	0700	12	0.5	8.3	16.5	12.4	0.0001222	16.0	0.768	1.112
	1900	12	0.5					22.5	1.080	
04	0700	12	0.5	13.2	19.2	16.2	0.0001103	19.5	0.936	1.110
	1900	12	0.5					16.5	0.792	
05	0700	12	0.5	4.6	16.9	10.8	0.0001277	13.5	0.648	0.918
	1900	12	0.5					20.0	0.960	
06	0700	12	0.5	8.9	16.1	12.5	0.0001218	16.5	0.792	1.065
07	0700	24	1.0	0.3	14.1	7.2	0.0001420	31.0	0.744	1.055
	1900	12	0.5					20.0	0.960	
08	0700	12	0.5	4.4	14.1	9.3	0.0001334	16.5	0.792	1.167
	1900	12	0.5					21.5	1.032	
09	0700	12	0.5	4.6	17.1	10.9	0.0001274	13.0	0.624	1.053
	1900	12	0.5					22.5	1.080	
10	0700	12	0.5	4.0	17.7	10.9	0.0001274	17.0	0.816	1.206
13	0700	72	3.0	8.6	17.2	12.9	0.0001205	111.0	0.888	
	1900	12	0.5					19.5	0.936	
14	0700	12	0.5	5.9	16.5	11.2	0.0001263	14.5	0.696	1.029
	1900	12	0.5					19.0	0.912	
15	0700	12	0.5	1.4	18.0	9.7	0.0001319	11.5	0.552	0.964
	1900	12	0.5					20.5	0.984	
16	0700	12	0.5	1.9	17.0	9.5	0.0001327	13.5	0.648	1.081
	1900	12	0.5					19.5	0.936	
17	0700	12	0.5	4.4	18.9	11.7	0.0001245	14.0	0.672	0.999
	1900	12	0.5					21.0	1.008	
18	0700	12	0.5	9.5	18.3	13.9	0.0001172	17.0	0.816	1.067
19	0700	24	1.0	10.2	18.0	14.1	0.0001166	33.0	0.792	0.922
									Mean	1.082

Permeameter Details

Appendix 3.5

Figure 1



Appendix 3.6

Determination of Specific Yield on Lake Sediments

Specific yield was determined on the saturated sand and clay columns after the completion of permeameter tests. Columns were suspended vertically and allowed to drain using the methods of Johnson, Prill & Morris (1963) and Prill, Johnson & Morris (1965). Particular attention was paid to obtaining specific yield for the initial 24 hours which was required for calculating estimates of evapotranspiration using water table fluctuations. Results are summarised in Figures 1 and 2.

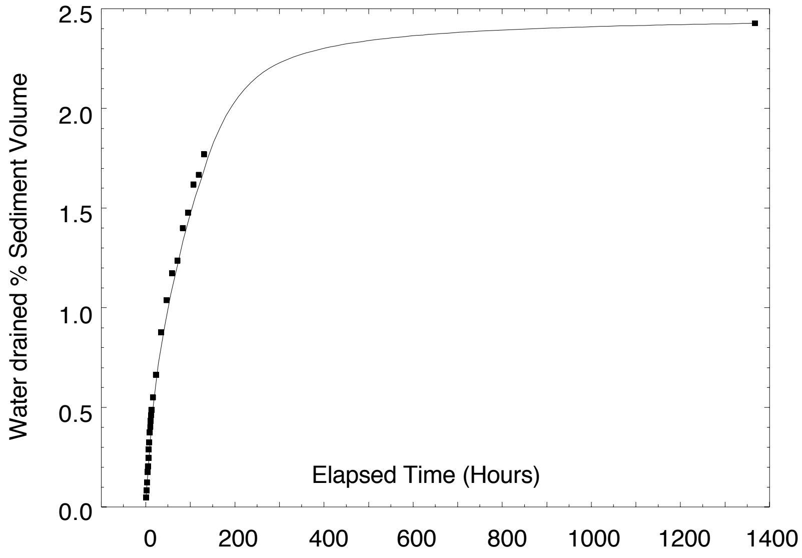


Figure 1: Specific yield lake bed clays, East Lake. Yield at t = 24 hr: 0.692%, Sy 0.0069

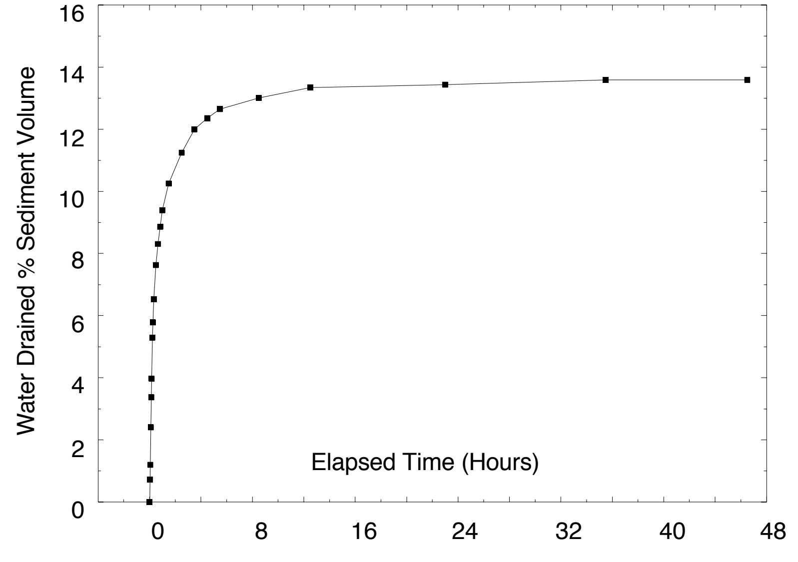
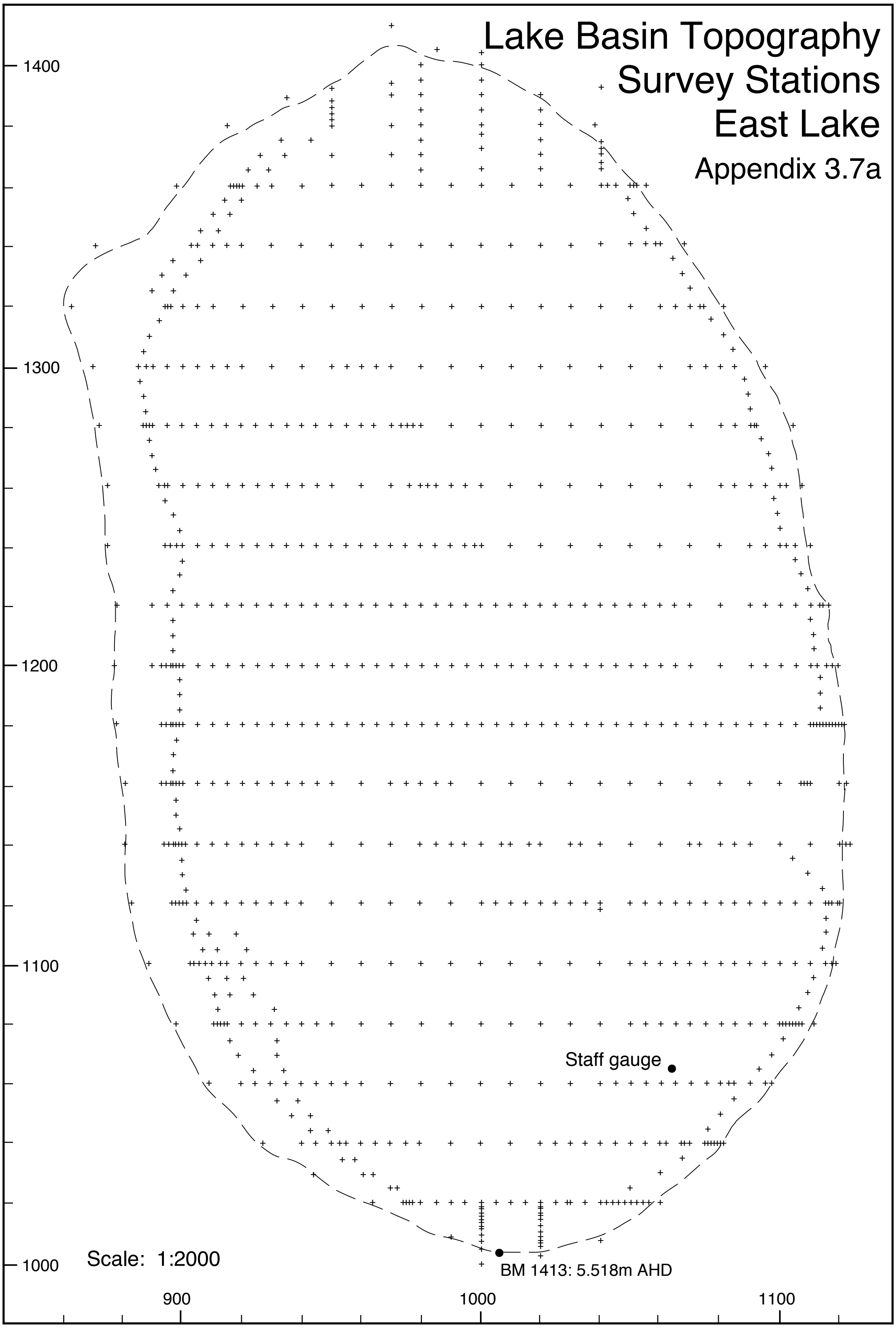


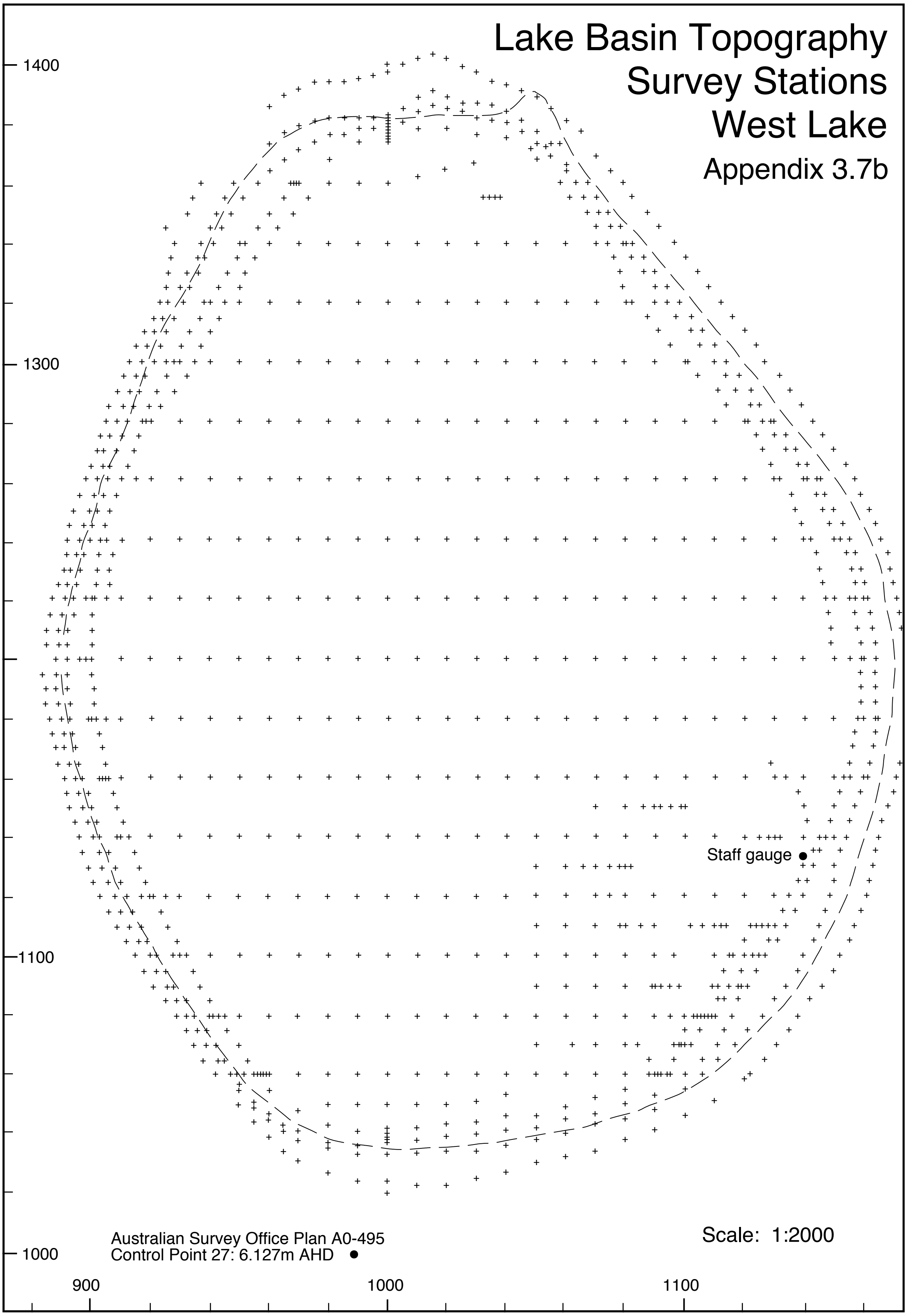
Figure 2: Specific yield, lake bed sands, East Lake. Yield at t = 24 hr: 13.44%, Sy 0.134



Lake Basin Topography
Survey Stations
East Lake
Appendix 3.7a

East Lake basin topography was generated from 1080 survey points. A surveyed local grid was established over the entire basin, lines 20m apart and 10m stations on each line marked with wooden survey pegs. This was done in January 1998 when the lake was dry apart from the South Basin. Temporary pegs were also established in the South Basin. All levels are metres (AHD), tied to bench mark 1413. Height at each station is accurate to +/- 1mm.

Outer basin margin defined by 5m contour (dashed)



West Lake basin topography generated from 1086 survey points. A surveyed local grid was established over the entire basin, lines 20m apart and 10m stations on each line marked with wooden survey pegs. This was done in February 1995 when the lake was dry apart from a small pond around the staff gauge. All levels are metres (AHD), tied to bench mark AO-495, control point 27. Height at each station is accurate to +/- 1mm. Some surveyed points lie outside the boundaries of the map.

Outer basin margin defined by 5m contour (dashed line).

Depth-Area-Volume Data, East Lake

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
2.690	0.03	14.2	2.730	16.5	1068.4	2.770	86.6	2454.2	2.810	220.7	4388.8	2.850	449.9	7110.1
2.691	0.05	18.0	2.731	17.6	1105.6	2.771	89.1	2491.6	2.811	225.1	4448.3	2.851	457.0	7186.0
2.692	0.07	21.9	2.732	18.7	1141.9	2.772	91.6	2529.3	2.812	229.6	4508.9	2.852	464.3	7259.5
2.693	0.09	28.0	2.733	19.8	1176.2	2.773	94.1	2567.4	2.813	234.1	4570.0	2.853	471.6	7331.5
2.694	0.12	35.8	2.734	21.1	1209.2	2.774	96.7	2605.7	2.814	238.7	4632.6	2.854	478.9	7402.8
2.695	0.16	43.7	2.735	22.3	1242.3	2.775	99.3	2644.4	2.815	243.4	4697.5	2.855	486.4	7474.4
2.696	0.21	52.3	2.736	23.6	1275.5	2.776	102.0	2683.3	2.816	248.1	4763.2	2.856	493.9	7546.9
2.697	0.27	61.8	2.737	24.9	1308.4	2.777	104.7	2722.8	2.817	252.9	4830.6	2.857	501.5	7620.0
2.698	0.34	72.5	2.738	26.2	1341.4	2.778	107.4	2762.7	2.818	257.8	4898.3	2.858	509.1	7694.0
2.699	0.41	84.5	2.739	27.5	1374.4	2.779	110.2	2803.1	2.819	262.7	4965.6	2.859	516.9	7770.3
2.700	0.51	98.1	2.740	28.9	1407.3	2.780	113.0	2843.8	2.820	267.7	5034.1	2.860	524.7	7847.6
2.701	0.61	113.6	2.741	30.4	1439.9	2.781	115.9	2885.0	2.821	272.8	5102.2	2.861	532.6	7926.0
2.702	0.73	130.6	2.742	31.8	1472.3	2.782	118.8	2927.0	2.822	277.9	5170.1	2.862	540.5	8006.7
2.703	0.87	149.9	2.743	33.3	1504.5	2.783	121.8	2969.6	2.823	283.1	5238.2	2.863	548.6	8092.9
2.704	1.03	170.9	2.744	34.8	1536.8	2.784	124.8	3012.8	2.824	288.4	5306.7	2.864	556.8	8279.7
2.705	1.21	194.3	2.745	36.4	1569.7	2.785	127.8	3056.8	2.825	293.8	5374.7	2.865	565.1	8414.1
2.706	1.42	220.0	2.746	38.0	1603.7	2.786	130.9	3102.8	2.826	299.2	5443.1	2.866	573.6	8534.0
2.707	1.66	248.7	2.747	39.6	1637.9	2.787	134.0	3150.3	2.827	304.6	5513.6	2.867	582.2	8651.2
2.708	1.92	280.9	2.748	41.2	1672.5	2.788	137.2	3201.2	2.828	310.2	5585.4	2.868	590.9	8773.2
2.709	2.22	315.0	2.749	42.9	1707.4	2.789	140.4	3263.0	2.829	315.8	5656.2	2.869	599.7	8884.3
2.710	2.55	347.6	2.750	44.6	1745.5	2.790	143.7	3322.6	2.830	321.5	5728.1	2.870	608.6	8986.0
2.711	2.91	379.5	2.751	46.4	1781.3	2.791	147.0	3378.5	2.831	327.3	5805.8	2.871	617.7	9081.5
2.712	3.31	411.1	2.752	48.2	1816.5	2.792	150.5	3431.7	2.832	333.1	5877.2	2.872	626.8	9172.7
2.713	3.74	442.8	2.753	50.0	1851.6	2.793	153.9	3484.5	2.833	339.0	5948.9	2.873	636.0	9261.0
2.714	4.19	475.6	2.754	51.9	1886.5	2.794	157.4	3536.9	2.834	345.0	6024.0	2.874	645.3	9346.8
2.715	4.69	509.5	2.755	53.8	1921.2	2.795	161.0	3588.3	2.835	351.1	6095.9	2.875	654.7	9430.2
2.716	5.21	544.2	2.756	55.8	1955.9	2.796	164.6	3640.1	2.836	357.2	6161.7	2.876	664.2	9512.0
2.717	5.78	584.1	2.757	57.7	1990.6	2.797	168.3	3692.2	2.837	363.4	6226.2	2.877	673.7	9591.9
2.718	6.38	625.9	2.758	59.7	2025.3	2.798	172.0	3744.0	2.838	369.7	6290.0	2.878	683.4	9670.3
2.719	7.03	664.1	2.759	61.8	2060.2	2.799	175.8	3795.7	2.839	376.0	6353.7	2.879	693.1	9747.6
2.720	7.71	700.6	2.760	63.9	2095.2	2.800	179.6	3847.5	2.840	382.4	6418.0	2.880	702.9	9823.9
2.721	8.43	735.8	2.761	66.0	2130.4	2.801	183.4	3899.5	2.841	388.8	6483.3	2.881	712.7	9898.9
2.722	9.18	770.6	2.762	68.1	2165.6	2.802	187.4	3952.0	2.842	395.3	6549.2	2.882	722.7	9973.0
2.723	9.97	805.5	2.763	70.3	2200.9	2.803	191.3	4004.7	2.843	401.9	6615.8	2.883	732.7	10046
2.724	10.8	840.7	2.764	72.5	2236.2	2.804	195.4	4057.8	2.844	408.6	6683.3	2.884	742.8	10118
2.725	11.7	876.3	2.765	74.8	2271.8	2.805	199.5	4111.5	2.845	415.3	6750.9	2.885	752.9	10189
2.726	12.6	912.8	2.766	77.1	2307.6	2.806	203.6	4165.8	2.846	422.1	6818.9	2.886	763.1	10259
2.727	13.5	950.1	2.767	79.4	2344.0	2.807	207.8	4220.7	2.847	428.9	6887.4	2.887	773.4	10329
2.728	14.5	990.0	2.768	81.8	2380.5	2.808	212.0	4276.0	2.848	435.8	6959.1	2.888	783.8	10398
2.729	15.5	1030.5	2.769	84.2	2417.3	2.809	216.3	4331.8	2.849	442.8	7032.8	2.889	794.2	10470

Stage AHD	Vol m^3	Area m^2
2.890	804.7	10539
2.891	815.3	10607
2.892	825.9	10676
2.893	836.7	10743
2.894	847.4	10810
2.895	858.3	10877
2.896	869.2	10945
2.897	880.2	11013
2.898	891.2	11086
2.899	902.3	11158
2.900	913.5	11228
2.901	924.7	11296
2.902	936.1	11363
2.903	947.5	11429
2.904	959.0	11495
2.905	970.5	11561
2.906	982.1	11627
2.907	993.8	11692
2.908	1006	11755
2.909	1017	11817
2.910	1029	11878
2.911	1041	11938
2.912	1053	11997
2.913	1065	12056
2.914	1077	12114
2.915	1089	12173
2.916	1102	12232
2.917	1114	12290
2.918	1126	12348
2.919	1138	12406
2.920	1151	12467
2.921	1163	12528
2.922	1176	12589
2.923	1189	12651
2.924	1201	12714
2.925	1214	12778
2.926	1227	12843
2.927	1240	12908
2.928	1253	12972
2.929	1266	13037

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
2.930	1279	13103	2.970	1861	16385	3.010	2615	21969	3.050	3609	27428	3.090	4796	31692	3.130	6132	35025
2.931	1292	13167	2.971	1878	16491	3.011	2637	22156	3.051	3637	27555	3.091	4828	31786	3.131	6167	35108
2.932	1305	13230	2.972	1894	16596	3.012	2659	22332	3.052	3665	27679	3.092	4859	31878	3.132	6202	35186
2.933	1318	13293	2.973	1911	16704	3.013	2681	22495	3.053	3692	27801	3.093	4891	31968	3.133	6237	35264
2.934	1332	13356	2.974	1928	16805	3.014	2704	22660	3.054	3720	27923	3.094	4923	32057	3.134	6272	35344
2.935	1345	13419	2.975	1945	16910	3.015	2727	22822	3.055	3748	28042	3.095	4955	32145	3.135	6308	35425
2.936	1358	13483	2.976	1962	17015	3.016	2750	22983	3.056	3776	28159	3.096	4988	32233	3.136	6343	35507
2.937	1372	13547	2.977	1979	17119	3.017	2773	23140	3.057	3804	28274	3.097	5020	32320	3.137	6379	35586
2.938	1386	13613	2.978	1996	17222	3.018	2796	23292	3.058	3833	28389	3.098	5052	32406	3.138	6414	35665
2.939	1399	13681	2.979	2013	17327	3.019	2819	23441	3.059	3861	28507	3.099	5085	32492	3.139	6450	35742
2.940	1413	13747	2.980	2031	17434	3.020	2843	23587	3.060	3890	28623	3.100	5117	32578	3.140	6486	35818
2.941	1427	13813	2.981	2048	17546	3.021	2866	23729	3.061	3918	28740	3.101	5150	32663	3.141	6522	35893
2.942	1441	13880	2.982	2066	17661	3.022	2890	23869	3.062	3947	28856	3.102	5183	32749	3.142	6558	35969
2.943	1454	13947	2.983	2083	17777	3.023	2914	24010	3.063	3976	28970	3.103	5215	32834	3.143	6594	36045
2.944	1468	14015	2.984	2101	17897	3.024	2938	24150	3.064	4005	29083	3.104	5248	32918	3.144	6630	36121
2.945	1482	14083	2.985	2119	18023	3.025	2962	24290	3.065	4034	29194	3.105	5281	33001	3.145	6666	36197
2.946	1497	14154	2.986	2137	18151	3.026	2987	24430	3.066	4064	29304	3.106	5314	33084	3.146	6702	36275
2.947	1511	14230	2.987	2155	18277	3.027	3011	24565	3.067	4093	29411	3.107	5347	33165	3.147	6738	36349
2.948	1525	14306	2.988	2174	18405	3.028	3036	24697	3.068	4122	29517	3.108	5381	33246	3.148	6775	36420
2.949	1539	14383	2.989	2192	18532	3.029	3061	24827	3.069	4152	29623	3.109	5414	33327	3.149	6811	36491
2.950	1554	14461	2.990	2211	18657	3.030	3086	24959	3.070	4182	29727	3.110	5447	33408	3.150	6848	36561
2.951	1568	14540	2.991	2230	18786	3.031	3111	25091	3.071	4211	29829	3.111	5481	33489	3.151	6884	36630
2.952	1583	14621	2.992	2248	18919	3.032	3136	25221	3.072	4241	29929	3.112	5514	33571	3.152	6921	36699
2.953	1598	14709	2.993	2267	19052	3.033	3161	25349	3.073	4271	30028	3.113	5548	33653	3.153	6958	36768
2.954	1612	14801	2.994	2287	19195	3.034	3186	25474	3.074	4301	30125	3.114	5582	33734	3.154	6995	36837
2.955	1627	14894	2.995	2306	19339	3.035	3212	25596	3.075	4332	30223	3.115	5615	33815	3.155	7032	36905
2.956	1642	14986	2.996	2325	19487	3.036	3238	25715	3.076	4362	30320	3.116	5649	33896	3.156	7068	36973
2.957	1657	15080	2.997	2345	19634	3.037	3263	25834	3.077	4392	30417	3.117	5683	33977	3.157	7105	37041
2.958	1672	15178	2.998	2364	19785	3.038	3289	25951	3.078	4423	30515	3.118	5717	34057	3.158	7143	37109
2.959	1687	15272	2.999	2384	19944	3.039	3315	26069	3.079	4453	30612	3.119	5751	34137	3.159	7180	37177
2.960	1703	15365	3.000	2404	20110	3.040	3341	26186	3.080	4484	30711	3.120	5785	34218	3.160	7217	37244
2.961	1718	15459	3.001	2425	20280	3.041	3368	26304	3.081	4515	30810	3.121	5820	34299	3.161	7254	37313
2.962	1734	15557	3.002	2445	20459	3.042	3394	26423	3.082	4545	30909	3.122	5854	34381	3.162	7292	37381
2.963	1749	15656	3.003	2465	20647	3.043	3421	26544	3.083	4576	31008	3.123	5888	34463	3.163	7329	37448
2.964	1765	15758	3.004	2486	20832	3.044	3447	26665	3.084	4607	31107	3.124	5923	34543	3.164	7366	37516
2.965	1781	15863	3.005	2507	21018	3.045	3474	26794	3.085	4639	31205	3.125	5958	34623	3.165	7404	37583
2.966	1797	15966	3.006	2528	21204	3.046	3501	26918	3.086	4670	31302	3.126	5992	34703	3.166	7442	37650
2.967	1813	16070	3.007	2550	21396	3.047	3528	27046	3.087	4701	31399	3.127	6027	34783	3.167	7479	37718
2.968	1829	16172	3.008	2571	21593	3.048	3555	27174	3.088	4733	31498	3.128	6062	34863	3.168	7517	37787
2.969	1845	16279	3.009	2593	21783	3.049	3582	27302	3.089	4764	31597	3.129	6097	34943	3.169	7555	37855

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
3.170	7593	37923	3.210	9163	40608	3.250	10850	43688	3.290	12650	46315	3.330	14558	49075	3.370	16569	51415
3.171	7631	37991	3.211	9204	40683	3.251	10894	43755	3.291	12696	46387	3.331	14607	49138	3.371	16620	51473
3.172	7669	38059	3.212	9244	40759	3.252	10938	43822	3.292	12742	46458	3.332	14656	49201	3.372	16672	51532
3.173	7707	38128	3.213	9285	40835	3.253	10981	43889	3.293	12789	46526	3.333	14706	49264	3.373	16723	51591
3.174	7745	38198	3.214	9326	40912	3.254	11025	43955	3.294	12835	46594	3.334	14755	49326	3.374	16775	51649
3.175	7783	38266	3.215	9367	40988	3.255	11069	44021	3.295	12882	46662	3.335	14804	49387	3.375	16827	51709
3.176	7821	38334	3.216	9408	41066	3.256	11113	44085	3.296	12929	46730	3.336	14854	49447	3.376	16878	51770
3.177	7860	38400	3.217	9449	41144	3.257	11158	44150	3.297	12975	46798	3.337	14903	49508	3.377	16930	51826
3.178	7898	38466	3.218	9490	41225	3.258	11202	44214	3.298	13022	46866	3.338	14953	49568	3.378	16982	51883
3.179	7937	38531	3.219	9532	41311	3.259	11246	44278	3.299	13069	46934	3.339	15002	49628	3.379	17034	51939
3.180	7975	38596	3.220	9573	41400	3.260	11290	44341	3.300	13116	47004	3.340	15052	49688	3.380	17086	51996
3.181	8014	38661	3.221	9614	41484	3.261	11335	44404	3.301	13163	47075	3.341	15102	49747	3.381	17138	52053
3.182	8053	38726	3.222	9656	41564	3.262	11379	44468	3.302	13210	47144	3.342	15152	49807	3.382	17190	52109
3.183	8091	38791	3.223	9697	41644	3.263	11424	44532	3.303	13257	47214	3.343	15201	49866	3.383	17242	52166
3.184	8130	38856	3.224	9739	41724	3.264	11468	44596	3.304	13305	47284	3.344	15251	49926	3.384	17294	52224
3.185	8169	38921	3.225	9781	41803	3.265	11513	44659	3.305	13352	47355	3.345	15301	49985	3.385	17347	52282
3.186	8208	38986	3.226	9823	41882	3.266	11557	44723	3.306	13399	47427	3.346	15351	50045	3.386	17399	52340
3.187	8247	39051	3.227	9865	41961	3.267	11602	44786	3.307	13447	47500	3.347	15401	50104	3.387	17451	52400
3.188	8286	39117	3.228	9907	42039	3.268	11647	44850	3.308	13494	47575	3.348	15451	50163	3.388	17504	52463
3.189	8325	39183	3.229	9949	42117	3.269	11692	44913	3.309	13542	47651	3.349	15502	50221	3.389	17556	52529
3.190	8365	39251	3.230	9991	42194	3.270	11737	44977	3.310	13590	47725	3.350	15552	50280	3.390	17609	52598
3.191	8404	39319	3.231	10033	42271	3.271	11782	45041	3.311	13638	47799	3.351	15602	50338	3.391	17661	52672
3.192	8443	39385	3.232	10075	42348	3.272	11827	45106	3.312	13685	47873	3.352	15653	50395	3.392	17714	52753
3.193	8483	39451	3.233	10118	42424	3.273	11872	45172	3.313	13733	47946	3.353	15703	50453	3.393	17767	52839
3.194	8522	39517	3.234	10160	42500	3.274	11917	45237	3.314	13781	48019	3.354	15753	50510	3.394	17820	52931
3.195	8562	39583	3.235	10203	42577	3.275	11963	45302	3.315	13829	48091	3.355	15804	50567	3.395	17873	53023
3.196	8601	39649	3.236	10245	42655	3.276	12008	45367	3.316	13877	48161	3.356	15855	50623	3.396	17926	53116
3.197	8641	39716	3.237	10288	42732	3.277	12053	45432	3.317	13926	48231	3.357	15905	50679	3.397	17979	53204
3.198	8681	39783	3.238	10331	42809	3.278	12099	45498	3.318	13974	48300	3.358	15956	50736	3.398	18032	53287
3.199	8721	39850	3.239	10374	42886	3.279	12144	45563	3.319	14022	48369	3.359	16007	50792	3.399	18086	53366
3.200	8760	39917	3.240	10417	42963	3.280	12190	45629	3.320	14071	48436	3.360	16058	50848	3.400	18139	53441
3.201	8800	39984	3.241	10460	43043	3.281	12236	45695	3.321	14119	48503	3.361	16108	50904	3.401	18192	53515
3.202	8840	40052	3.242	10503	43119	3.282	12281	45762	3.322	14168	48568	3.362	16159	50961	3.402	18246	53580
3.203	8880	40119	3.243	10546	43192	3.283	12327	45829	3.323	14216	48632	3.363	16210	51017	3.403	18300	53644
3.204	8921	40187	3.244	10589	43265	3.284	12373	45897	3.324	14265	48696	3.364	16261	51073	3.404	18353	53707
3.205	8961	40254	3.245	10632	43337	3.285	12419	45966	3.325	14314	48760	3.365	16312	51129	3.405	18407	53771
3.206	9001	40323	3.246	10676	43409	3.286	12465	46035	3.326	14362	48823	3.366	16364	51185	3.406	18461	53831
3.207	9041	40394	3.247	10719	43479	3.287	12511	46104	3.327	14411	48886	3.367	16415	51241	3.407	18515	53889
3.208	9082	40465	3.248	10763	43550	3.288	12557	46173	3.328	14460	48949	3.368	16466	51298	3.408	18569	53945
3.209	9122	40536	3.249	10806	43619	3.289	12603	46243	3.329	14509	49013	3.369	16517	51356	3.409	18623	54000

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
3.410	18677	54055	3.450	20877	55906	3.490	23149	57724	3.530	25499	59643	3.570	27923	61779	3.650	33159	67575
3.411	18731	54109	3.451	20933	55948	3.491	23207	57771	3.531	25558	59684	3.571	27985	61873	3.655	33497	67670
3.412	18785	54163	3.452	20989	55991	3.492	23265	57819	3.532	25618	59725	3.572	28047	61984	3.660	33835	67753
3.413	18839	54214	3.453	21045	56034	3.493	23323	57868	3.533	25678	59766	3.573	28109	62082	3.665	34174	67828
3.414	18893	54264	3.454	21101	56077	3.494	23381	57918	3.534	25738	59808	3.574	28171	62176	3.670	34514	67888
3.415	18948	54314	3.455	21157	56120	3.495	23438	57969	3.535	25798	59850	3.575	28233	62269	3.675	34853	67947
3.416	19002	54363	3.456	21213	56163	3.496	23496	58020	3.536	25857	59892	3.576	28295	62361	3.680	35193	68006
3.417	19056	54412	3.457	21270	56206	3.497	23555	58071	3.537	25917	59935	3.577	28358	62451	3.685	35533	68065
3.418	19111	54461	3.458	21326	56249	3.498	23613	58122	3.538	25977	59978	3.578	28420	62545	3.690	35874	68123
3.419	19165	54510	3.459	21382	56293	3.499	23671	58174	3.539	26037	60022	3.579	28483	62642	3.695	36215	68181
3.420	19220	54558	3.460	21438	56337	3.500	23729	58226	3.540	26097	60065	3.580	28546	62743	3.700	36556	68238
3.421	19274	54605	3.461	21495	56382	3.501	23787	58279	3.541	26157	60110	3.581	28608	62847	3.705	36897	68295
3.422	19329	54652	3.462	21551	56428	3.502	23846	58334	3.542	26218	60156	3.582	28671	62955	3.710	37239	68352
3.423	19384	54699	3.463	21608	56474	3.503	23904	58389	3.543	26278	60205	3.583	28734	63076	3.715	37580	68408
3.424	19438	54746	3.464	21664	56522	3.504	23962	58447	3.544	26338	60255	3.584	28797	63207	3.720	37923	68464
3.425	19493	54793	3.465	21721	56571	3.505	24021	58511	3.545	26398	60310	3.585	28861	63344	3.725	38265	68519
3.426	19547	54840	3.466	21777	56617	3.506	24079	58581	3.546	26459	60363	3.586	28924	63466	3.730	38608	68574
3.427	19603	54887	3.467	21834	56663	3.507	24138	58648	3.547	26519	60416	3.587	28988	63587	3.735	38951	68629
3.428	19658	54935	3.468	21891	56709	3.508	24197	58713	3.548	26579	60471	3.588	29051	63711	3.740	39294	68683
3.429	19713	54984	3.469	21947	56754	3.509	24255	58761	3.549	26640	60526	3.589	29115	63838	3.745	39638	68738
3.430	19768	55036	3.470	22004	56800	3.510	24314	58809	3.550	26700	60580	3.590	29179	63959	3.750	39981	68792
3.431	19823	55085	3.471	22060	56845	3.511	24373	58857	3.551	26761	60631	3.591	29243	64092	3.755	40326	68845
3.432	19878	55133	3.472	22118	56890	3.512	24432	58901	3.552	26822	60684	3.592	29307	64215	3.760	40670	68899
3.433	19933	55178	3.473	22175	56935	3.513	24491	58945	3.553	26882	60736	3.593	29371	64338	3.765	41015	68952
3.434	19988	55221	3.474	22232	56980	3.514	24550	58987	3.554	26943	60789	3.594	29436	64465	3.770	41359	69005
3.435	20043	55265	3.475	22289	57025	3.515	24609	59030	3.555	27004	60842	3.595	29500	64596	3.775	41705	69058
3.436	20099	55308	3.476	22346	57070	3.516	24668	59072	3.556	27065	60895	3.596	29565	64713	3.780	42050	69110
3.437	20154	55351	3.477	22403	57115	3.517	24727	59115	3.557	27126	60947	3.597	29630	64822	3.785	42396	69163
3.438	20209	55395	3.478	22460	57161	3.518	24786	59155	3.558	27187	60999	3.598	29695	64925	3.790	42742	69215
3.439	20265	55438	3.479	22517	57207	3.519	24845	59195	3.559	27248	61051	3.599	29760	65024	3.795	43088	69267
3.440	20320	55481	3.480	22574	57254	3.520	24904	59236	3.560	27309	61103	3.600	29825	65122	3.800	43434	69318
3.441	20376	55523	3.481	22632	57301	3.521	24964	59277	3.561	27370	61155	3.605	30152	65593	3.805	43781	69370
3.442	20431	55566	3.482	22689	57347	3.522	25023	59318	3.562	27431	61209	3.610	30481	65994	3.810	44128	69421
3.443	20487	55608	3.483	22746	57393	3.523	25082	59359	3.563	27492	61269	3.615	30811	66300	3.815	44475	69473
3.444	20543	55651	3.484	22804	57439	3.524	25142	59400	3.564	27554	61331	3.620	31144	66598	3.820	44823	69524
3.445	20598	55694	3.485	22861	57486	3.525	25201	59441	3.565	27615	61397	3.625	31477	66881	3.825	45171	69576
3.446	20654	55736	3.486	22919	57533	3.526	25261	59481	3.566	27677	61466	3.630	31812	67056	3.830	45519	69627
3.447	20710	55778	3.487	22976	57581	3.527	25320	59522	3.567	27738	61539	3.635	32148	67202	3.835	45867	69679
3.448	20766	55821	3.488	23034	57628	3.528	25380	59563	3.568	27800	61615	3.640	32484	67340	3.840	46215	69731
3.449	20821	55863	3.489	23092	57676	3.529	25439	59603	3.569	27861	61693	3.645	32821	67468	3.845	46564	69782

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
3.850	46913	69835	4.100	64691	72391	4.500	94498	76642	4.900	126165	82174
3.855	47262	69887	4.110	65415	72497	4.510	95265	76757	4.910	126988	82348
3.860	47612	69939	4.120	66140	72605	4.520	96033	76871	4.920	127812	82523
3.865	47962	69991	4.130	66867	72711	4.530	96802	76986	4.930	128639	82706
3.870	48312	70042	4.140	67595	72826	4.540	97573	77101	4.940	129467	82898
3.875	48662	70093	4.150	68324	72944	4.550	98345	77216	4.950	130297	83098
3.880	49013	70144	4.160	69054	73061	4.560	99117	77332	4.960	131129	83299
3.885	49364	70195	4.170	69785	73173	4.570	99891	77447	4.970	131962	83497
3.890	49715	70246	4.180	70517	73281	4.580	100666	77564	4.980	132798	83699
3.895	50066	70298	4.190	71250	73386	4.590	101442	77681	4.990	133637	83909
3.900	50418	70351	4.200	71985	73488	4.600	102220	77800	5.000	134477	84120
3.905	50770	70403	4.210	72720	73589	4.610	102998	77919			
3.910	51122	70454	4.220	73457	73691	4.620	103778	78040			
3.915	51474	70505	4.230	74194	73794	4.630	104559	78163			
3.920	51827	70556	4.240	74932	73896	4.640	105341	78287			
3.925	52180	70607	4.250	75672	74000	4.650	106125	78411			
3.930	52533	70657	4.260	76412	74103	4.660	106910	78535			
3.935	52886	70707	4.270	77154	74206	4.670	107696	78661			
3.940	53240	70757	4.280	77897	74310	4.680	108483	78789			
3.945	53594	70807	4.290	78640	74418	4.690	109271	78916			
3.950	53948	70857	4.300	79385	74523	4.700	110061	79044			
3.955	54302	70907	4.310	80131	74626	4.710	110852	79175			
3.960	54657	70957	4.320	80877	74728	4.720	111645	79308			
3.965	55012	71007	4.330	81625	74830	4.730	112438	79443			
3.970	55367	71057	4.340	82374	74933	4.740	113233	79580			
3.975	55723	71107	4.350	83124	75036	4.750	114030	79725			
3.980	56078	71157	4.360	83875	75139	4.760	114828	79868			
3.985	56434	71207	4.370	84627	75243	4.770	115627	80018			
3.990	56790	71257	4.380	85380	75347	4.780	116428	80170			
3.995	57147	71307	4.390	86134	75452	4.790	117231	80322			
4.000	57503	71357	4.400	86889	75557	4.800	118035	80478			
4.010	58217	71458	4.410	87645	75663	4.810	118840	80635			
4.020	58932	71560	4.420	88402	75770	4.820	119647	80795			
4.030	59648	71662	4.430	89160	75877	4.830	120456	80956			
4.040	60366	71765	4.440	89919	75984	4.840	121267	81121			
4.050	61084	71869	4.450	90680	76092	4.850	122079	81297			
4.060	61803	71974	4.460	91441	76200	4.860	122893	81474			
4.070	62523	72078	4.470	92204	76309	4.870	123708	81647			
4.080	63245	72183	4.480	92967	76418	4.880	124526	81821			
4.090	63967	72287	4.490	93732	76530	4.890	125345	81995			

Depth-Area-Volume Data, West Lake

Appendix 3.8b

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
			2.250	0.275	14.6	2.290	1.140	28.7	2.330	2.581	43.5	2.370	4.647	60.2	2.410	7.453	80.5
			2.251	0.290	15.0	2.291	1.169	29.0	2.331	2.625	43.9	2.371	4.707	60.6	2.411	7.533	81.0
			2.252	0.305	15.3	2.292	1.198	29.4	2.332	2.669	44.3	2.372	4.768	61.1	2.412	7.615	81.5
2.213	0.000	0.00	2.253	0.320	15.7	2.293	1.227	29.8	2.333	2.713	44.7	2.373	4.829	61.6	2.413	7.696	82.0
2.214	0.000	0.34	2.254	0.336	16.0	2.294	1.257	30.1	2.334	2.758	45.1	2.374	4.891	62.0	2.414	7.779	82.6
2.215	0.001	0.68	2.255	0.352	16.4	2.295	1.288	30.5	2.335	2.803	45.5	2.375	4.953	62.5	2.415	7.862	83.1
2.216	0.002	1.04	2.256	0.369	16.8	2.296	1.318	30.8	2.336	2.849	45.9	2.376	5.016	63.0	2.416	7.945	83.6
2.217	0.003	1.41	2.257	0.386	17.1	2.297	1.349	31.2	2.337	2.895	46.3	2.377	5.079	63.5	2.417	8.029	84.1
2.218	0.004	1.78	2.258	0.403	17.5	2.298	1.381	31.6	2.338	2.942	46.7	2.378	5.143	64.0	2.418	8.113	84.7
2.219	0.006	2.17	2.259	0.421	17.8	2.299	1.413	31.9	2.339	2.988	47.1	2.379	5.207	64.5	2.419	8.198	85.2
2.220	0.009	2.57	2.260	0.439	18.2	2.300	1.445	32.3	2.340	3.036	47.5	2.380	5.272	65.0	2.420	8.284	85.7
2.221	0.011	2.97	2.261	0.457	18.6	2.301	1.477	32.7	2.341	3.083	47.9	2.381	5.338	65.5	2.421	8.370	86.3
2.222	0.015	3.39	2.262	0.476	18.9	2.302	1.510	33.0	2.342	3.131	48.3	2.382	5.403	66.0	2.422	8.456	86.8
2.223	0.018	3.81	2.263	0.495	19.2	2.303	1.543	33.4	2.343	3.180	48.7	2.383	5.470	66.5	2.423	8.543	87.3
2.224	0.022	4.25	2.264	0.515	19.6	2.304	1.577	33.8	2.344	3.229	49.1	2.384	5.536	67.0	2.424	8.631	87.9
2.225	0.027	4.70	2.265	0.534	19.9	2.305	1.611	34.1	2.345	3.278	49.5	2.385	5.604	67.5	2.425	8.719	88.4
2.226	0.032	5.15	2.266	0.554	20.2	2.306	1.645	34.5	2.346	3.328	49.9	2.386	5.671	68.0	2.426	8.808	88.9
2.227	0.037	5.61	2.267	0.575	20.6	2.307	1.680	34.9	2.347	3.378	50.3	2.387	5.740	68.5	2.427	8.897	89.4
2.228	0.043	6.07	2.268	0.595	20.9	2.308	1.715	35.3	2.348	3.428	50.7	2.388	5.808	69.1	2.428	8.986	90.0
2.229	0.049	6.52	2.269	0.617	21.3	2.309	1.750	35.6	2.349	3.479	51.1	2.389	5.878	69.6	2.429	9.077	90.5
2.230	0.056	6.97	2.270	0.638	21.6	2.310	1.786	36.0	2.350	3.530	51.5	2.390	5.948	70.1	2.430	9.167	91.0
2.231	0.063	7.41	2.271	0.660	21.9	2.311	1.822	36.4	2.351	3.582	52.0	2.391	6.018	70.6	2.431	9.259	91.6
2.232	0.071	7.84	2.272	0.682	22.3	2.312	1.859	36.7	2.352	3.634	52.4	2.392	6.089	71.1	2.432	9.351	92.3
2.233	0.079	8.27	2.273	0.704	22.6	2.313	1.896	37.1	2.353	3.687	52.8	2.393	6.160	71.6	2.433	9.443	93.3
2.234	0.087	8.68	2.274	0.727	23.0	2.314	1.933	37.5	2.354	3.740	53.2	2.394	6.232	72.1	2.434	9.537	94.5
2.235	0.096	9.10	2.275	0.750	23.3	2.315	1.971	37.8	2.355	3.793	53.7	2.395	6.304	72.7	2.435	9.632	95.5
2.236	0.105	9.50	2.276	0.774	23.7	2.316	2.009	38.2	2.356	3.847	54.1	2.396	6.377	73.2	2.436	9.728	96.6
2.237	0.115	9.90	2.277	0.798	24.0	2.317	2.047	38.6	2.357	3.902	54.5	2.397	6.451	73.7	2.437	9.825	97.5
2.238	0.125	10.3	2.278	0.822	24.4	2.318	2.086	39.0	2.358	3.956	54.9	2.398	6.525	74.2	2.438	9.923	98.4
2.239	0.135	10.7	2.279	0.846	24.7	2.319	2.125	39.3	2.359	4.011	55.4	2.399	6.599	74.7	2.439	10.022	99.3
2.240	0.146	11.1	2.280	0.871	25.1	2.320	2.165	39.7	2.360	4.067	55.8	2.400	6.674	75.2	2.440	10.122	100.1
2.241	0.157	11.4	2.281	0.896	25.4	2.321	2.205	40.1	2.361	4.123	56.2	2.401	6.750	75.8	2.441	10.222	100.9
2.242	0.169	11.8	2.282	0.922	25.8	2.322	2.245	40.5	2.362	4.179	56.7	2.402	6.826	76.3	2.442	10.324	101.7
2.243	0.181	12.2	2.283	0.948	26.1	2.323	2.285	40.9	2.363	4.236	57.1	2.403	6.902	76.8	2.443	10.426	102.5
2.244	0.193	12.5	2.284	0.974	26.5	2.324	2.327	41.2	2.364	4.294	57.5	2.404	6.979	77.3	2.444	10.529	103.3
2.245	0.206	12.9	2.285	1.001	26.9	2.325	2.368	41.6	2.365	4.351	58.0	2.405	7.057	77.8	2.445	10.632	104.1
2.246	0.219	13.2	2.286	1.028	27.2	2.326	2.410	42.0	2.366	4.410	58.4	2.406	7.135	78.4	2.446	10.737	104.9
2.247	0.233	13.6	2.287	1.055	27.6	2.327	2.452	42.4	2.367	4.468	58.8	2.407	7.214	78.9	2.447	10.842	105.8
2.248	0.246	13.9	2.288	1.083	27.9	2.328	2.495	42.8	2.368	4.527	59.3	2.408	7.293	79.4	2.448	10.948	106.6
2.249	0.261	14.3	2.289	1.111	28.3	2.329	2.537	43.1	2.369	4.587	59.7	2.409	7.373	79.9	2.449	11.06	107.4

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
2.450	11.16	108.3	2.490	16.26	158.6	2.530	24.92	291.3	2.570	39.97	465.1	2.610	62.16	651.2	2.650	93.14	901.0
2.451	11.27	109.1	2.491	16.42	162.0	2.531	25.21	295.6	2.571	40.44	469.4	2.611	62.81	656.7	2.651	94.04	906.6
2.452	11.38	109.9	2.492	16.58	165.5	2.532	25.51	300.1	2.572	40.91	473.7	2.612	63.47	662.2	2.652	94.95	912.1
2.453	11.49	110.8	2.493	16.75	168.9	2.533	25.82	304.7	2.573	41.38	477.9	2.613	64.13	667.8	2.653	95.86	917.6
2.454	11.60	111.6	2.494	16.92	171.9	2.534	26.12	309.2	2.574	41.86	482.1	2.614	64.81	673.4	2.654	96.78	923.1
2.455	11.72	112.5	2.495	17.09	174.2	2.535	26.43	313.4	2.575	42.35	486.3	2.615	65.48	679.2	2.655	97.71	928.6
2.456	11.83	113.4	2.496	17.27	176.5	2.536	26.75	317.6	2.576	42.84	490.5	2.616	66.16	685.1	2.656	98.64	934.0
2.457	11.94	114.2	2.497	17.45	178.8	2.537	27.07	321.5	2.577	43.33	494.8	2.617	66.85	691.5	2.657	99.58	939.4
2.458	12.06	115.1	2.498	17.63	181.0	2.538	27.39	325.4	2.578	43.83	499.1	2.618	67.55	697.7	2.658	100.5	944.7
2.459	12.17	116.0	2.499	17.81	183.3	2.539	27.72	329.3	2.579	44.33	503.4	2.619	68.25	704.0	2.659	101.5	950.1
2.460	12.29	116.9	2.500	17.99	185.6	2.540	28.05	333.2	2.580	44.83	507.7	2.620	68.95	710.2	2.660	102.4	955.4
2.461	12.41	117.8	2.501	18.18	187.9	2.541	28.39	337.2	2.581	45.34	512.1	2.621	69.67	716.3	2.661	103.4	960.7
2.462	12.52	118.7	2.502	18.37	190.3	2.542	28.72	341.1	2.582	45.86	516.6	2.622	70.39	722.4	2.662	104.3	966.1
2.463	12.64	119.6	2.503	18.56	192.6	2.543	29.07	345.1	2.583	46.38	521.0	2.623	71.11	728.4	2.663	105.3	971.4
2.464	12.76	120.5	2.504	18.75	194.9	2.544	29.41	349.1	2.584	46.90	525.6	2.624	71.84	734.4	2.664	106.3	976.7
2.465	12.88	121.4	2.505	18.94	197.3	2.545	29.77	353.2	2.585	47.43	530.1	2.625	72.58	740.4	2.665	107.3	982.1
2.466	13.01	122.3	2.506	19.15	199.6	2.546	30.12	357.3	2.586	47.96	534.8	2.626	73.32	746.4	2.666	108.2	987.7
2.467	13.13	123.2	2.507	19.35	202.0	2.547	30.48	361.4	2.587	48.50	539.4	2.627	74.07	752.5	2.667	109.2	993.7
2.468	13.25	124.1	2.508	19.55	204.4	2.548	30.84	365.6	2.588	49.04	544.1	2.628	74.83	758.6	2.668	110.2	1000.1
2.469	13.38	125.0	2.509	19.76	206.8	2.549	31.21	369.8	2.589	49.59	548.9	2.629	75.59	765.0	2.669	111.2	1006.8
2.470	13.50	125.9	2.510	19.97	209.2	2.550	31.58	374.0	2.590	50.14	553.7	2.630	76.36	771.7	2.670	112.2	1013.9
2.471	13.63	126.8	2.511	20.18	211.7	2.551	31.96	378.2	2.591	50.69	558.5	2.631	77.14	778.3	2.671	113.3	1021.0
2.472	13.76	127.7	2.512	20.39	214.5	2.552	32.34	382.6	2.592	51.25	563.1	2.632	77.92	784.9	2.672	114.3	1028.4
2.473	13.88	128.7	2.513	20.61	217.6	2.553	32.72	387.0	2.593	51.82	567.7	2.633	78.70	791.6	2.673	115.3	1035.8
2.474	14.01	129.6	2.514	20.82	221.2	2.554	33.11	391.4	2.594	52.39	572.3	2.634	79.50	798.5	2.674	116.4	1043.3
2.475	14.14	130.6	2.515	21.05	225.1	2.555	33.51	395.9	2.595	52.96	576.8	2.635	80.30	805.4	2.675	117.4	1050.9
2.476	14.28	131.6	2.516	21.27	229.1	2.556	33.91	400.5	2.596	53.54	581.4	2.636	81.11	812.2	2.676	118.5	1058.7
2.477	14.41	132.7	2.517	21.51	233.3	2.557	34.31	405.1	2.597	54.13	586.0	2.637	81.92	819.2	2.677	119.5	1066.1
2.478	14.54	133.8	2.518	21.74	237.8	2.558	34.72	409.8	2.598	54.71	590.7	2.638	82.74	826.1	2.678	120.6	1073.2
2.479	14.67	134.9	2.519	21.98	242.3	2.559	35.13	414.5	2.599	55.31	595.4	2.639	83.58	833.4	2.679	121.7	1080.3
2.480	14.81	136.1	2.520	22.23	246.8	2.560	35.55	419.2	2.600	55.91	600.1	2.640	84.42	840.8	2.680	122.8	1087.5
2.481	14.95	137.2	2.521	22.48	251.3	2.561	35.97	423.8	2.601	56.51	604.9	2.641	85.26	848.0	2.681	123.8	1094.9
2.482	15.08	138.5	2.522	22.73	255.8	2.562	36.39	428.5	2.602	57.12	609.7	2.642	86.11	854.3	2.682	124.9	1102.8
2.483	15.22	139.7	2.523	22.99	260.4	2.563	36.82	433.2	2.603	57.73	614.6	2.643	86.97	860.4	2.683	126.1	1110.9
2.484	15.36	141.1	2.524	23.25	265.1	2.564	37.26	438.0	2.604	58.34	619.7	2.644	87.83	866.4	2.684	127.2	1119.5
2.485	15.51	143.0	2.525	23.52	269.9	2.565	37.70	442.7	2.605	58.97	624.8	2.645	88.70	872.4	2.685	128.3	1129.1
2.486	15.65	145.5	2.526	23.79	274.4	2.566	38.14	447.3	2.606	59.59	629.9	2.646	89.58	878.2	2.686	129.4	1141.3
2.487	15.80	148.6	2.527	24.07	278.7	2.567	38.59	451.9	2.607	60.23	635.2	2.647	90.46	883.9	2.687	130.6	1153.7
2.488	15.95	152.0	2.528	24.35	283.0	2.568	39.05	456.4	2.608	60.86	640.4	2.648	91.34	889.6	2.688	131.7	1166.4
2.489	16.10	155.3	2.529	24.63	287.2	2.569	39.51	460.8	2.609	61.51	645.8	2.649	92.24	895.3	2.689	132.9	1179.0

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
2.690	134.1	1190.3	2.730	189.0	1552.2	2.770	261.4	2207.6	2.810	386.3	4311.3	2.850	624.2	7690.5	2.890	1020	12390
2.691	135.3	1201.2	2.731	190.6	1562.3	2.771	263.6	2238.3	2.811	390.7	4383.2	2.851	631.9	7785.4	2.891	1033	12513
2.692	136.5	1211.6	2.732	192.1	1572.6	2.772	265.9	2270.4	2.812	395.1	4455.1	2.852	639.7	7880.9	2.892	1045	12636
2.693	137.7	1221.7	2.733	193.7	1582.9	2.773	268.2	2304.5	2.813	399.6	4527.6	2.853	647.7	7977.6	2.893	1058	12760
2.694	138.9	1231.4	2.734	195.3	1593.4	2.774	270.5	2339.5	2.814	404.1	4601.0	2.854	655.7	8078.7	2.894	1071	12884
2.695	140.2	1240.8	2.735	196.9	1603.9	2.775	272.9	2376.0	2.815	408.8	4675.9	2.855	663.8	8177.0	2.895	1084	13008
2.696	141.4	1250.1	2.736	198.5	1614.6	2.776	275.3	2416.5	2.816	413.5	4752.6	2.856	672.0	8273.9	2.896	1097	13133
2.697	142.7	1259.3	2.737	200.1	1625.2	2.777	277.7	2458.9	2.817	418.3	4832.4	2.857	680.4	8371.3	2.897	1110	13258
2.698	143.9	1268.4	2.738	201.8	1635.7	2.778	280.2	2501.3	2.818	423.1	4916.4	2.858	688.8	8469.8	2.898	1123	13386
2.699	145.2	1277.4	2.739	203.4	1646.1	2.779	282.7	2545.0	2.819	428.1	5001.9	2.859	697.3	8570.4	2.899	1137	13517
2.700	146.5	1286.4	2.740	205.1	1656.3	2.780	285.3	2591.9	2.820	433.1	5089.1	2.860	705.9	8672.4	2.900	1150	13653
2.701	147.8	1295.4	2.741	206.7	1666.5	2.781	287.9	2638.5	2.821	438.3	5178.1	2.861	714.6	8775.8	2.901	1164	13796
2.702	149.1	1304.3	2.742	208.4	1676.6	2.782	290.6	2685.3	2.822	443.5	5265.9	2.862	723.5	8880.4	2.902	1178	13931
2.703	150.4	1313.2	2.743	210.1	1686.8	2.783	293.3	2730.9	2.823	448.8	5354.8	2.863	732.4	8986.2	2.903	1192	14060
2.704	151.7	1322.1	2.744	211.8	1698.1	2.784	296.0	2775.3	2.824	454.2	5439.3	2.864	741.4	9093.3	2.904	1206	14185
2.705	153.0	1330.9	2.745	213.5	1710.0	2.785	298.8	2817.7	2.825	459.7	5521.8	2.865	750.6	9202.9	2.905	1220	14309
2.706	154.4	1339.6	2.746	215.2	1722.4	2.786	301.6	2860.9	2.826	465.3	5603.6	2.866	759.8	9315.1	2.906	1235	14432
2.707	155.7	1348.2	2.747	216.9	1735.0	2.787	304.5	2905.2	2.827	470.9	5684.8	2.867	769.2	9434.9	2.907	1249	14555
2.708	157.1	1356.7	2.748	218.7	1747.6	2.788	307.5	2950.8	2.828	476.6	5766.8	2.868	778.7	9554.1	2.908	1264	14674
2.709	158.4	1365.2	2.749	220.4	1760.0	2.789	310.4	3000.0	2.829	482.4	5850.4	2.869	788.3	9673.2	2.909	1278	14790
2.710	159.8	1373.6	2.750	222.2	1772.1	2.790	313.5	3051.2	2.830	488.3	5935.6	2.870	798.1	9795.5	2.910	1293	14906
2.711	161.2	1382.1	2.751	224.0	1784.3	2.791	316.5	3103.5	2.831	494.3	6021.5	2.871	807.9	9930.2	2.911	1308	15021
2.712	162.6	1390.6	2.752	225.7	1797.6	2.792	319.7	3156.1	2.832	500.4	6106.8	2.872	817.9	10069	2.912	1323	15136
2.713	164.0	1399.1	2.753	227.6	1812.6	2.793	322.9	3209.4	2.833	506.5	6190.7	2.873	828.1	10204	2.913	1339	15250
2.714	165.4	1407.7	2.754	229.4	1829.8	2.794	326.1	3264.1	2.834	512.8	6273.8	2.874	838.3	10335	2.914	1354	15365
2.715	166.8	1416.4	2.755	231.2	1847.8	2.795	329.4	3321.2	2.835	519.1	6356.9	2.875	848.7	10465	2.915	1369	15483
2.716	168.2	1425.1	2.756	233.1	1866.9	2.796	332.7	3379.7	2.836	525.5	6440.8	2.876	859.3	10592	2.916	1385	15604
2.717	169.6	1433.9	2.757	234.9	1886.8	2.797	336.1	3440.4	2.837	531.9	6525.3	2.877	869.9	10718	2.917	1400	15726
2.718	171.1	1442.8	2.758	236.8	1907.4	2.798	339.6	3507.6	2.838	538.5	6610.3	2.878	880.7	10844	2.918	1416	15849
2.719	172.5	1451.7	2.759	238.8	1928.8	2.799	343.2	3568.6	2.839	545.2	6695.1	2.879	891.6	10970	2.919	1432	15969
2.720	174.0	1460.5	2.760	240.7	1951.1	2.800	346.8	3628.8	2.840	551.9	6779.9	2.880	902.6	11096	2.920	1448	16088
2.721	175.4	1469.3	2.761	242.7	1973.8	2.801	350.4	3689.3	2.841	558.7	6865.1	2.881	913.8	11225	2.921	1464	16208
2.722	176.9	1478.1	2.762	244.6	1996.9	2.802	354.1	3750.2	2.842	565.6	6950.9	2.882	925.1	11356	2.922	1481	16326
2.723	178.4	1486.9	2.763	246.7	2020.4	2.803	357.9	3813.6	2.843	572.6	7038.1	2.883	936.5	11492	2.923	1497	16445
2.724	179.9	1495.8	2.764	248.7	2044.4	2.804	361.8	3879.7	2.844	579.7	7126.6	2.884	948.1	11632	2.924	1514	16569
2.725	181.4	1504.7	2.765	250.7	2069.2	2.805	365.7	3946.6	2.845	586.9	7216.2	2.885	959.8	11762	2.925	1530	16695
2.726	182.9	1513.8	2.766	252.8	2094.8	2.806	369.7	4015.5	2.846	594.1	7310.5	2.886	971.6	11889	2.926	1547	16818
2.727	184.4	1523.0	2.767	254.9	2121.4	2.807	373.7	4087.5	2.847	601.5	7406.2	2.887	983.5	12015	2.927	1564	16937
2.728	185.9	1532.5	2.768	257.1	2149.2	2.808	377.8	4163.5	2.848	609.0	7501.2	2.888	995.6	12143	2.928	1581	17054
2.729	187.5	1542.2	2.769	259.2	2178.0	2.809	382.0	4238.9	2.849	616.5	7595.9	2.889	1008	12268	2.929	1598	17173

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
2.930	1615	17292	2.970	2414	22635	3.010	3409	26955	3.050	4560	30521	3.090	5849	34025	3.130	7280	37509
2.931	1632	17410	2.971	2437	22761	3.011	3436	27051	3.051	4590	30606	3.091	5883	34117	3.131	7317	37598
2.932	1650	17529	2.972	2460	22887	3.012	3463	27147	3.052	4621	30691	3.092	5917	34208	3.132	7355	37688
2.933	1668	17650	2.973	2483	23011	3.013	3490	27242	3.053	4651	30776	3.093	5951	34297	3.133	7393	37778
2.934	1685	17772	2.974	2506	23130	3.014	3517	27337	3.054	4682	30860	3.094	5985	34386	3.134	7431	37869
2.935	1703	17895	2.975	2529	23247	3.015	3545	27430	3.055	4713	30944	3.095	6020	34475	3.135	7468	37962
2.936	1721	18025	2.976	2552	23362	3.016	3572	27522	3.056	4744	31027	3.096	6054	34564	3.136	7506	38056
2.937	1739	18165	2.977	2576	23476	3.017	3600	27614	3.057	4775	31110	3.097	6089	34652	3.137	7545	38150
2.938	1757	18298	2.978	2599	23590	3.018	3627	27706	3.058	4806	31192	3.098	6124	34741	3.138	7583	38247
2.939	1776	18429	2.979	2623	23704	3.019	3655	27798	3.059	4838	31275	3.099	6158	34828	3.139	7621	38345
2.940	1794	18561	2.980	2647	23815	3.020	3683	27890	3.060	4869	31358	3.100	6193	34916	3.140	7659	38445
2.941	1813	18697	2.981	2670	23925	3.021	3711	27983	3.061	4900	31441	3.101	6228	35003	3.141	7698	38544
2.942	1832	18845	2.982	2694	24034	3.022	3739	28076	3.062	4932	31523	3.102	6263	35091	3.142	7737	38642
2.943	1851	18984	2.983	2718	24142	3.023	3767	28166	3.063	4963	31606	3.103	6299	35179	3.143	7775	38738
2.944	1870	19132	2.984	2743	24249	3.024	3795	28255	3.064	4995	31689	3.104	6334	35267	3.144	7814	38835
2.945	1889	19275	2.985	2767	24356	3.025	3824	28344	3.065	5027	31772	3.105	6369	35354	3.145	7853	38932
2.946	1908	19418	2.986	2791	24463	3.026	3852	28432	3.066	5059	31856	3.106	6404	35443	3.146	7892	39030
2.947	1928	19568	2.987	2816	24570	3.027	3880	28519	3.067	5091	31941	3.107	6440	35532	3.147	7931	39130
2.948	1947	19720	2.988	2841	24676	3.028	3909	28606	3.068	5122	32026	3.108	6476	35620	3.148	7970	39231
2.949	1967	19867	2.989	2865	24781	3.029	3938	28693	3.069	5155	32111	3.109	6511	35706	3.149	8009	39334
2.950	1987	20011	2.990	2890	24886	3.030	3966	28780	3.070	5187	32197	3.110	6547	35792	3.150	8049	39438
2.951	2007	20153	2.991	2915	24991	3.031	3995	28867	3.071	5219	32282	3.111	6583	35877	3.151	8088	39544
2.952	2027	20294	2.992	2940	25095	3.032	4024	28953	3.072	5251	32369	3.112	6619	35961	3.152	8128	39652
2.953	2048	20432	2.993	2965	25200	3.033	4053	29040	3.073	5284	32456	3.113	6655	36046	3.153	8168	39767
2.954	2068	20566	2.994	2990	25304	3.034	4082	29127	3.074	5316	32546	3.114	6691	36131	3.154	8207	39880
2.955	2089	20700	2.995	3016	25409	3.035	4111	29214	3.075	5349	32636	3.115	6727	36215	3.155	8247	39992
2.956	2110	20839	2.996	3041	25513	3.036	4141	29301	3.076	5381	32729	3.116	6763	36300	3.156	8287	40096
2.957	2130	20983	2.997	3067	25618	3.037	4170	29388	3.077	5414	32820	3.117	6800	36385	3.157	8328	40193
2.958	2152	21124	2.998	3093	25726	3.038	4199	29477	3.078	5447	32910	3.118	6836	36470	3.158	8368	40292
2.959	2173	21260	2.999	3118	25833	3.039	4229	29569	3.079	5480	33000	3.119	6872	36555	3.159	8408	40393
2.960	2194	21388	3.000	3144	25939	3.040	4259	29662	3.080	5513	33091	3.120	6909	36640	3.160	8449	40497
2.961	2215	21513	3.001	3170	26045	3.041	4288	29752	3.081	5546	33181	3.121	6946	36726	3.161	8489	40594
2.962	2237	21637	3.002	3196	26150	3.042	4318	29840	3.082	5579	33272	3.122	6983	36811	3.162	8530	40687
2.963	2259	21760	3.003	3222	26253	3.043	4348	29927	3.083	5613	33362	3.123	7019	36897	3.163	8570	40777
2.964	2281	21886	3.004	3249	26357	3.044	4378	30013	3.084	5646	33454	3.124	7056	36983	3.164	8611	40865
2.965	2303	22010	3.005	3275	26459	3.045	4408	30099	3.085	5680	33546	3.125	7093	37069	3.165	8652	40953
2.966	2325	22136	3.006	3302	26561	3.046	4438	30183	3.086	5713	33641	3.126	7130	37156	3.166	8693	41039
2.967	2347	22261	3.007	3328	26661	3.047	4468	30268	3.087	5747	33738	3.127	7168	37243	3.167	8734	41123
2.968	2369	22387	3.008	3355	26760	3.048	4499	30352	3.088	5781	33838	3.128	7205	37331	3.168	8775	41208
2.969	2392	22511	3.009	3382	26858	3.049	4529	30436	3.089	5815	33932	3.129	7242	37419	3.169	8817	41290

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
3.170	8858	41372	3.210	10574	44396	3.250	12412	47562	3.290	14368	50032	3.330	16411	52151	3.370	18542	54408
3.171	8899	41454	3.211	10619	44472	3.251	12459	47661	3.291	14418	50083	3.331	16464	52207	3.371	18597	54472
3.172	8941	41535	3.212	10663	44548	3.252	12507	47744	3.292	14468	50134	3.332	16516	52262	3.372	18651	54538
3.173	8983	41615	3.213	10708	44624	3.253	12555	47824	3.293	14519	50185	3.333	16568	52319	3.373	18706	54604
3.174	9024	41695	3.214	10752	44701	3.254	12603	47900	3.294	14569	50235	3.334	16620	52375	3.374	18760	54666
3.175	9066	41775	3.215	10797	44778	3.255	12650	47974	3.295	14619	50286	3.335	16673	52432	3.375	18815	54728
3.176	9108	41854	3.216	10842	44856	3.256	12698	48048	3.296	14669	50337	3.336	16725	52489	3.376	18870	54790
3.177	9150	41935	3.217	10887	44933	3.257	12747	48120	3.297	14720	50389	3.337	16778	52547	3.377	18925	54854
3.178	9192	42017	3.218	10932	45010	3.258	12795	48192	3.298	14770	50442	3.338	16830	52605	3.378	18980	54919
3.179	9234	42098	3.219	10977	45086	3.259	12843	48263	3.299	14821	50495	3.339	16883	52665	3.379	19034	54983
3.180	9276	42177	3.220	11022	45162	3.260	12891	48332	3.300	14871	50547	3.340	16936	52726	3.380	19089	55045
3.181	9318	42256	3.221	11067	45238	3.261	12940	48400	3.301	14922	50600	3.341	16989	52790	3.381	19145	55106
3.182	9360	42334	3.222	11113	45315	3.262	12988	48469	3.302	14972	50653	3.342	17041	52877	3.382	19200	55166
3.183	9403	42413	3.223	11158	45393	3.263	13037	48539	3.303	15023	50707	3.343	17094	52907	3.383	19255	55226
3.184	9445	42492	3.224	11203	45471	3.264	13085	48606	3.304	15074	50760	3.344	17147	52961	3.384	19310	55286
3.185	9488	42570	3.225	11249	45547	3.265	13134	48671	3.305	15125	50814	3.345	17200	53014	3.385	19365	55347
3.186	9530	42646	3.226	11294	45622	3.266	13182	48735	3.306	15175	50867	3.346	17253	53067	3.386	19421	55408
3.187	9573	42721	3.227	11340	45697	3.267	13231	48797	3.307	15226	50921	3.347	17306	53119	3.387	19476	55469
3.188	9616	42795	3.228	11386	45772	3.268	13280	48859	3.308	15277	50973	3.348	17359	53171	3.388	19532	55531
3.189	9659	42868	3.229	11432	45848	3.269	13329	48920	3.309	15328	51025	3.349	17413	53223	3.389	19587	55594
3.190	9701	42941	3.230	11478	45923	3.270	13378	48982	3.310	15379	51077	3.350	17466	53274	3.390	19643	55656
3.191	9744	43013	3.231	11524	45999	3.271	13427	49046	3.311	15430	51129	3.351	17519	53325	3.391	19699	55718
3.192	9787	43085	3.232	11570	46075	3.272	13476	49104	3.312	15482	51181	3.352	17573	53376	3.392	19754	55778
3.193	9831	43158	3.233	11616	46150	3.273	13525	49160	3.313	15533	51233	3.353	17626	53427	3.393	19810	55839
3.194	9874	43230	3.234	11662	46226	3.274	13574	49216	3.314	15584	51285	3.354	17679	53478	3.394	19866	55902
3.195	9917	43303	3.235	11708	46301	3.275	13624	49270	3.315	15635	51336	3.355	17733	53529	3.395	19922	55966
3.196	9960	43375	3.236	11754	46376	3.276	13673	49322	3.316	15687	51388	3.356	17786	53580	3.396	19978	56031
3.197	10004	43447	3.237	11801	46451	3.277	13722	49373	3.317	15738	51440	3.357	17840	53631	3.397	20034	56093
3.198	10047	43519	3.238	11847	46527	3.278	13772	49423	3.318	15790	51492	3.358	17894	53682	3.398	20090	56155
3.199	10091	43591	3.239	11894	46603	3.279	13821	49474	3.319	15841	51545	3.359	17947	53735	3.399	20146	56217
3.200	10134	43662	3.240	11941	46680	3.280	13871	49525	3.320	15893	51598	3.360	18001	53793	3.400	20203	56280
3.201	10178	43734	3.241	11987	46758	3.281	13920	49575	3.321	15944	51651	3.361	18055	53853	3.401	20259	56344
3.202	10221	43807	3.242	12034	46839	3.282	13970	49626	3.322	15996	51705	3.362	18109	53913	3.402	20315	56407
3.203	10265	43879	3.243	12081	46921	3.283	14019	49677	3.323	16048	51760	3.363	18163	53975	3.403	20372	56468
3.204	10309	43952	3.244	12128	47006	3.284	14069	49728	3.324	16100	51816	3.364	18217	54037	3.404	20428	56531
3.205	10353	44026	3.245	12175	47091	3.285	14119	49778	3.325	16151	51873	3.365	18271	54100	3.405	20485	56592
3.206	10397	44099	3.246	12222	47177	3.286	14169	49829	3.326	16203	51930	3.366	18325	54161	3.406	20541	56652
3.207	10441	44173	3.247	12269	47265	3.287	14218	49880	3.327	16255	51985	3.367	18379	54222	3.407	20598	56712
3.208	10486	44247	3.248	12317	47357	3.288	14268	49931	3.328	16307	52041	3.368	18433	54284	3.408	20655	56763
3.209	10530	44321	3.249	12364	47459	3.289	14318	49982	3.329	16359	52096	3.369	18488	54345	3.409	20712	56812

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
3.410	20768	56859	3.450	23074	58313	3.490	25434	59613	3.530	27835	60356	3.570	30261	60921	3.650	35174	61860
3.411	20825	56906	3.451	23133	58343	3.491	25494	59639	3.531	27896	60371	3.571	30322	60934	3.655	35483	61912
3.412	20882	56952	3.452	23191	58374	3.492	25554	59667	3.532	27956	60386	3.572	30383	60946	3.660	35793	61964
3.413	20939	56998	3.453	23250	58407	3.493	25613	59696	3.533	28016	60401	3.573	30444	60959	3.665	36103	62015
3.414	20996	57043	3.454	23308	58440	3.494	25673	59723	3.534	28077	60415	3.574	30505	60972	3.670	36413	62065
3.415	21053	57087	3.455	23366	58474	3.495	25733	59750	3.535	28137	60430	3.575	30566	60984	3.675	36723	62115
3.416	21110	57132	3.456	23425	58507	3.496	25792	59772	3.536	28198	60445	3.576	30627	60997	3.680	37034	62164
3.417	21168	57176	3.457	23483	58541	3.497	25852	59794	3.537	28258	60460	3.577	30688	61010	3.685	37345	62212
3.418	21225	57220	3.458	23542	58576	3.498	25912	59815	3.538	28319	60474	3.578	30749	61022	3.690	37656	62261
3.419	21282	57263	3.459	23601	58610	3.499	25972	59836	3.539	28379	60489	3.579	30810	61035	3.695	37968	62309
3.420	21339	57305	3.460	23659	58645	3.500	26032	59857	3.540	28440	60503	3.580	30871	61048	3.700	38279	62357
3.421	21397	57347	3.461	23718	58679	3.501	26092	59877	3.541	28500	60518	3.581	30932	61060	3.705	38591	62404
3.422	21454	57389	3.462	23777	58714	3.502	26152	59895	3.542	28561	60532	3.582	30993	61073	3.710	38903	62451
3.423	21511	57430	3.463	23835	58748	3.503	26211	59914	3.543	28621	60547	3.583	31054	61086	3.715	39216	62497
3.424	21569	57470	3.464	23894	58781	3.504	26271	59932	3.544	28682	60561	3.584	31115	61098	3.720	39528	62543
3.425	21626	57508	3.465	23953	58815	3.505	26331	59950	3.545	28742	60576	3.585	31176	61111	3.725	39841	62589
3.426	21684	57545	3.466	24012	58851	3.506	26391	59968	3.546	28803	60590	3.586	31237	61123	3.730	40154	62634
3.427	21741	57581	3.467	24071	58887	3.507	26451	59986	3.547	28863	60605	3.587	31299	61136	3.735	40468	62678
3.428	21799	57616	3.468	24130	58925	3.508	26511	60003	3.548	28924	60619	3.588	31360	61148	3.740	40781	62723
3.429	21857	57652	3.469	24188	58968	3.509	26571	60021	3.549	28985	60634	3.589	31421	61161	3.745	41095	62767
3.430	21914	57686	3.470	24247	59011	3.510	26631	60038	3.550	29045	60649	3.590	31482	61173	3.750	41409	62811
3.431	21972	57721	3.471	24306	59051	3.511	26691	60055	3.551	29106	60663	3.591	31543	61185	3.755	41723	62855
3.432	22030	57754	3.472	24366	59090	3.512	26751	60072	3.552	29167	60678	3.592	31604	61197	3.760	42037	62899
3.433	22088	57787	3.473	24425	59129	3.513	26811	60089	3.553	29227	60692	3.593	31666	61210	3.765	42352	62943
3.434	22145	57819	3.474	24484	59169	3.514	26872	60105	3.554	29288	60707	3.594	31727	61222	3.770	42667	62986
3.435	22203	57851	3.475	24543	59207	3.515	26932	60122	3.555	29349	60721	3.595	31788	61234	3.775	42982	63029
3.436	22261	57882	3.476	24602	59240	3.516	26992	60139	3.556	29409	60736	3.596	31849	61246	3.780	43297	63072
3.437	22319	57914	3.477	24661	59271	3.517	27052	60155	3.557	29470	60750	3.597	31911	61258	3.785	43612	63115
3.438	22377	57945	3.478	24721	59301	3.518	27112	60171	3.558	29531	60764	3.598	31972	61270	3.790	43928	63158
3.439	22435	57975	3.479	24780	59330	3.519	27172	60187	3.559	29592	60778	3.599	32033	61282	3.795	44244	63201
3.440	22493	58006	3.480	24839	59359	3.520	27232	60202	3.560	29653	60792	3.600	32094	61294	3.800	44560	63243
3.441	22551	58037	3.481	24899	59387	3.521	27293	60218	3.561	29713	60805	3.605	32401	61354	3.805	44877	63285
3.442	22609	58067	3.482	24958	59414	3.522	27353	60234	3.562	29774	60818	3.610	32708	61414	3.810	45193	63327
3.443	22667	58098	3.483	25018	59441	3.523	27413	60249	3.563	29835	60831	3.615	33015	61475	3.815	45510	63369
3.444	22725	58129	3.484	25077	59466	3.524	27473	60264	3.564	29896	60844	3.620	33323	61534	3.820	45827	63410
3.445	22783	58160	3.485	25137	59491	3.525	27534	60280	3.565	29957	60857	3.625	33631	61591	3.825	46144	63452
3.446	22841	58191	3.486	25196	59516	3.526	27594	60295	3.566	30018	60870	3.630	33939	61646	3.830	46461	63493
3.447	22900	58222	3.487	25256	59540	3.527	27654	60310	3.567	30078	60883	3.635	34247	61700	3.835	46779	63534
3.448	22958	58252	3.488	25315	59564	3.528	27715	60326	3.568	30139	60896	3.640	34556	61754	3.840	47097	63575
3.449	23016	58283	3.489	25375	59588	3.529	27775	60341	3.569	30200	60908	3.645	34865	61807	3.845	47415	63616

Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2	Stage AHD	Vol m^3	Area m^2
3.850	47733	63657	4.100	63896	65618	4.500	90753	68690	4.900	118890	72112
3.855	48051	63698	4.110	64552	65694	4.510	91440	68768	4.910	119612	72213
3.860	48370	63739	4.120	65209	65770	4.520	92128	68847	4.920	120334	72316
3.865	48689	63779	4.130	65868	65845	4.530	92817	68927	4.930	121058	72422
3.870	49008	63820	4.140	66526	65921	4.540	93507	69005	4.940	121783	72527
3.875	49327	63860	4.150	67186	65996	4.550	94197	69084	4.950	122508	72633
3.880	49646	63901	4.160	67846	66072	4.560	94888	69163	4.960	123235	72739
3.885	49966	63941	4.170	68507	66147	4.570	95580	69242	4.970	123963	72845
3.890	50286	63981	4.180	69169	66223	4.580	96273	69321	4.980	124692	72952
3.895	50606	64022	4.190	69832	66298	4.590	96967	69401	4.990	125422	73059
3.900	50926	64062	4.200	70495	66374	4.600	97661	69482	5.000	126153	73165
3.905	51246	64102	4.210	71159	66450	4.610	98356	69563			
3.910	51567	64142	4.220	71824	66526	4.620	99053	69644			
3.915	51888	64182	4.230	72490	66602	4.630	99749	69727			
3.920	52209	64222	4.240	73156	66678	4.640	100448	69809			
3.925	52530	64262	4.250	73823	66755	4.650	101146	69893			
3.930	52851	64302	4.260	74491	66831	4.660	101845	69977			
3.935	53173	64341	4.270	75160	66907	4.670	102546	70062			
3.940	53495	64381	4.280	75830	66984	4.680	103247	70149			
3.945	53817	64421	4.290	76500	67060	4.690	103949	70236			
3.950	54139	64460	4.300	77171	67136	4.700	104651	70326			
3.955	54461	64500	4.310	77843	67213	4.710	105355	70420			
3.960	54784	64539	4.320	78515	67289	4.720	106060	70505			
3.965	55107	64579	4.330	79188	67366	4.730	106765	70587			
3.970	55430	64618	4.340	79862	67443	4.740	107471	70670			
3.975	55753	64657	4.350	80537	67520	4.750	108179	70752			
3.980	56076	64697	4.360	81213	67597	4.760	108887	70836			
3.985	56400	64736	4.370	81889	67675	4.770	109595	70920			
3.990	56724	64775	4.380	82566	67753	4.780	110305	71004			
3.995	57048	64814	4.390	83244	67830	4.790	111015	71089			
4.000	57372	64853	4.400	83923	67908	4.800	111727	71176			
4.010	58021	64930	4.410	84602	67985	4.810	112439	71264			
4.020	58670	65008	4.420	85283	68063	4.820	113152	71353			
4.030	59321	65085	4.430	85964	68142	4.830	113866	71442			
4.040	59972	65162	4.440	86645	68220	4.840	114581	71533			
4.050	60624	65238	4.450	87328	68298	4.850	115297	71625			
4.060	61277	65315	4.460	88011	68376	4.860	116013	71719			
4.070	61930	65391	4.470	88696	68454	4.870	116731	71814			
4.080	62585	65467	4.480	89381	68533	4.880	117450	71912			
4.090	63240	65543	4.490	90066	68611	4.890	118169	72011			

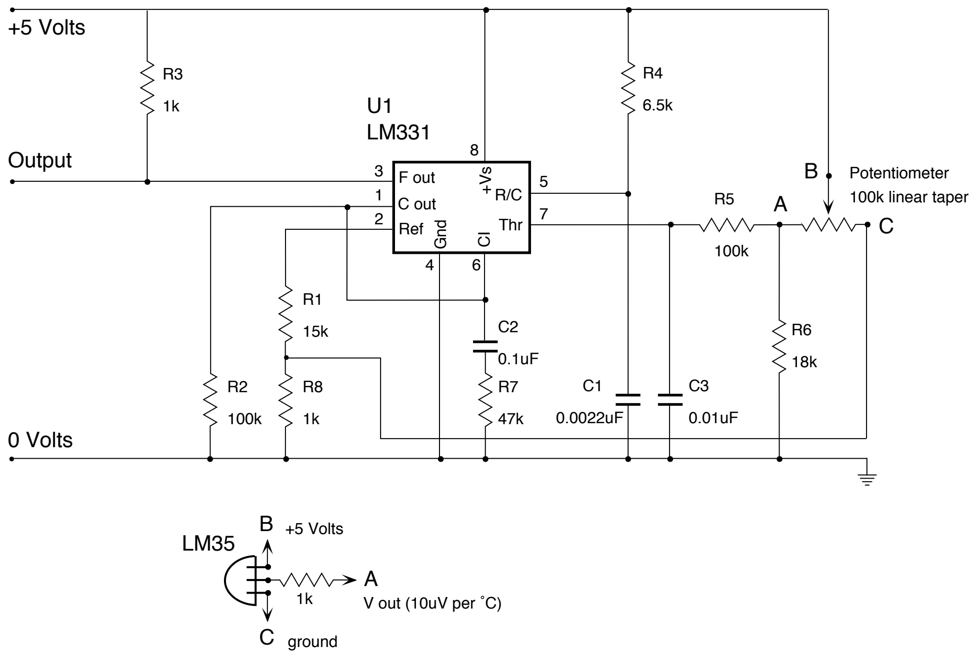
CHAPTER

5

APPENDICES

Appendix 5.1 Individual Drain Calibration

Individual drain calibration was a complex process, made more difficult by the different construction techniques employed in each drain. Float arm logger data was obtained from the East Main (EM) and Basketball Stadium (BB) drains. The float arm logger employed a Dataflow 392 logger with voltage to frequency converter originally used for temperature logging with an LM35 temperature sensor. This was replaced with a 100k linear taper potentiometer mounted on the swing arm logger. With the circuit configuration shown here a frequency shift of about 7000Hz was obtained over a potentiometer shaft rotation of 180 degrees.



In its original configuration the LM35 temperature sensor was connected at the points marked A to C. The logger and V to F converter was calibrated for each drain after installation. Gearing of the potentiometer was required to provide adequate resolution.

Perry East 'PE' Drain

A series of storm events July 5-7 1997 was used to calibrate the drain against float arm data. Figure 1a shows water height in the sediment trap and pipe for individual storm events A to J. A phase lag of variable length occurs between the water height in the sediment trap and the water height in the pipe, measured by the swing arm logger at the pipe exit 234m distant. An additional complication is run-off from Meagher Drive and car parks adjacent to the basketball stadium which enter the PE drain between the gauged sediment trap and the lake. This in part, explains why levels in the pipe are consistently greater than levels in the sediment trap. Overall similar rainfall was assumed for the drain catchment and Meagher Drive. Placing the float arm logger at the pipe exit therefore allowed these additional inputs to be included in the PE discharge. When examined in detail (Figure 1b) an approximate 4 minute phase lag is evident at higher pipe depths. Figure 1c demonstrates how water velocity (mean velocity as defined by Manning's equation) and phase lag between the two monitoring points varies with water depth in the pipe. At the heights encountered at storm peaks (pipe depths 0.1-0.5m) this lag varies from 5.3 to 3.1 minutes. A final calibration expression was derived by plotting water height in pipe against water height in sediment trap adjusted for phase lag.

Manual Calibration

Manual calibration data was collected during an intense storm event June 17, 1996 by measuring water depth (difference from top of pipe to top of flow) at the pipe exit. The measurements were made an arms length inside the pipe to preclude any head losses close to the exit. The resulting expression based on only five points (Figure 1d) is not affected by the errors in pipe 'zero real depth' (see below) and produced a very linear fit (R=0.994) and included one of the highest recorded flow depths in the PE pipe, 0.435m (0.64 pipe internal diameter).

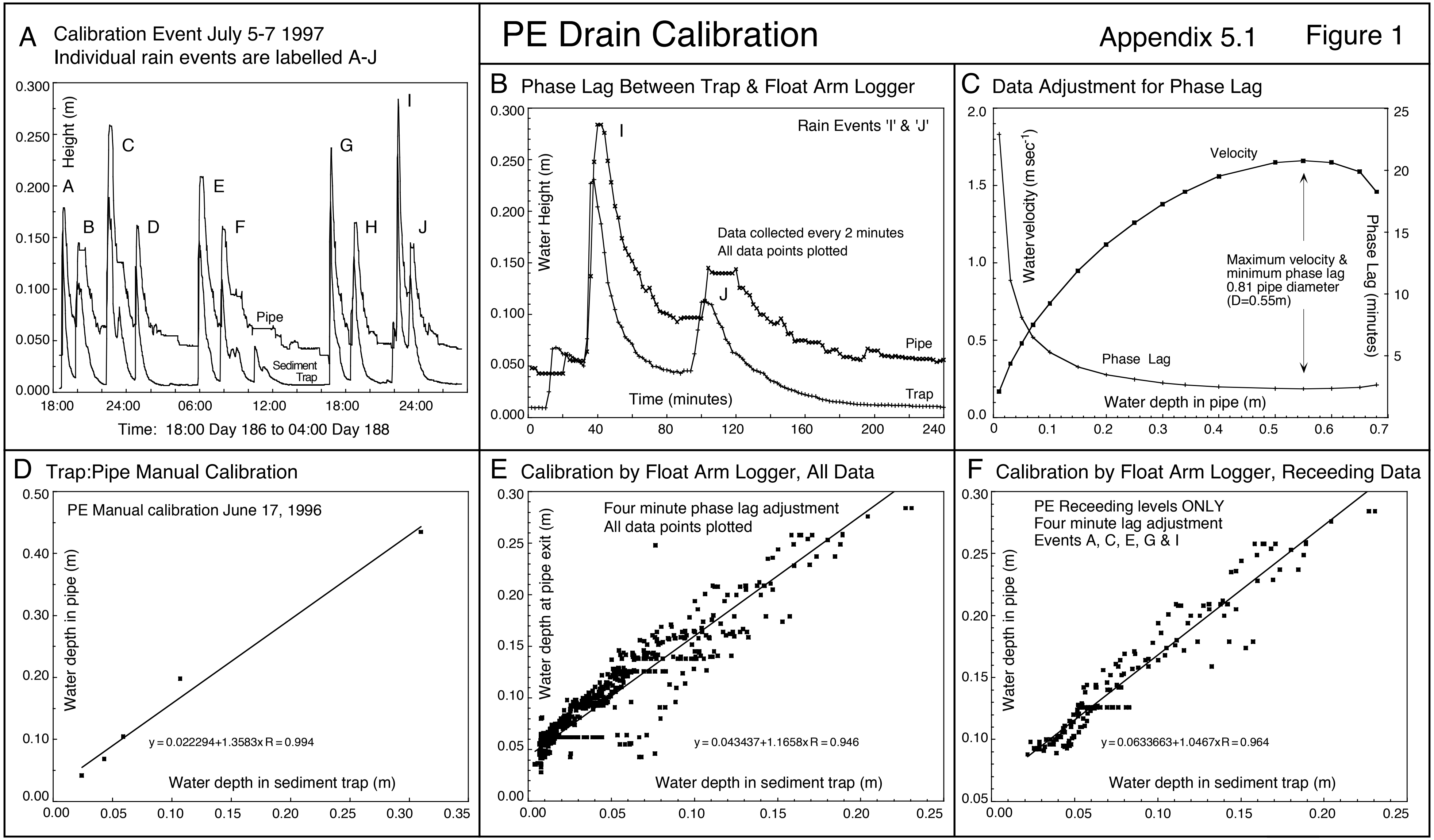
Calibration Using the Float Arm Logger

Sediment trap data was collected at 2 minute intervals, while the float arm data was collected at 1 minute intervals. Phase lags of 1-6 minutes were tested to derive linear and polynomial curve fits (the relationship between water height and arc created by the pivoting arm is not quite linear due to the fixed rather than self adjusting float design). A four minute lag adjustment produced the best linear fit (R=0.946), Figure 1e. Polynomial curve fitting (not illustrated) produced little improvement (R=0.950).

One significant design problem with the swing arm logger was slop in the gear train and a tendency for the float to rest slightly off pipe centre as water receded. These two faults

PE Drain Calibration

Appendix 5.1 Figure 1



A Calibration Event July 5-7 1997
Individual rain events are labelled A-J

B Phase Lag Between Trap & Float Arm Logger

C Data Adjustment for Phase Lag

D Trap:Pipe Manual Calibration

E Calibration by Float Arm Logger, All Data

F Calibration by Float Arm Logger, Receeding Data combined frequently resulted in about 40mm of water indicated at zero real depth (notice in Figure 1e the 'y' intercept of 43mm). As a final attempt to produce a best fit, receding level data only was used (peak to 0.1m) from events A to J. The use of receding water level data also eliminates the generally poor correlation between trap and pipe during the initial surge as the pipes commence flowing. Receding data (Figure 1f) produced an improved linear fit (R= 0.964) but with a greater 'y' intercept, which ideally should be zero. Given the wide variation between the float arm and manual calibration coefficients, a range of coefficients between 1.046(x) and 1.358(x) were tested in the final calibration.

Basketball 'BB' Drain

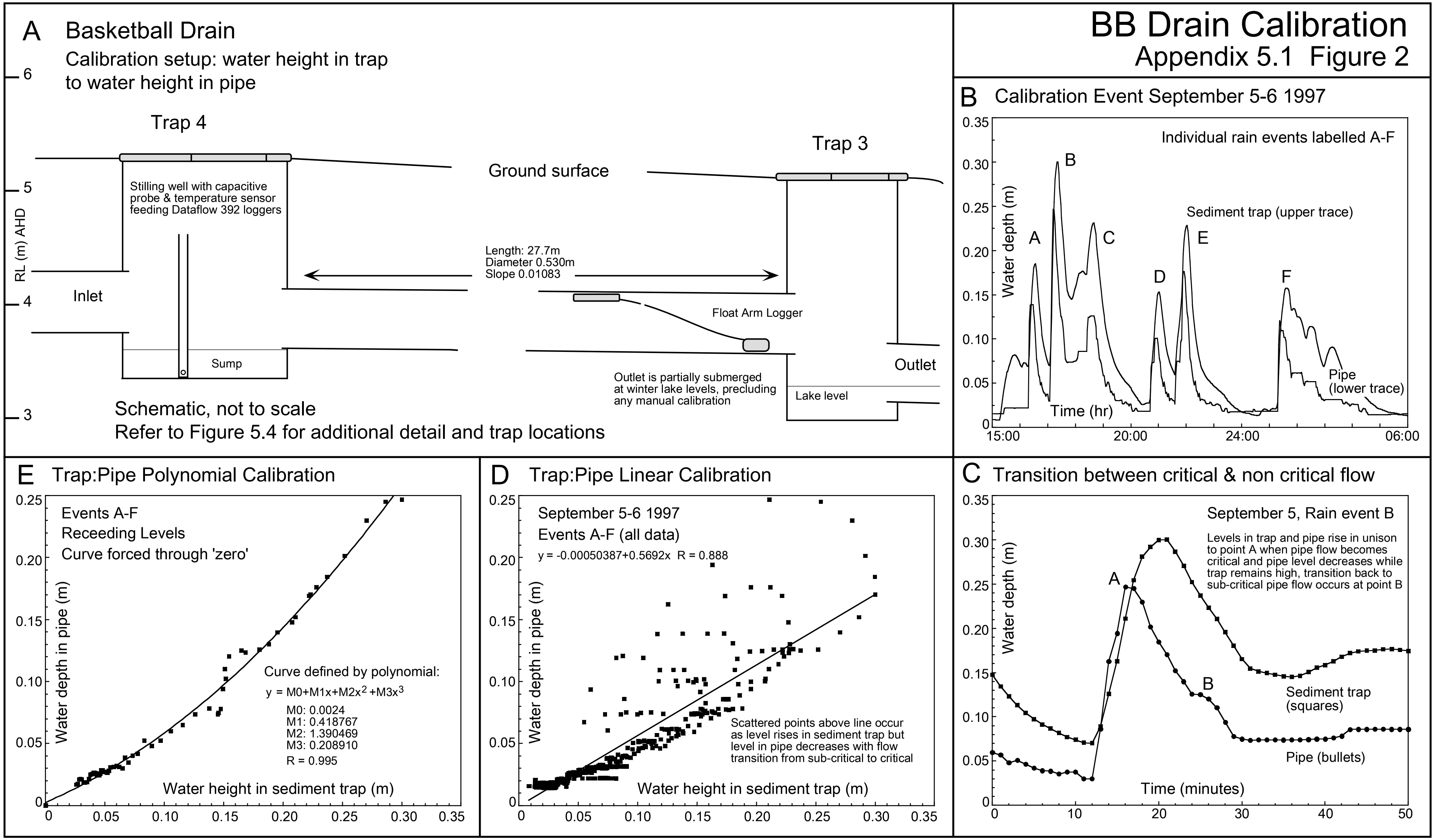
The Basketball drain carries roof and surface run-off from the athletic and basketball stadium complexes. It consists of a series of cascaded sediment traps, the last two of which are illustrated in Figure 2a. The outlet to East Lake is partially submerged at winter lake stages, precluding any manual calibration. A series of storm events (Figure 2b) September 5-6 1997 was used to calibrate the water height in sediment trap 4 against depth in pipe. The small pipe diameter (0.53m) precluded physical access to mount the float arm logger directly to the upper pipe surface. Instead it was secured to a rigid steel channel secured within and extending from trap 3.

Calibration Using the Float Arm Logger

Sediment trap data was collected at 2 minute intervals, while the float arm data was collected at 1 minute intervals. The internal clocks in all loggers were reset from the same PC. The loggers assume the time of the PC internal clock and are therefore synchronous. No phase lag was expected due to the very short distance (27m) between the sediment trap and the float arm. Detailed analysis of data from individual rain events however displayed an unexpected relationship between trap and pipe data. As a storm event commenced, trap and pipe levels commence rising synchronously. Pipe levels then commence falling while trap levels continue to rise and peak. Both levels then fall but with a later rise or plateau in pipe levels which is not accompanied by a similar rise in trap levels (Figure 2c). Theoretical velocity-discharge analysis (see below) confirmed that this section of the drain was cycling between subcritical and critical flow. The 'spiky' pipe flow trace evident in Figure 2b at pipe depths around 0.05m is likely caused by unstable transitional flows close to Froude Number 1 (Figure 3b) which are typically wavy or undulating (Hamill 1995). Better trap:pipe relationships, expressed as polynomial expressions were generated using receding level data only (Figure 2e) however in the final integrated calibration using all four drains against lake volume changes, the linear expression provided the best fit. This probably reflects the fact that it represents an averaging of both flow regimes.

BB Drain Calibration

Appendix 5.1 Figure 2



Calibration was achieved by assuming that the linear relationship evident at low flows could be extended and assuming all flow to be non critical. In Figure 2d, a linear relationship with little data scatter is evident up to trap depths of about 0.07m. This linear trend then continues but with considerable scatter above the line. Detailed analysis of Figure 2 c&d show that this scatter is largely generated during the initial phase of each rain event where pipe depth is greater than trap depth. Once critical flow is established, this relationship is reversed. The linear relationship in Figure 2d is therefore a simple average which, over an entire storm event or balance period, provides a good estimate of water height in trap to water height in pipe and ultimately total flow volume.

CSIRO 'CS' Drain

Calibration of the CS drain was achieved using data collected manually during two rain events in 1996 and 1997 which provided a mean trap:pipe coefficient of 0.815. Despite the theoretical velocity-discharge analysis (Figure 4) which suggested critical flows would dominate, obvious critical flows were not observed in visual inspections during storm events.

Underwood 'UW' Drain

The UW drain has the steepest gradient and probably exhibits critical flows most of the time. Visual inspection of trap 7 (refer Figure 5.4 in thesis text) during storm events indicated that trap and pipe depths appeared roughly similar (*i.e.* trap:pipe depths of about 1:1). This seemingly linear relationship probably results from the increased flow resistance within narrow diameter pipes. A number of possible linear relationships were tested in the integrated calibration with a final relationship of 0.8 trap height providing the best overall fit.

Supercritical and subcritical flow in Perry Lakes Drains

The initial problem calibrating the BB drain prompted the generation of theoretical velocity-discharge curves for all Perry Lakes drains. Velocity, discharge and Froude number plots were generated at water depth increments of 0.01m over ranges of Manning's 'n' typical of cast concrete pipes (Figure 3). Above Froude number 1 supercritical flow can occur, characterised by an increase in velocity and decrease in depth. The West Lake and Perry East Main ('PE') drains display subcritical flows over all water depths. Artificial open channels, which includes storm drains are typically constructed at gradients of about 0.001 (French 1985). This is approximately the gradient utilised in the West Lake drains which operate at Froude numbers <0.6 (Figure 3e). The Perry East drain (Figure 3a) exhibits Froude numbers which just exceed unity (maximum 1.038 at n=0.010) and approach unity (maximum 0.943 at n=0.011). The remaining

Velocity-Discharge Analysis

Appendix 5.1

Figure 3

Notes

Each plot contains three sets of velocity, volume and Froude No curves generated for different values of Manning's 'n':

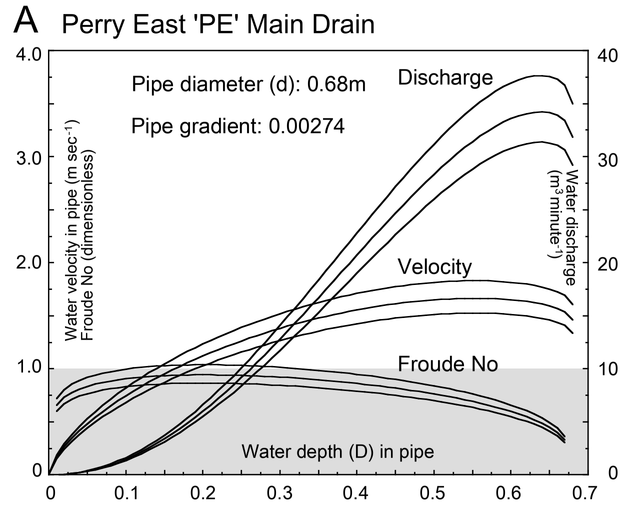
0.010 (upper curves)
0.011 (middle curves)
0.012 (lower curves)

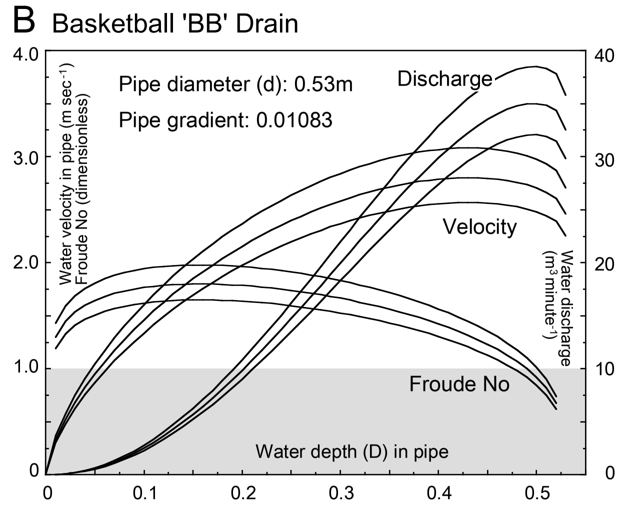
Where Froude Number exceeds unity, critical flow conditions may occur. Sub-critical flow occurs within the shaded area of each graph

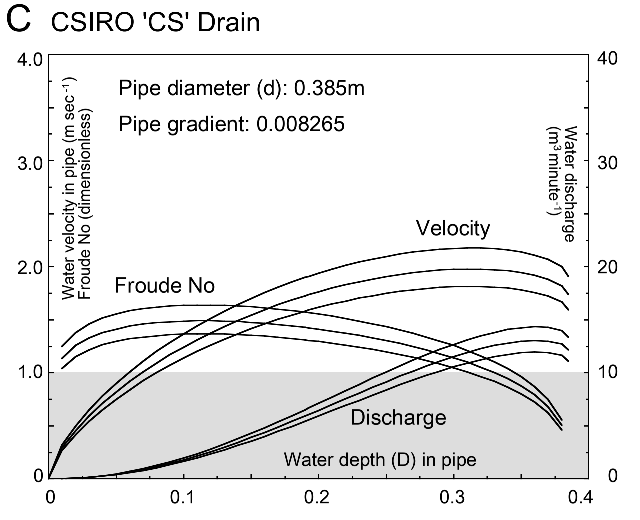
High Froude Numbers in the smaller BB, CS & UW drains result from abnormally steep pipe gradients approximately 10x greater than those in the West Lake & PE drain

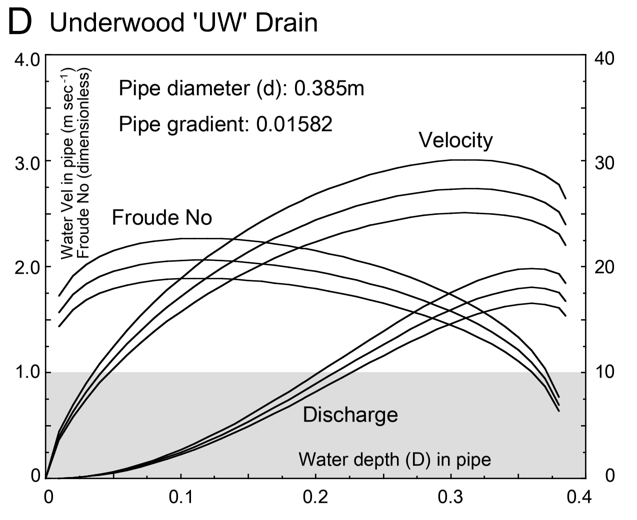
Maximum discharge occurs at D=0.95d
Maximum velocity occurs at D=0.81d

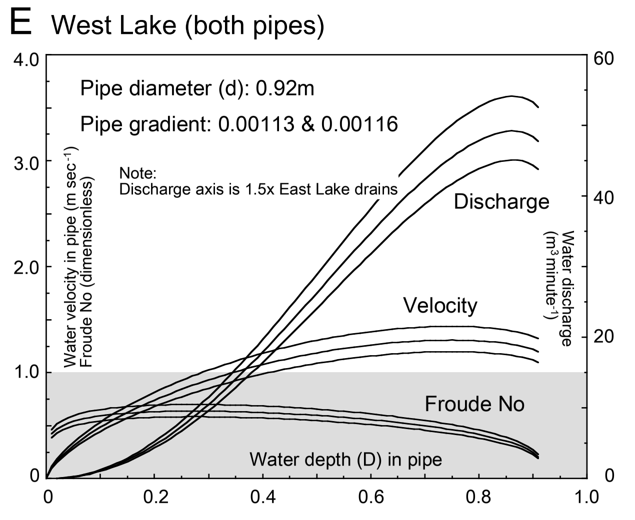
Note that discharge axis for West Lake drain graph is 1.5x that of the East Lake drains











small diameter drains have Froude numbers >1 over most of their operating range. These drains probably oscillate between subcritical and supercritical flow during storm events.

In summary, estimates of discharge are based on

- the fact that for a given specific energy, two alternate depths of flow are possible representing subcritical and supercritical flow (Chow 1959 p41)
- for the BB, CS & UW drains calibration expressions and discharge volumes have been derived which *assume* subcritical flow throughout

Therefore while the actual depths which may occur in the pipes during supercritical flow will be less than those used in the calculations, the estimated volumes will be similar.

Final Calibration East Lake

For each drain a number of possible depth in sediment trap to depth in pipe co-efficients were computed based on manual and float arm data and other factors such as variable time lag in the PE drain where the float arm and manual data was collected over 200m from the trap site (see above). Discharge from each drain therefore, was described by a 'family' of rating curves defined by the trap:pipe and pipe friction coefficients (Manning's 'n'). These are summarised in Table 1. There are 120 possible combinations.

Table 1 Trap:pipe factors tested for 'best fit' against lake volume changes

Perry East 'PE'	Basketball 'BB'	CSIRO 'CS'	Underwood 'UW'
1.046(x)	0.569(x)	0.815(x)	0.800(x)
1.165(x)	polynomial 1		1.000(x)
1.200(x)	polynomial 2		1.100(x)
1.250(x)	polynomial 3		1.200(x)
1.300(x)			1.450(x)
1.358(x)			

Notes

PE: 1.046 & 1.165 from float arm logger, 1.358 from manual calibration. Additional intermediate coefficients tested (refer text).

BB: 0.569 is general linear fit of all float arm data. Polynomial expressions developed from float arm data, levels receding from peak.

	Polynomial 1	Polynomial 2	Polynomial 3
M0	0.006476	0.016735	0.002489
M1*x	0.381904	0.0110965	0.418767
$M2*x^2$	0.371370	4.285177	1.390469
$M3*x^3$	3.642878	-5.614196	0.995492

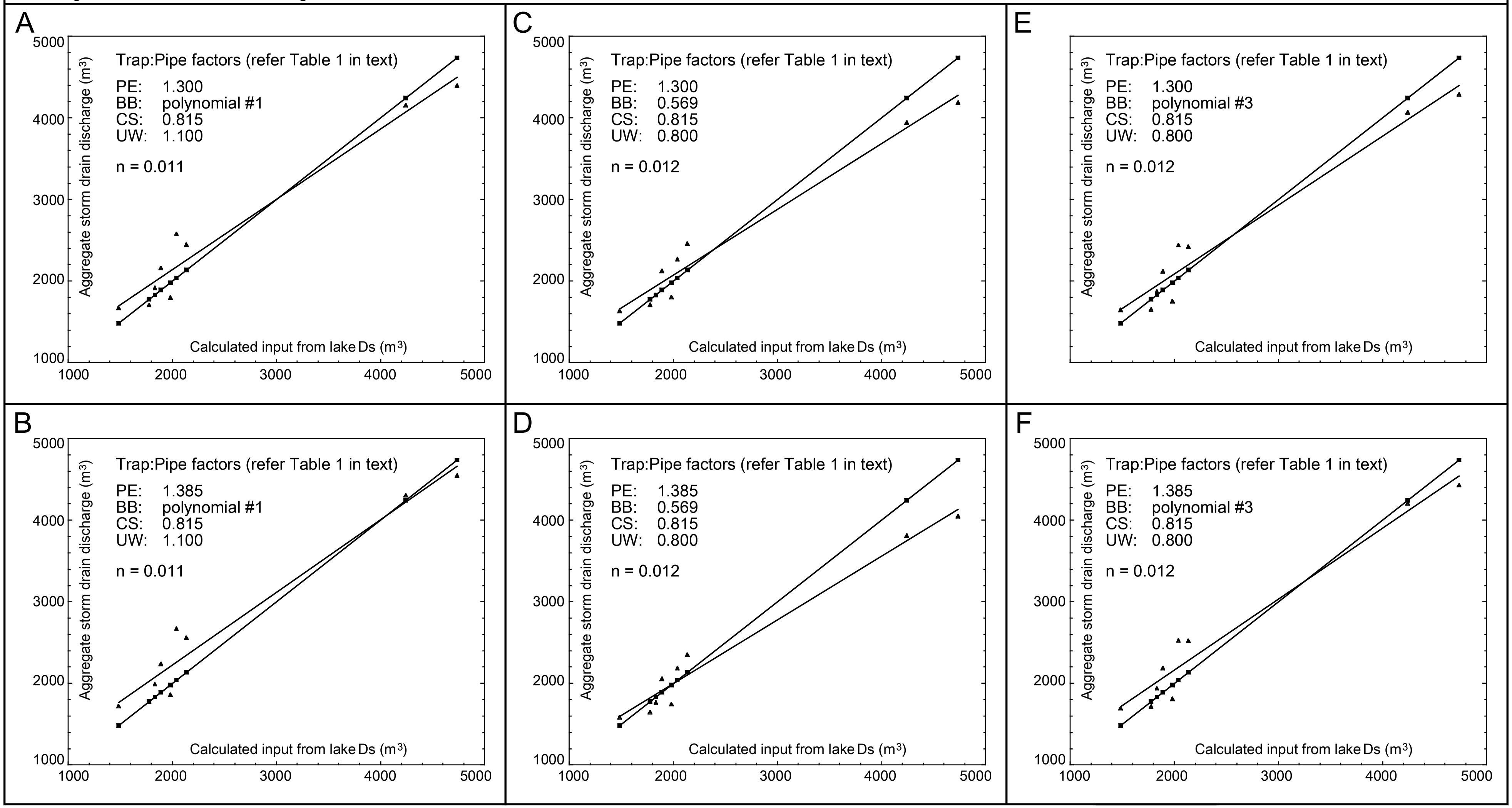
CS: the excellent manual data fit for the CS drain was accepted without modification

UW: manual calibration 1.450(x) was based on a very poor data fit. Field observation suggested discharge from the UW drain was small. The range of smaller coefficients was tested against best fit total discharge.

Key
Squares: theoretical perfect match where
lake Ds = aggregate drain discharge
Triangles: fit for individual drain rating curves as shown

Aggregate Drain Calibration
East Lake

Appendix 5.1
Figure 4



Aggregate discharge using all permutations of pipe discharge were plotted against data derived from lake volume changes for 9 rain events. A perfect match is defined by a line of slope =1 and y intercept of 0. Data combinations which appeared close using 'n' = 0.011 were retested with 'n' =0.010 and 0.012. Examples of various 'close fits' are included in Figure 4. Final drain discharge was computed using the following trap:pipe coefficients: PE: 1.300, BB: 0.569, CS: 0.815, UW: 0.800. This was based on the better fit for storm events in the discharge range 1500-2500m^3, which are more typical of winter frontal passages than the extreme 4000-5000m^3 events.

Calibration West Lake Drains

Individual Microcom[1] DDT-200 loggers operated in the two West Lake drains continuously from July 7, 1996 to January 3, 1998. Each instrument was set to log drain flow depth (height minus dry height) at a one minute scan rate. The loggers also measure air temperature in the drains which is used to correct the final data for sound velocity changes. Flow volumes were calculated using Microcom 'II Study' inflow analysis software (V2.35) employing Manning's equation. The optimal value for Manning's 'n' was determined by independently estimating discharge for discreet rain events using the same methodology applied at East Lake. Aggregate discharge for these events was also estimated using the II Study software set at various values of Manning's 'n' (Figure 5).

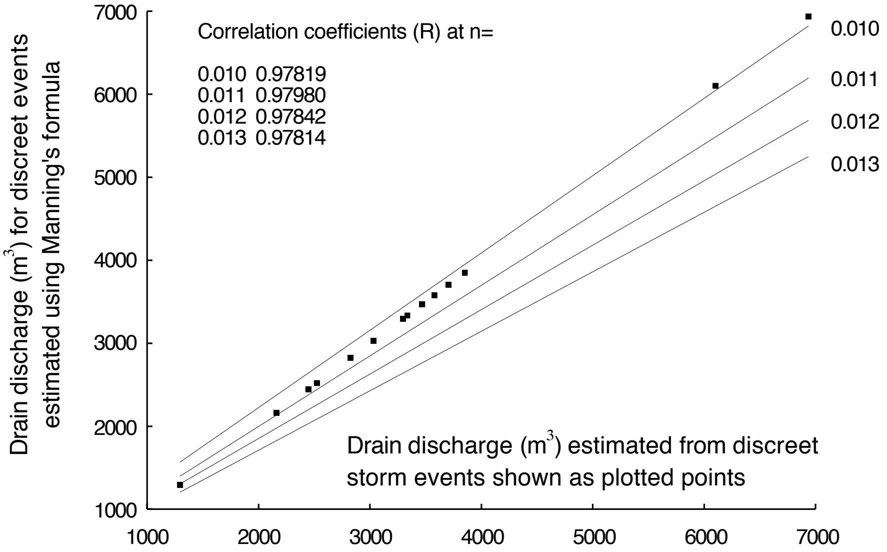


Figure 5 West Lake storm drain calibration, discharge estimates from hydrographs vs estimates at various values of Manning's 'n'

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[1] Microcom Pty Ltd P.O. Box 1182 Fremantle W.A. 6160

In all cases the same value of 'n' was applied to both drains which are of a similar age and construction. The slope of the line representing the estimated values differs from the linear best fit plots at different values of 'n'. This presumably represents inaccuracies in the estimates which rely on assumptions concerning seepage, direct rainfall and evaporative losses from a water body whose area is changing rapidly over hours. It is also likely that at low discharge, sand in the drains results in an effective rise in 'n' while at high discharge effective 'n' is decreased. Discharge rates were calculated using 'n' of 0.011 which is considered 'normal' for concrete pipes free of debris (Chow 1959). Discharge events exceeding 3000m^3 were calculated at 'n' of 0.010, corresponding to Chow's 'minimum' value for drains of this construction.

Appendix 5.2 Estimation of Missing Data

Balance periods 1-5 (East Lake) and 1-6 (West Lake) predate complete instrumentation of the drains. Estimates of total drain inputs for each lake for rain events during these balance periods were calculated using relationships derived from rainfall versus total measured drain flow where complete data was available (Figure 1 a&b).

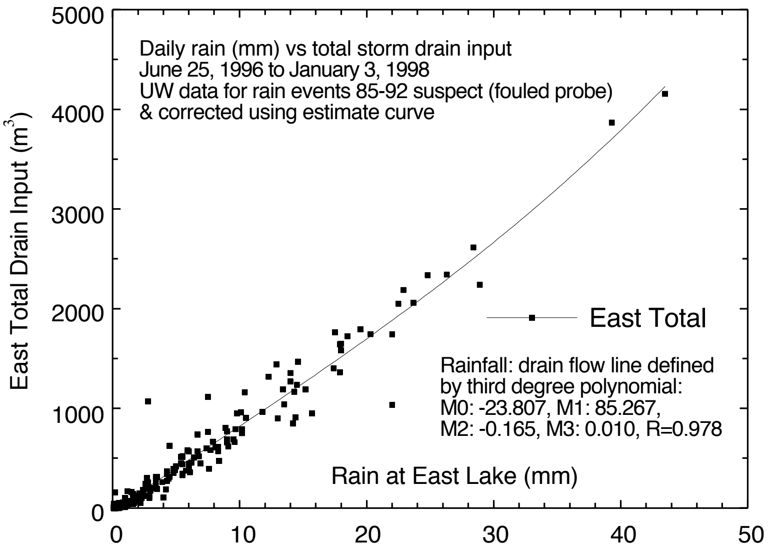


Figure 1a East Lake Rainfall vs Total Drain Input (PE, BB, CS & UW drains)

This method of estimation assumes that rainfall measured at Perry Lakes was consistently equal to that occurring everywhere in the drain catchment. It also assumes that rainfall-run off relationships did not vary seasonally (Viessman *et al* 1989). Neither assumption is strictly valid however curves were considered sufficiently accurate to provide reasonable estimates of drain flow.

Correction of Flow Peak Suppression

The depth range over which the DDT-200 transducer operates is approximately 0.4 to 5.0m. Transducer-water distances less than 40cm occupy a 'dead zone' within which no or erroneous data will occur. Normal installation procedure is to place the transducer at a height where the maximum anticipated water height occurs outside the dead zone. Height limitations in the West Lake drain saddle traps (Figure 5.4) meant that during a number of extreme rain events levels in the West Lake, drains entered the dead zone.

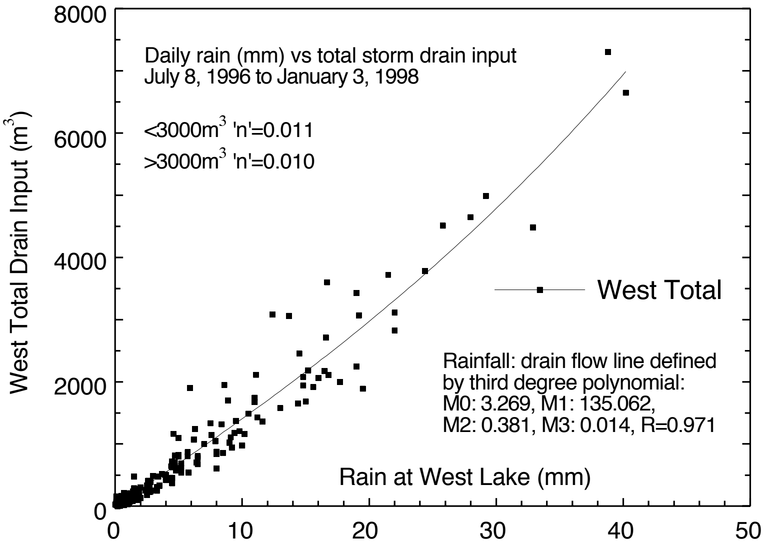


Figure 1b West Lake Rainfall vs Total Drain Input (East & West pipes)

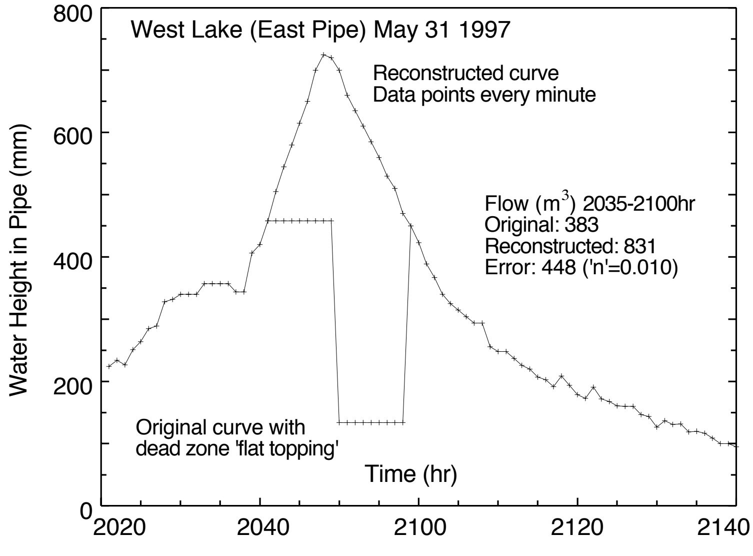


Figure 2 Typical correction for peak flows within acoustic transducer 'dead zone'. Trend of slope each side of the dead zone was extrapolated, curve shape adjusted to match that in adjacent pipe

These incursions are expressed either as 'flat topped' flow peaks and/or sudden reversion to very low flow values (Figure 2). Incursions into the dead zone were recorded on 15 occasions. Flow values were corrected by reconstructing the curves (extrapolating the rate of rise and fall) and calculating the missing flow volumes.

Appendix 6.1

Lake Stage and Inputs Summary Balance Periods 1-50

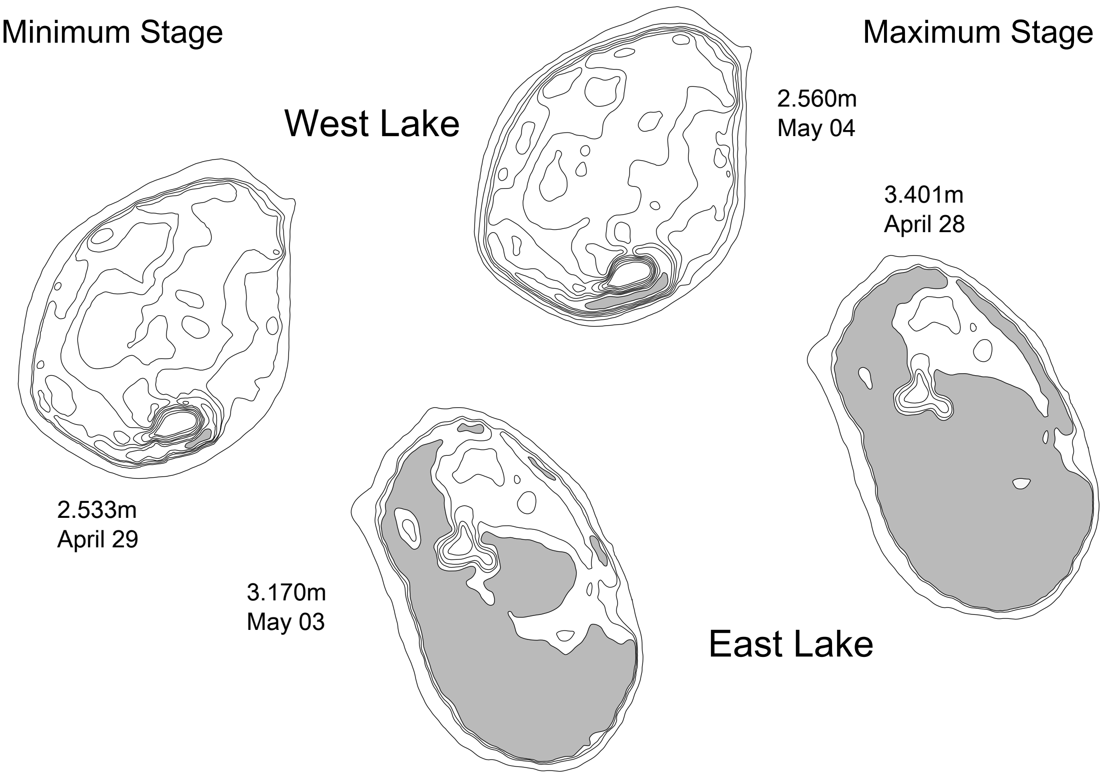
There are 50 balance periods, each with a number (usually three) four day sub-balances.

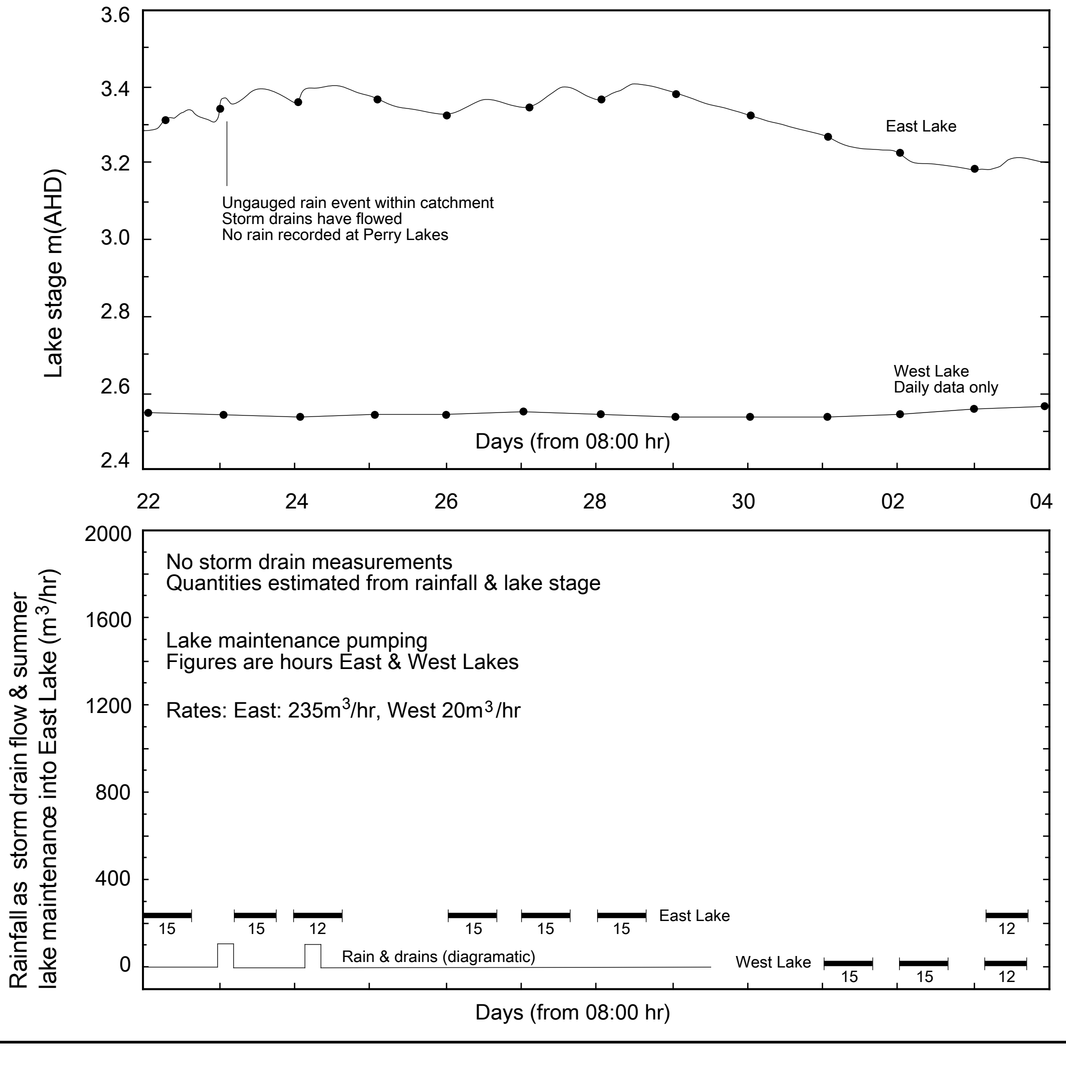
Balance	Start	End	Days	Balance	Start	End	Days
1996							
1	April 22	May 04	12	26	March 04	March 16	12
2	May 04	May 16	12	27	March 16	March 28	12
3	May 16	May 28	12	28	March 28	April 09	12
4	May 28	June 09	12	29	April 09	April 21	12
5	June 09	June 25	16	30	April 21	May 03	12
6	June 25	July 07	12	31	May 03	May 15	12
7	July 07	July 19	12	32	May 15	May 27	12
8	July 19	August 08	20	33	May 27	June 16	20
9	August 08	August 20	12	34	June 16	June 28	12
10	August 20	September 01	12	35	June 28	July 10	12
11	September 01	September 13	12	36	July 10	July 22	12
12	September 13	September 25	12	37	July 22	August 03	12
13	September 25	October 07	12	38	August 03	August 19	16
14	October 07	October 19	12	39	August 19	August 31	12
15	October 19	October 31	12	40	August 31	September 12	12
16	October 31	November 12	12	41	September 12	September 24	12
17	November 12	November 24	12	42	September 24	October 06	12
18	November 24	December 10	16	43	October 06	October 18	12
19	December 10	December 22	12	44	October 18	October 30	12
1997				45	October 30	November 11	12
20	December 22	January 03	12	46	November 11	November 23	12
21	January 03	January 15	12	47	November 23	December 05	12
22	January 15	January 27	12	48	December 05	December 17	12
23	January 27	February 08	12	49	December 17	December 25	8
24	February 08	February 20	12	1998			
25	February 20	March 04	12	50	December 25	January 03	9

There is one sheet for each balance period. Thumbnail maps of East and West Lake show date and height of minimum and maximum lake stage and the water cover in each basin over the balance period. The maps are miniatures of Figures 3.10 a&b. Dual graphs plot lake stage (as daily manual staff gauge readings indicated by bullets and the trace from electronic lake level loggers), relative rainfall (as indicated by aggregate storm drain flow volumes) and lake maintenance pumping. The pumping is shown as bar graphs with pumping time in hours.

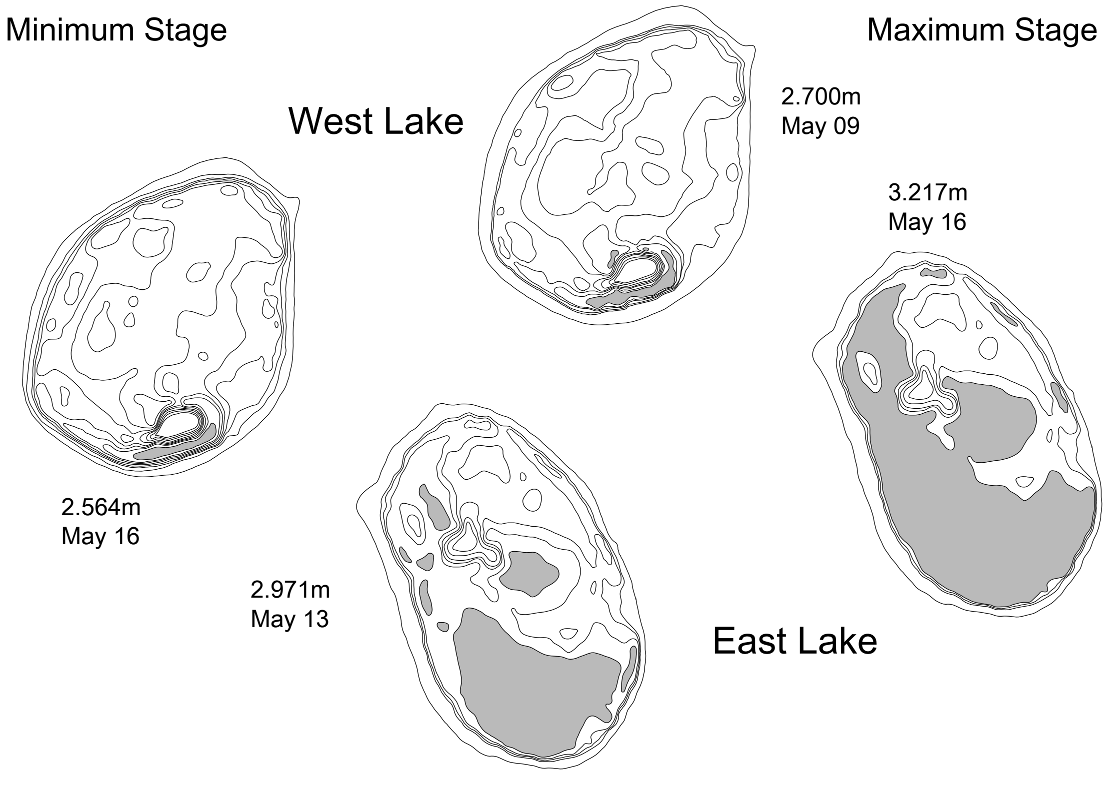
These summary sheets provide an over view of lake hydrology to complement and to be examined in conjunction with the balance sheets (Appendices 6.2 and 6.3).

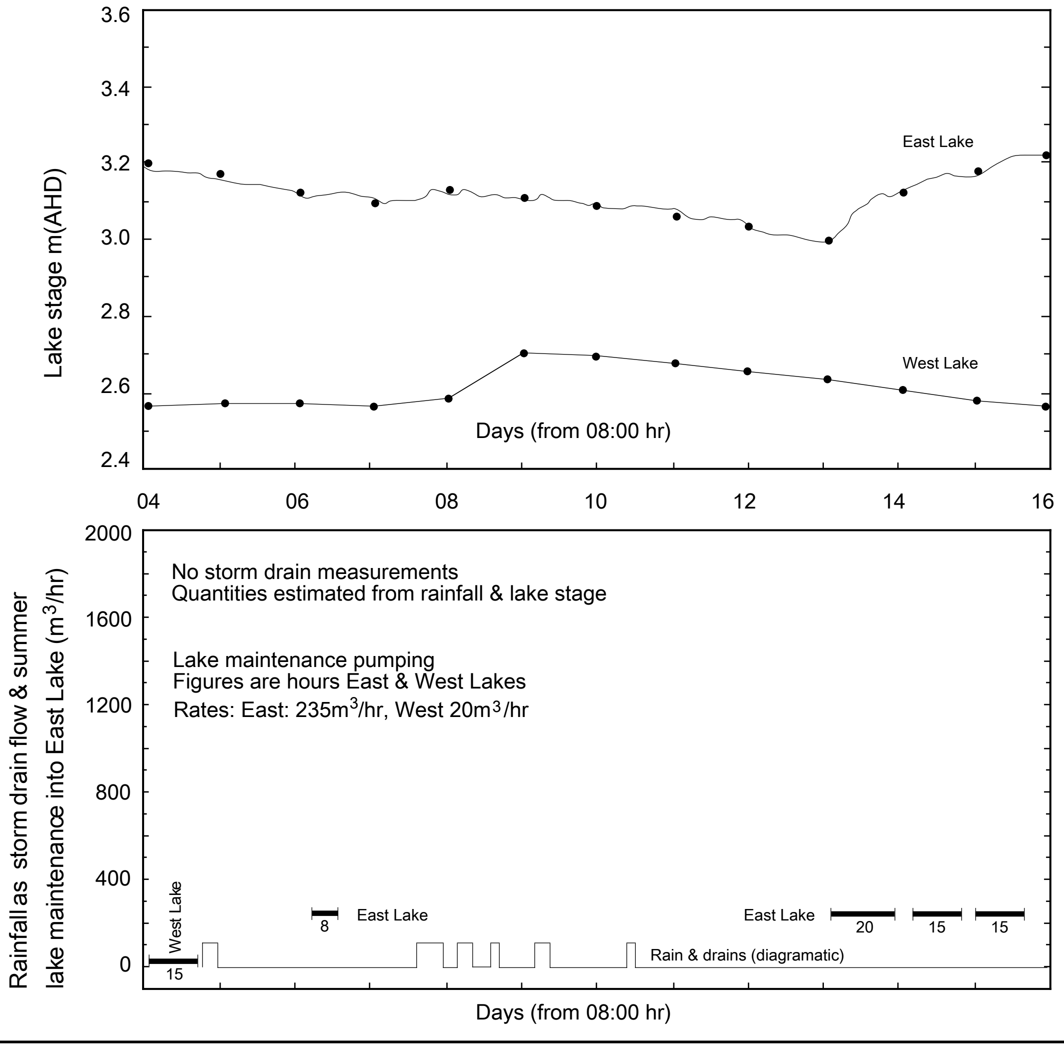
Balance 01 April 22 to May 04 1996



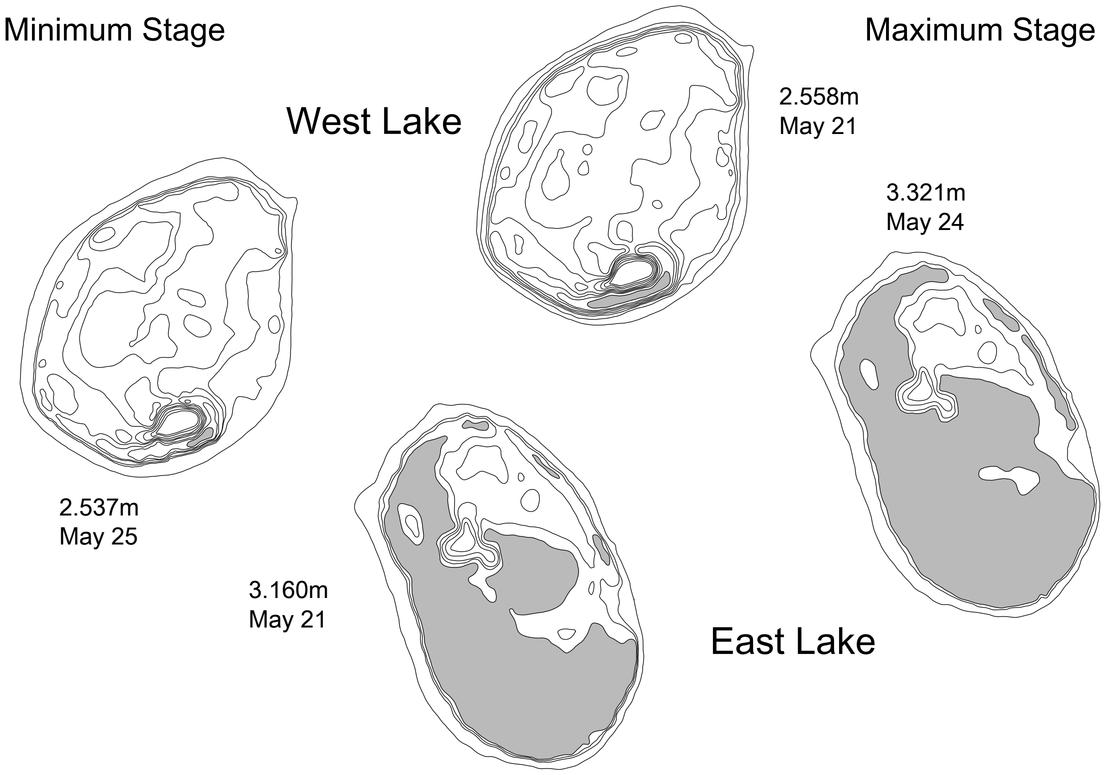


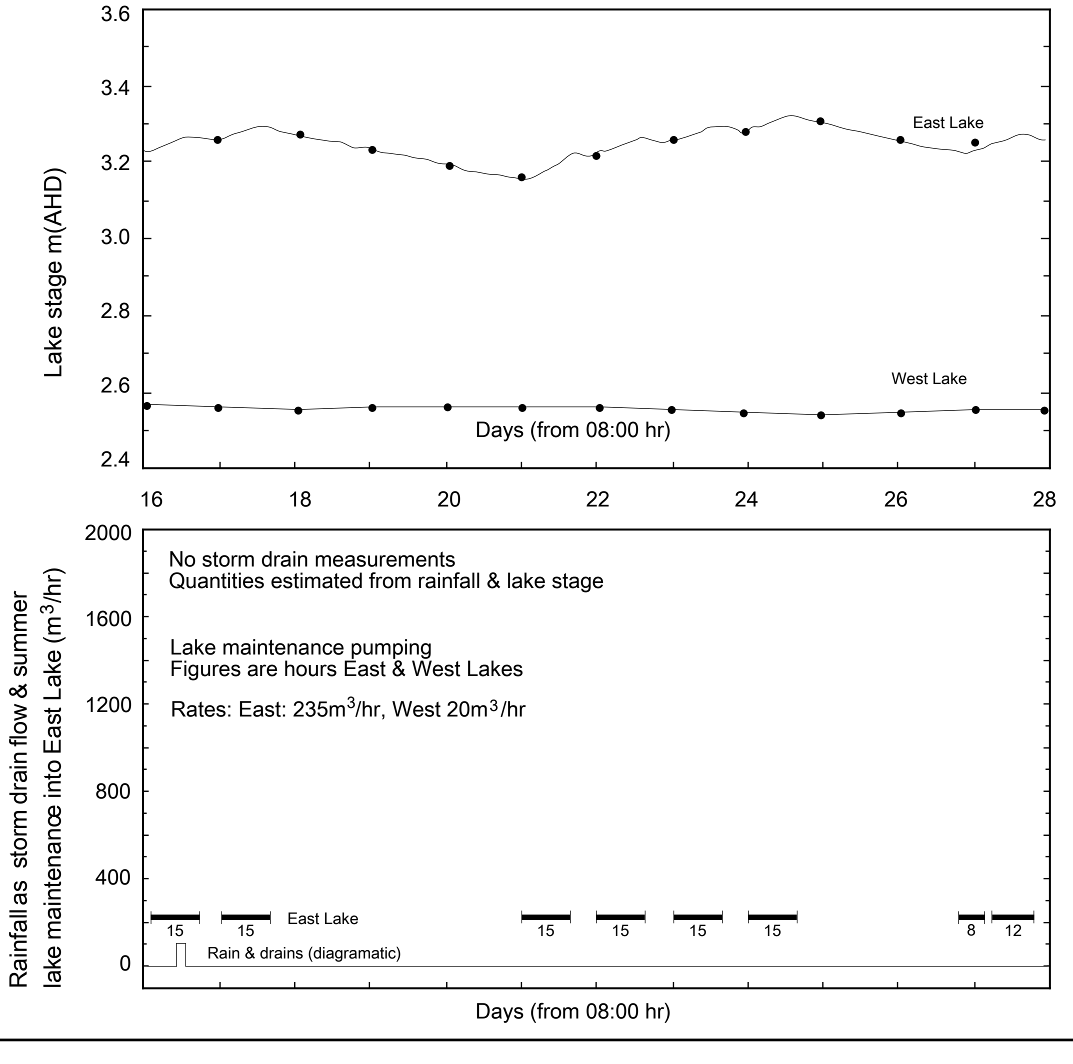
Balance 02 May 04 to May 16 1996



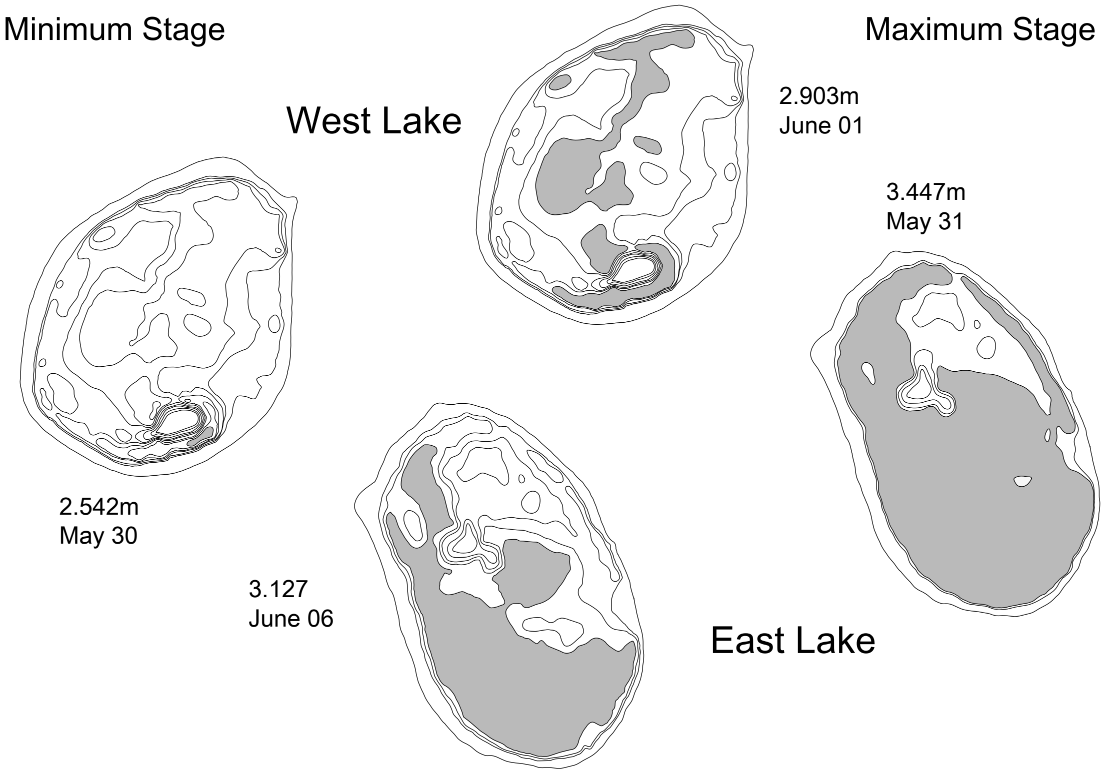


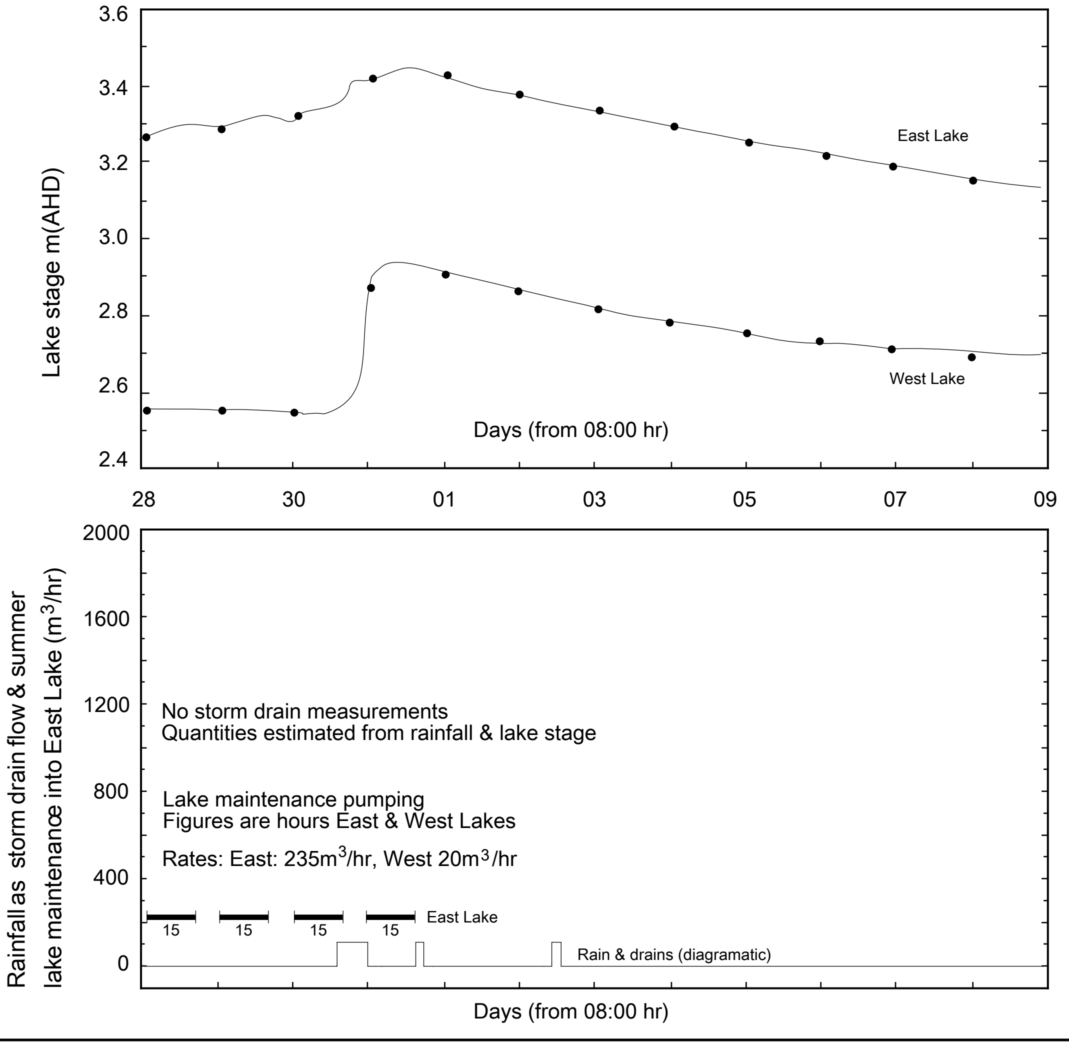
Balance 03 May 16 to May 28 1996



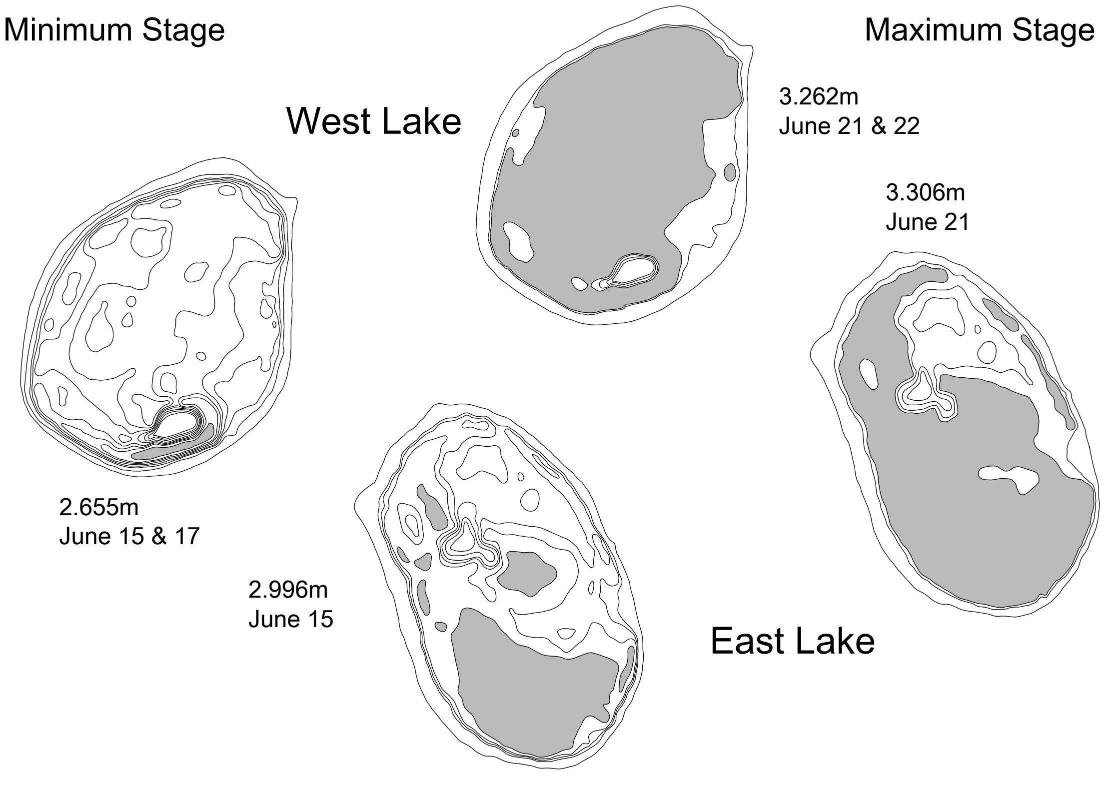


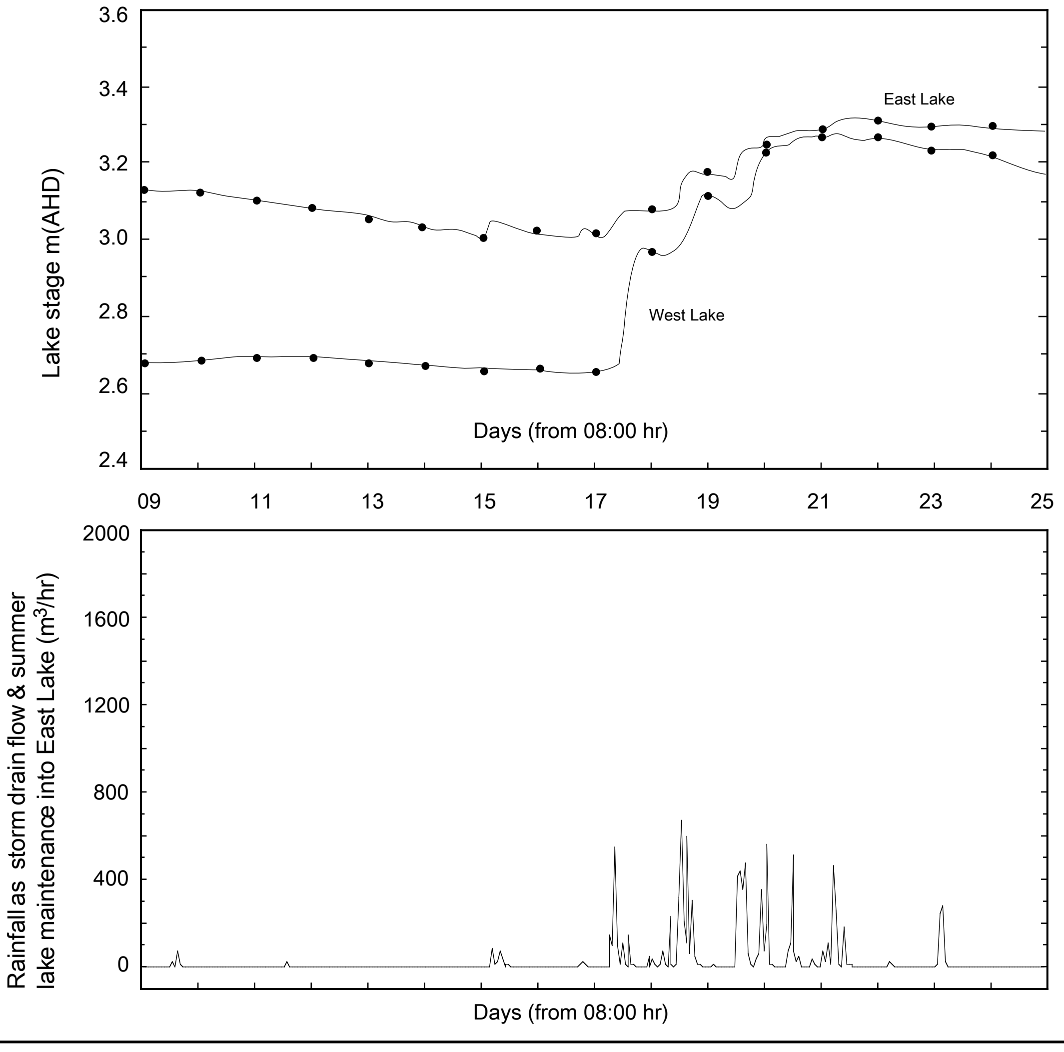
Balance 04 May 28 to June 09 1996



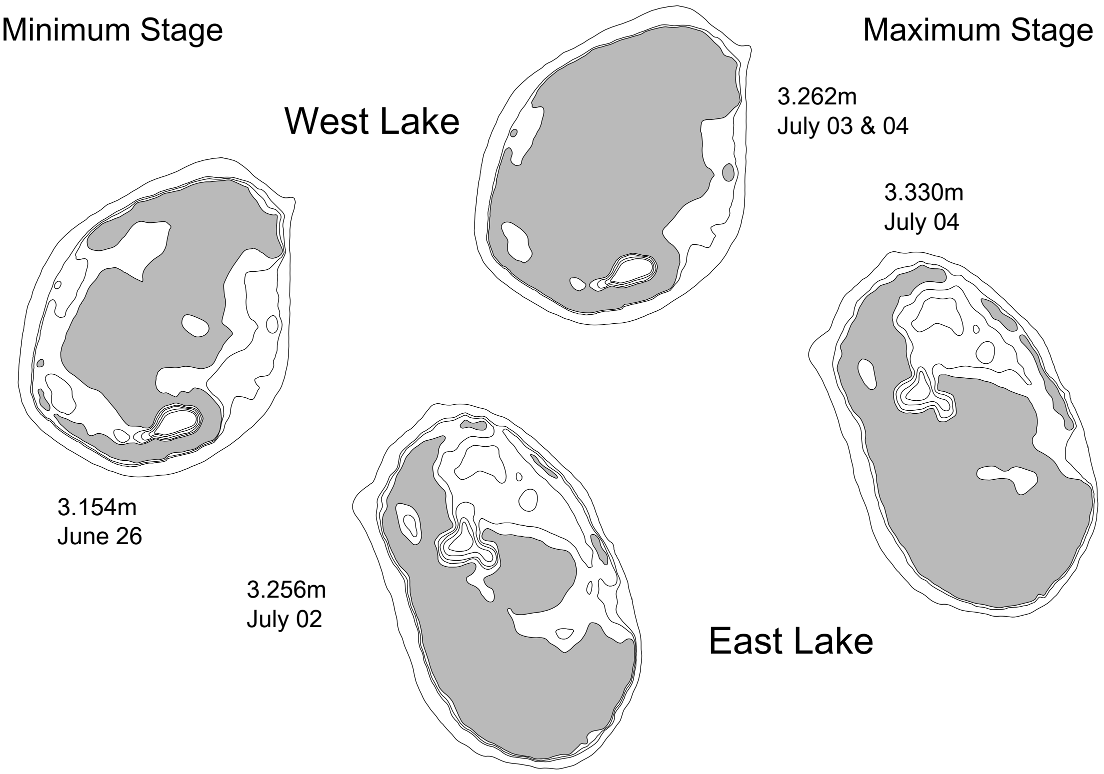


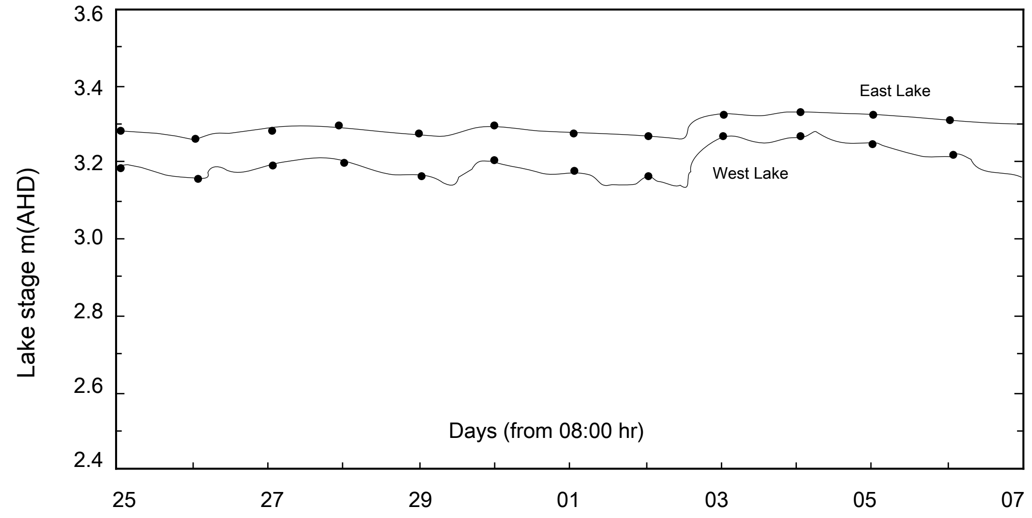
Balance 05 June 09 to June 25 1996

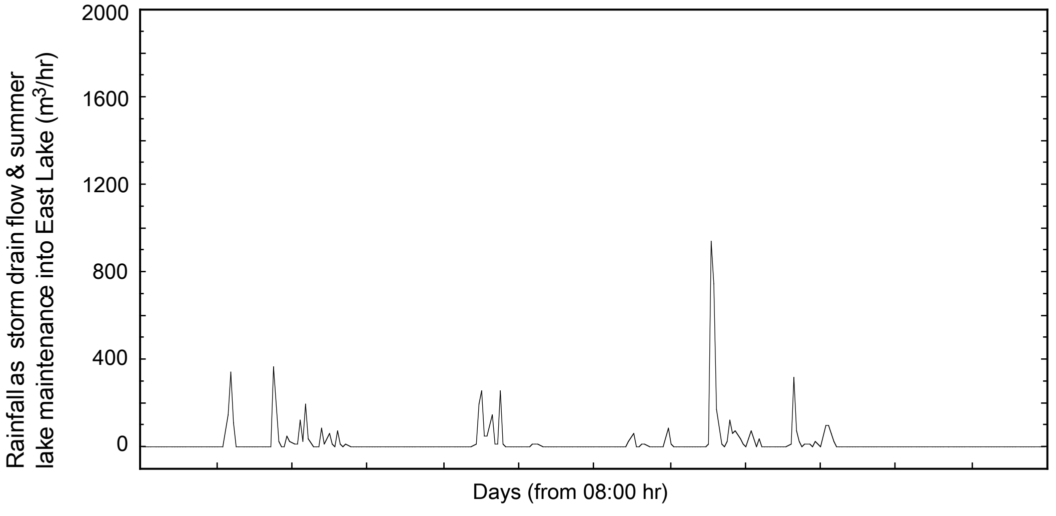




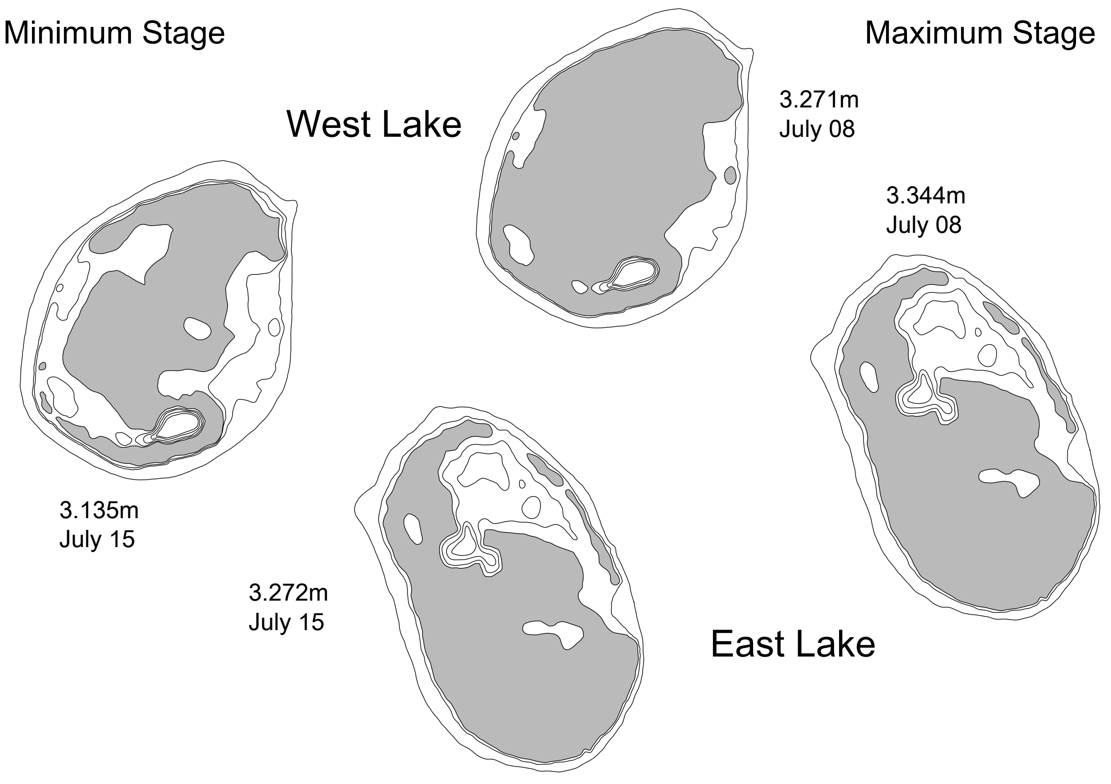
Balance 06 June 25 to July 07 1996

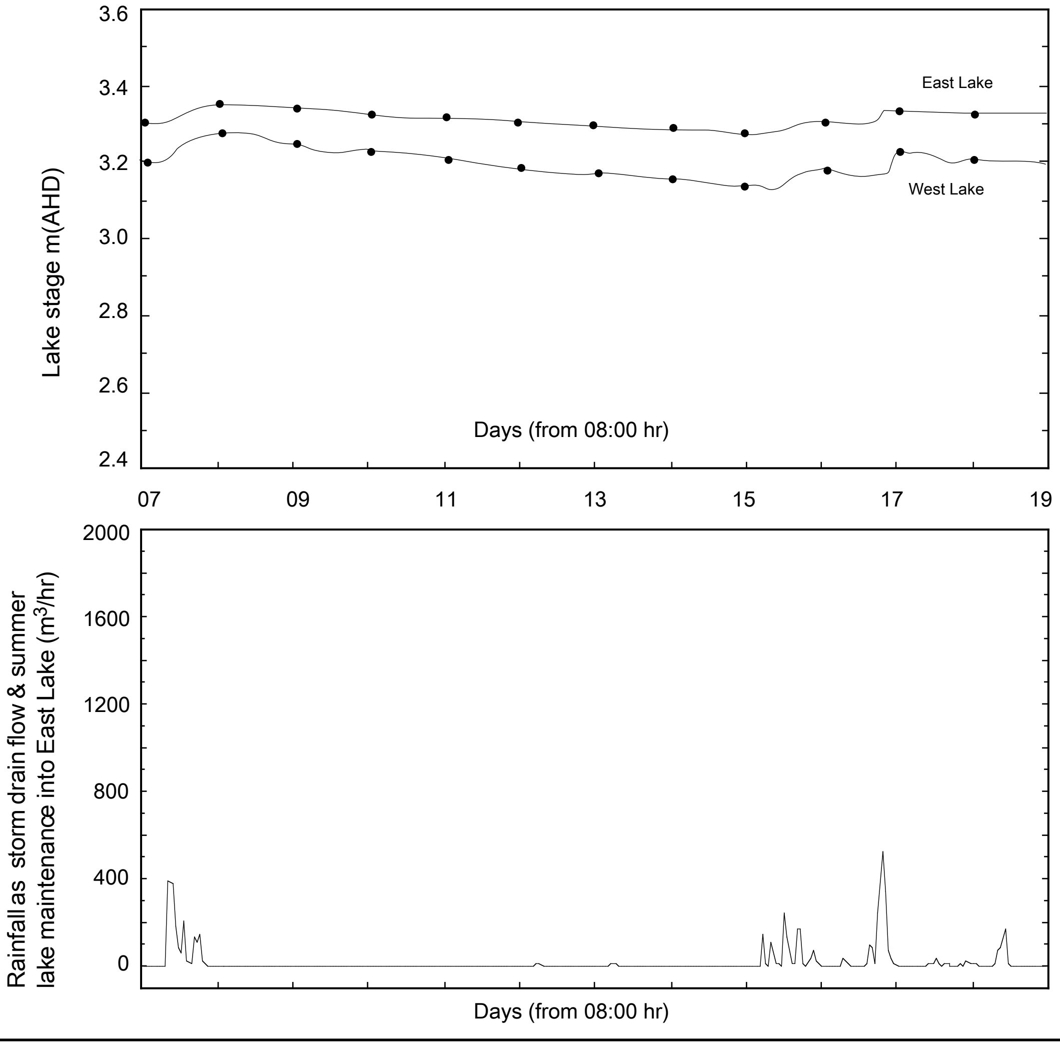




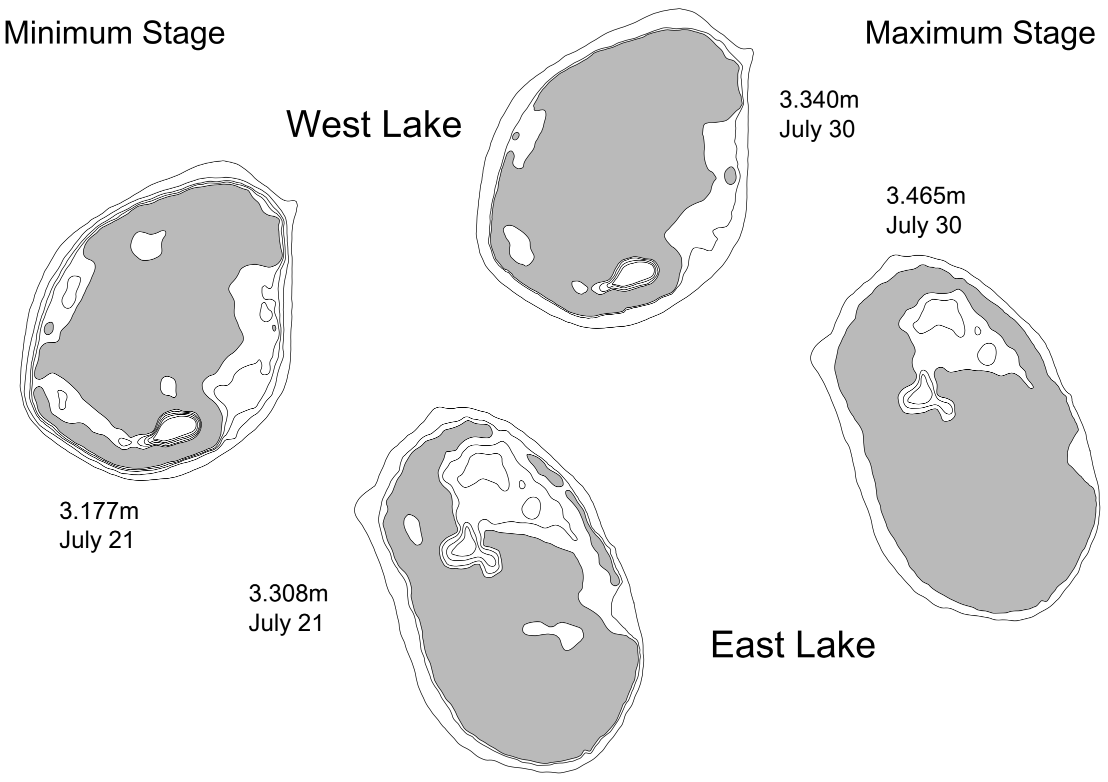


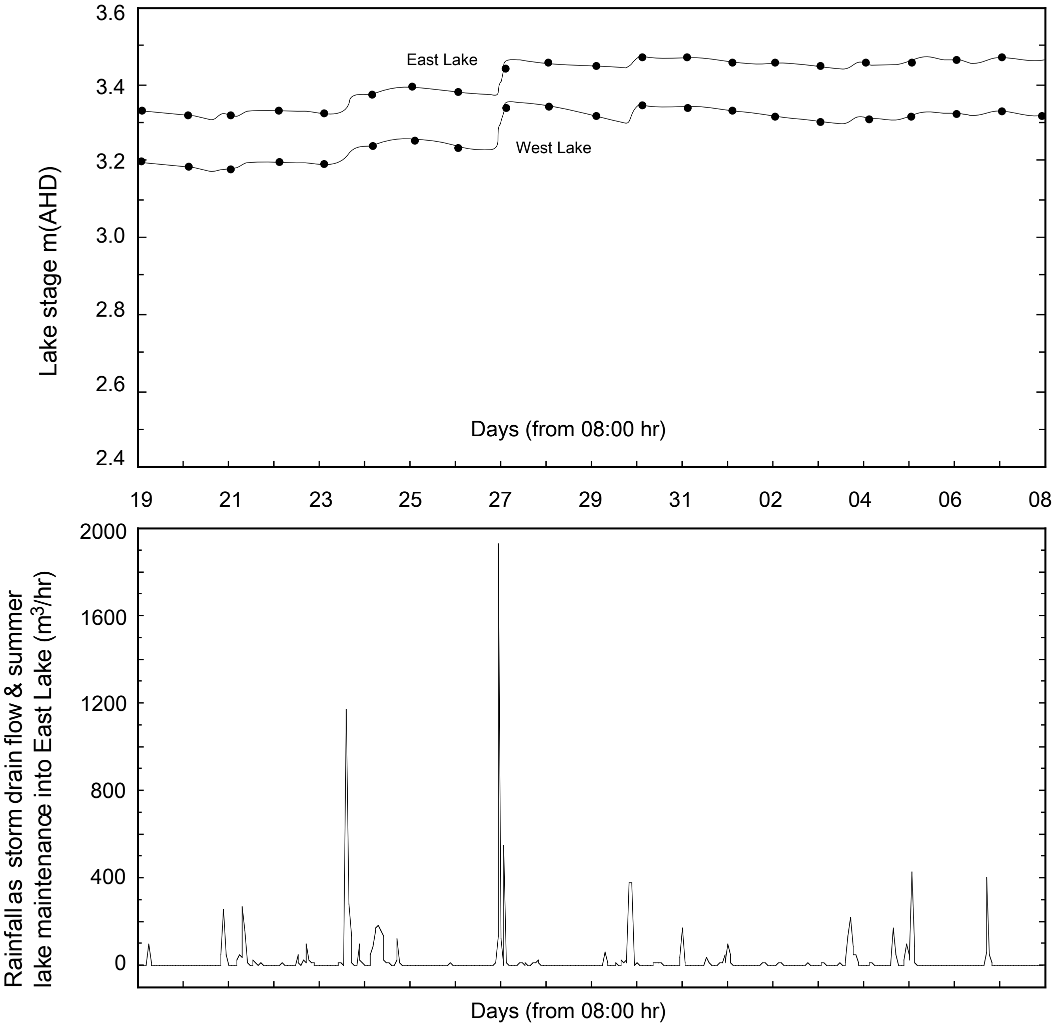
Balance 07 July 07 to July 19 1996



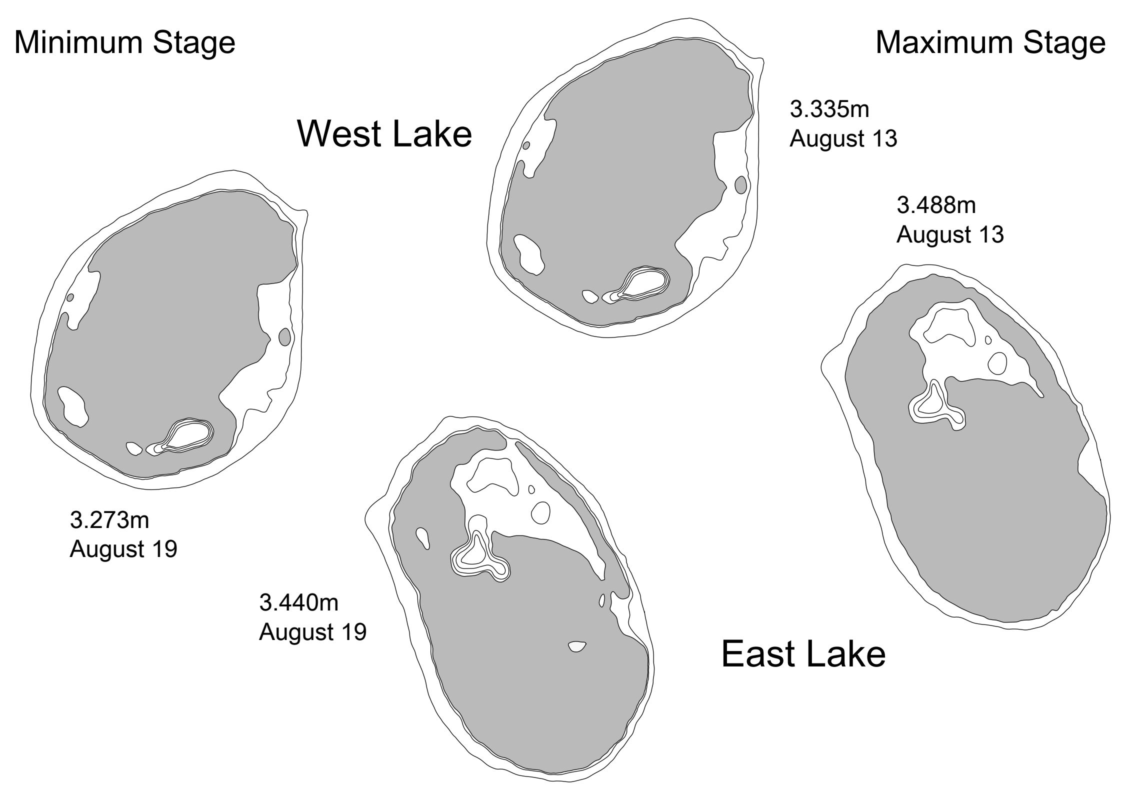


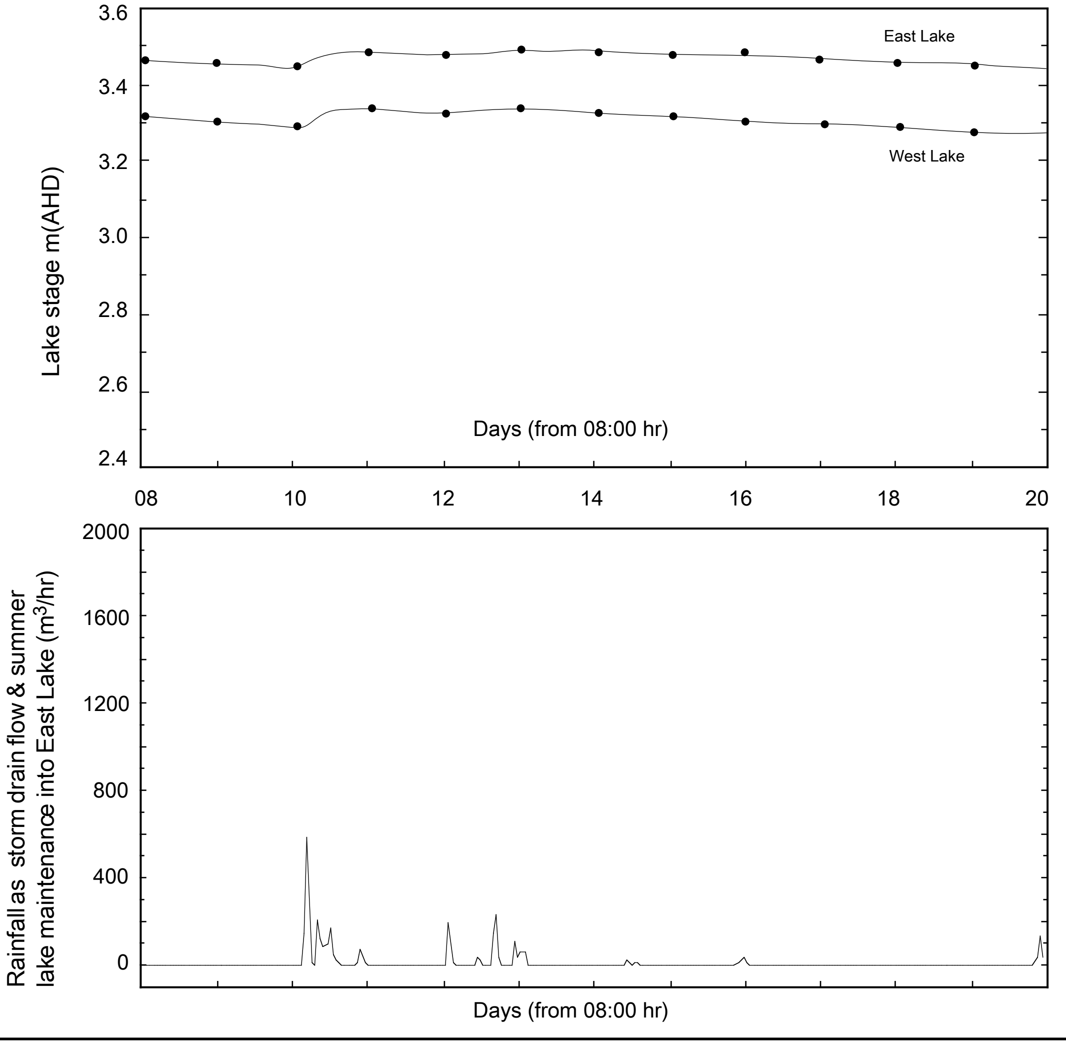
Balance 08 July 19 to August 08 1996



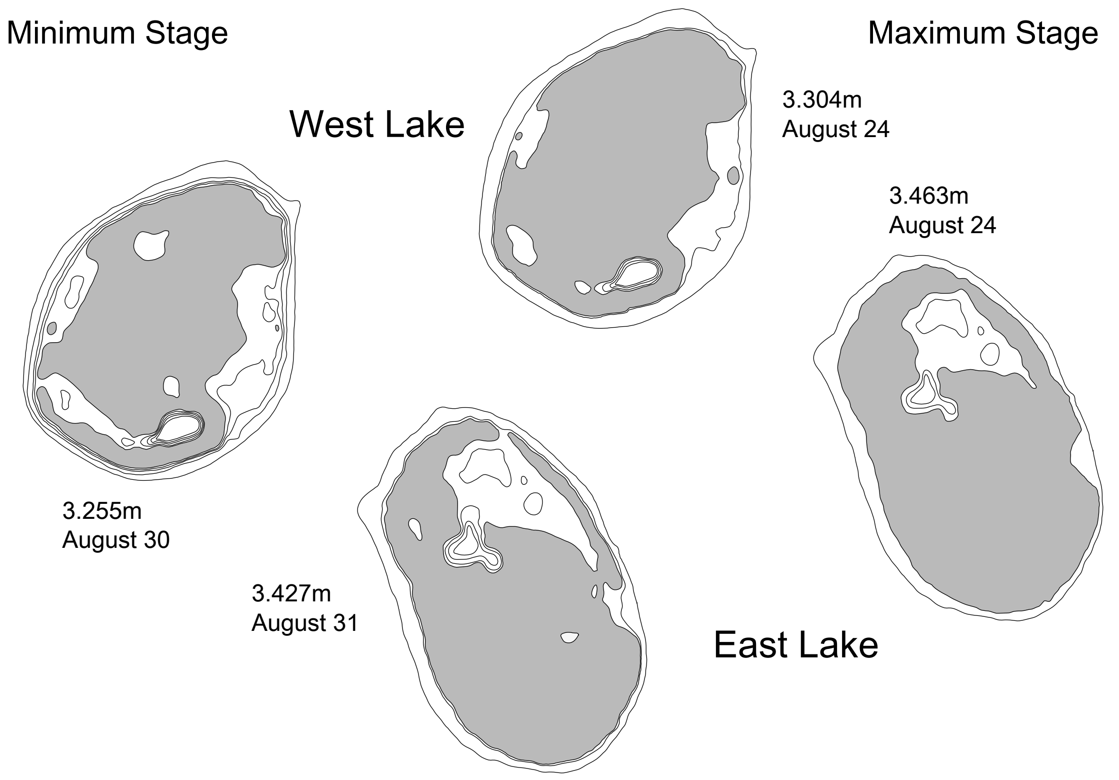


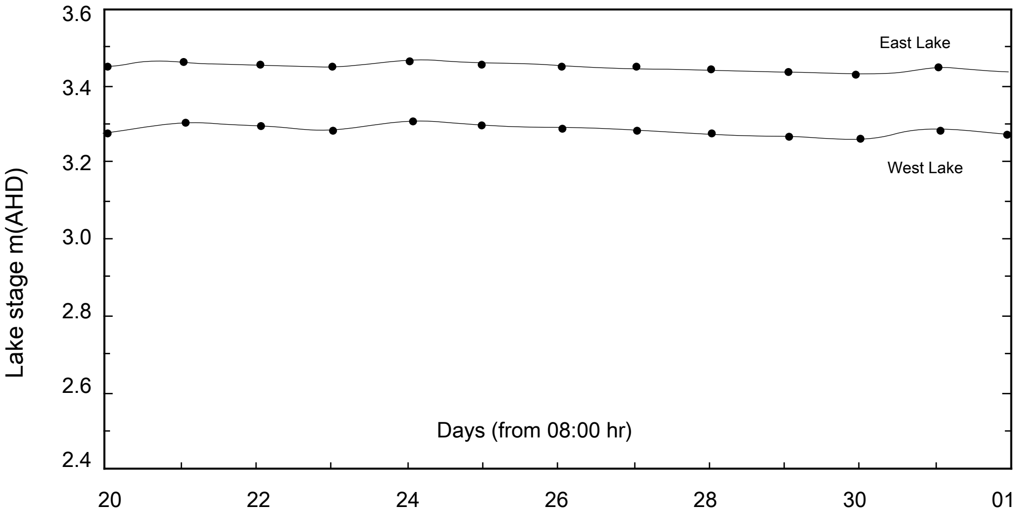
Balance 09 August 08 to August 20 1996

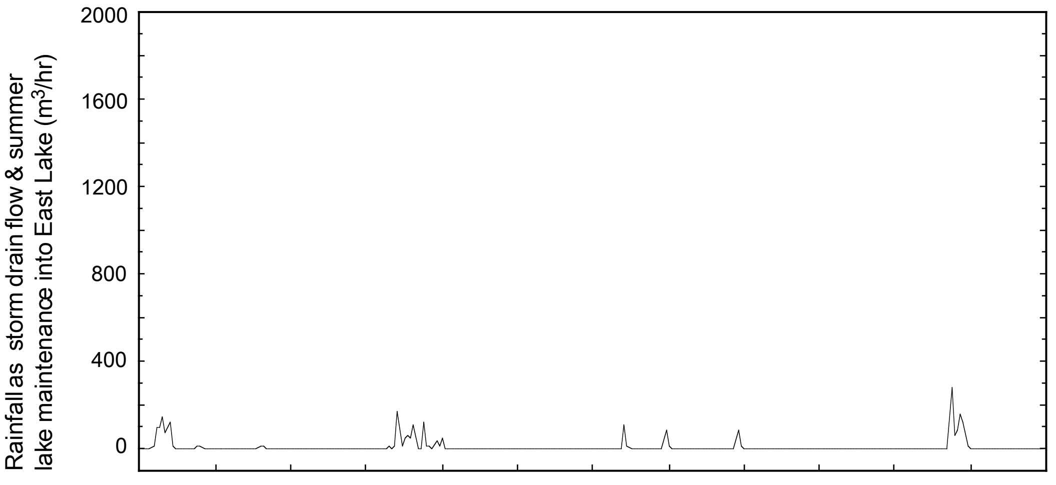




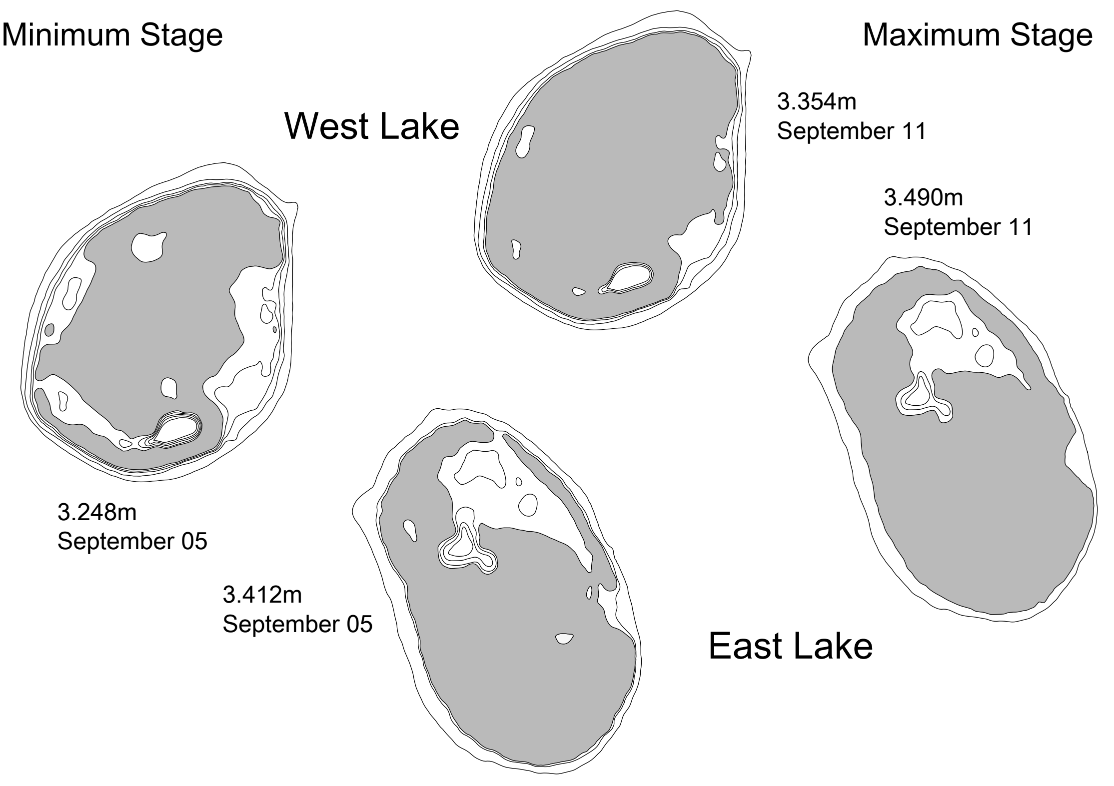
Balance 10 August 20 to September 01 1996

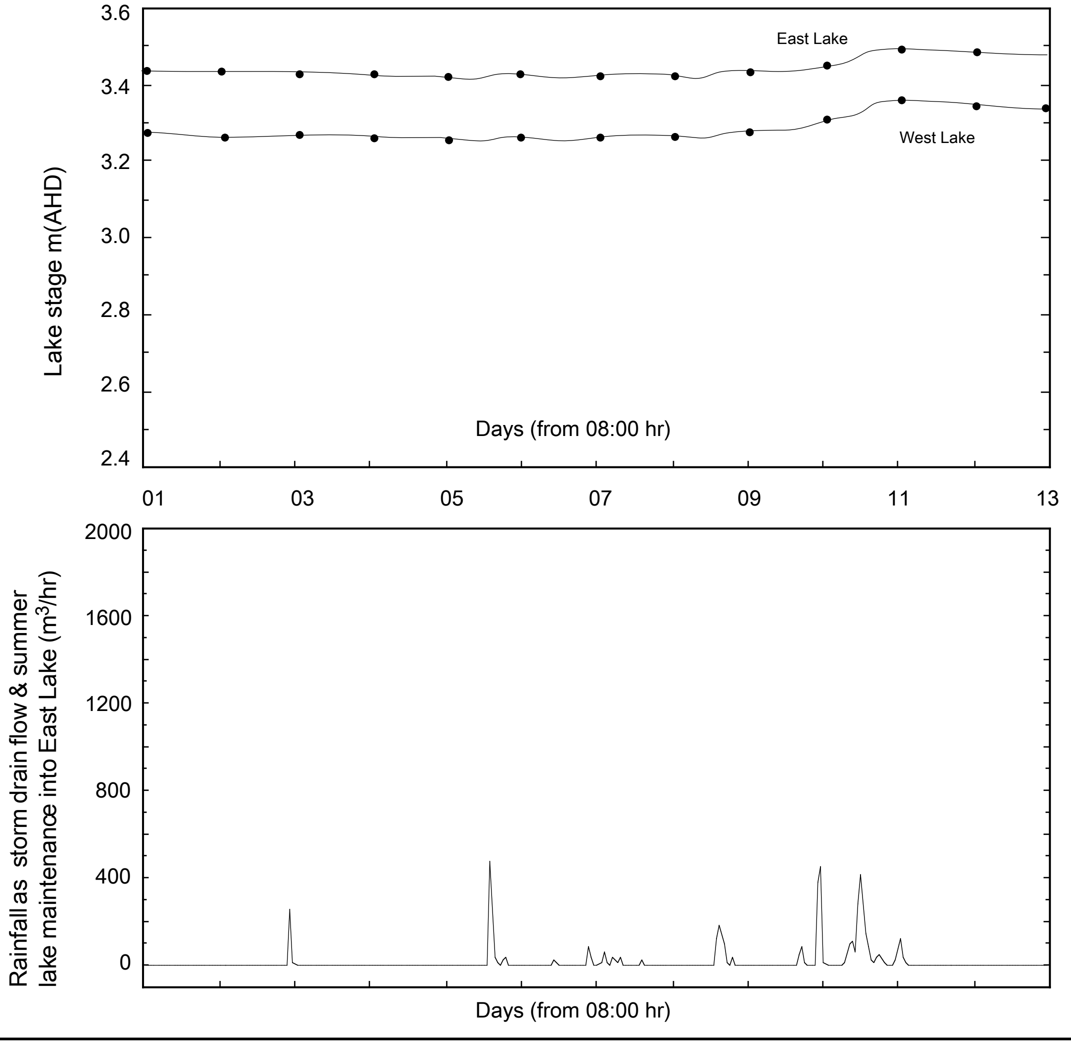




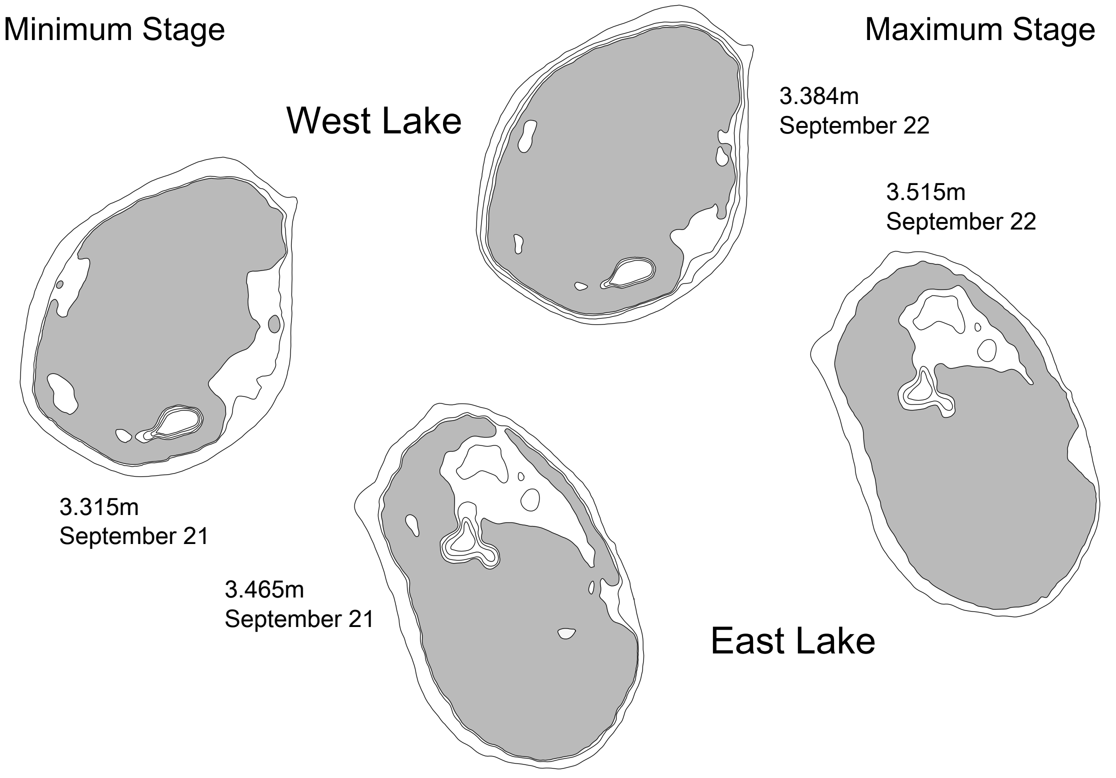


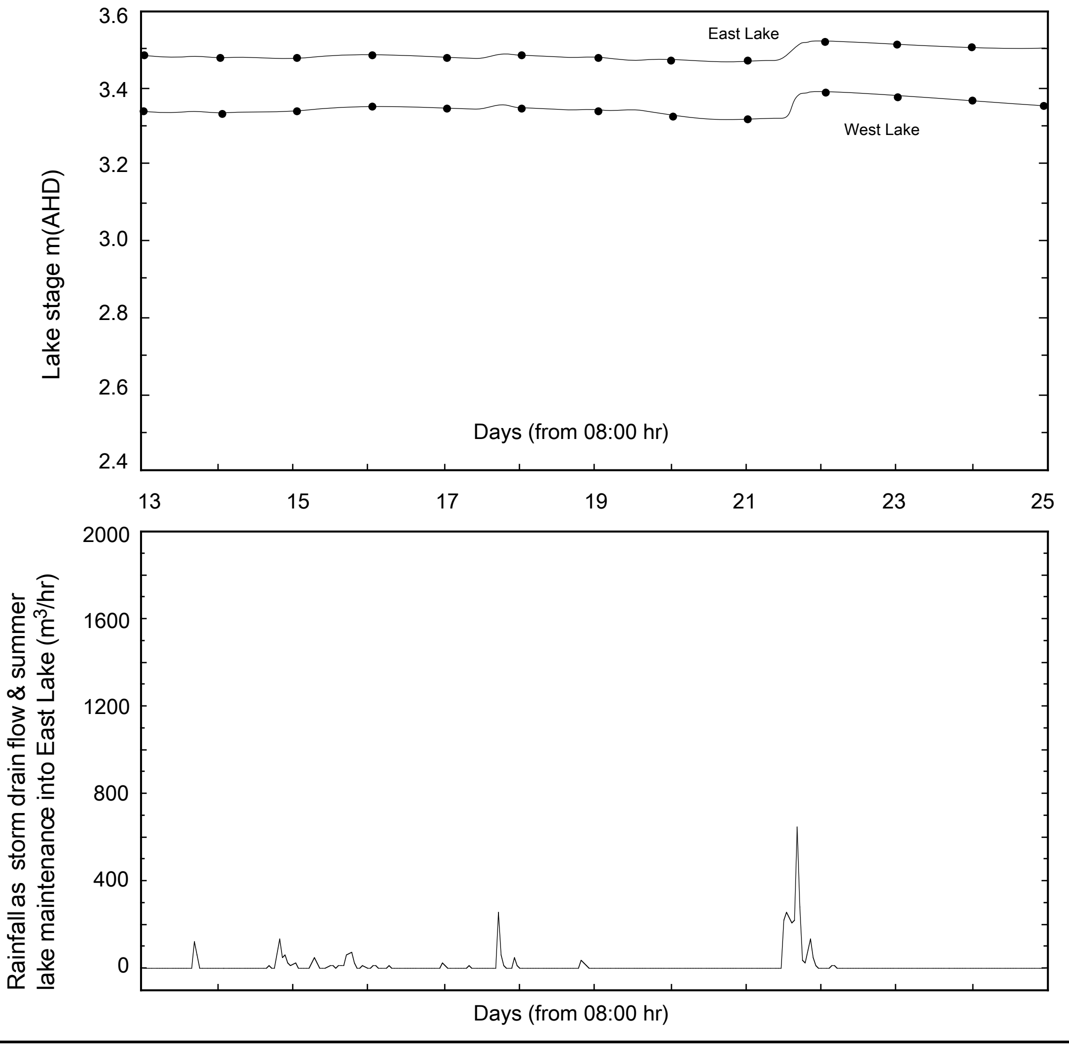
Balance 11 September 01 to September 13 1996



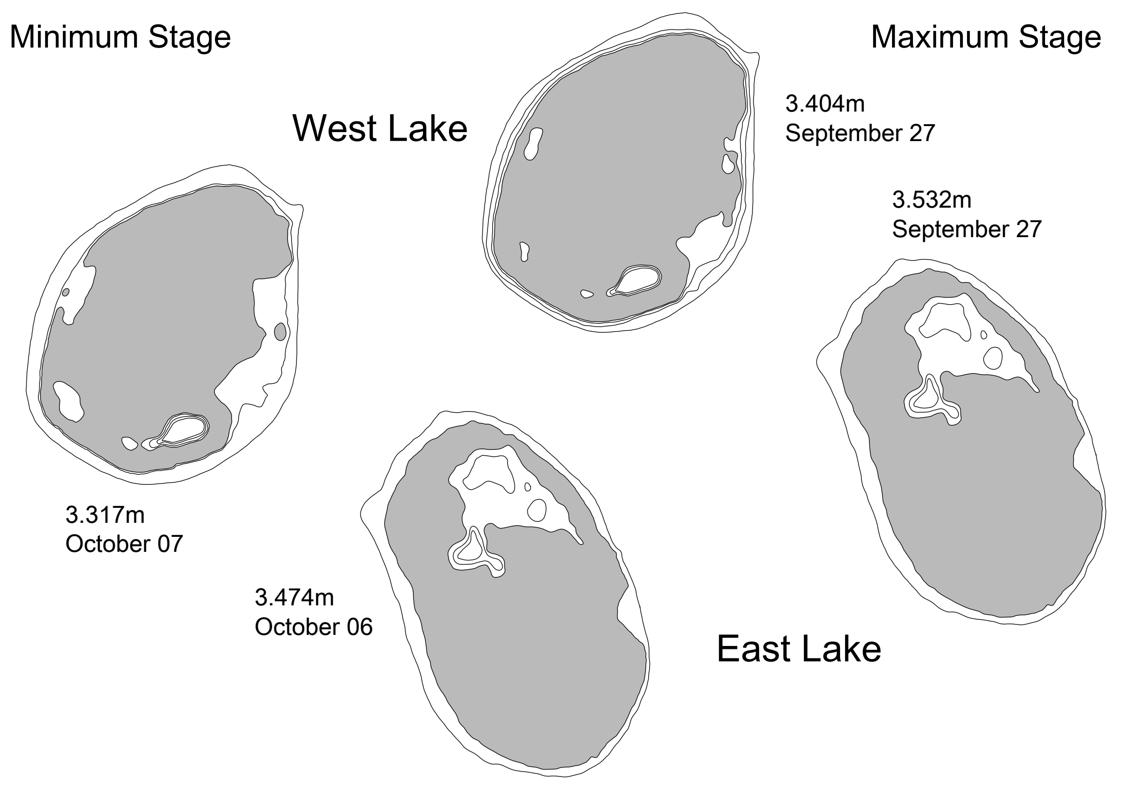


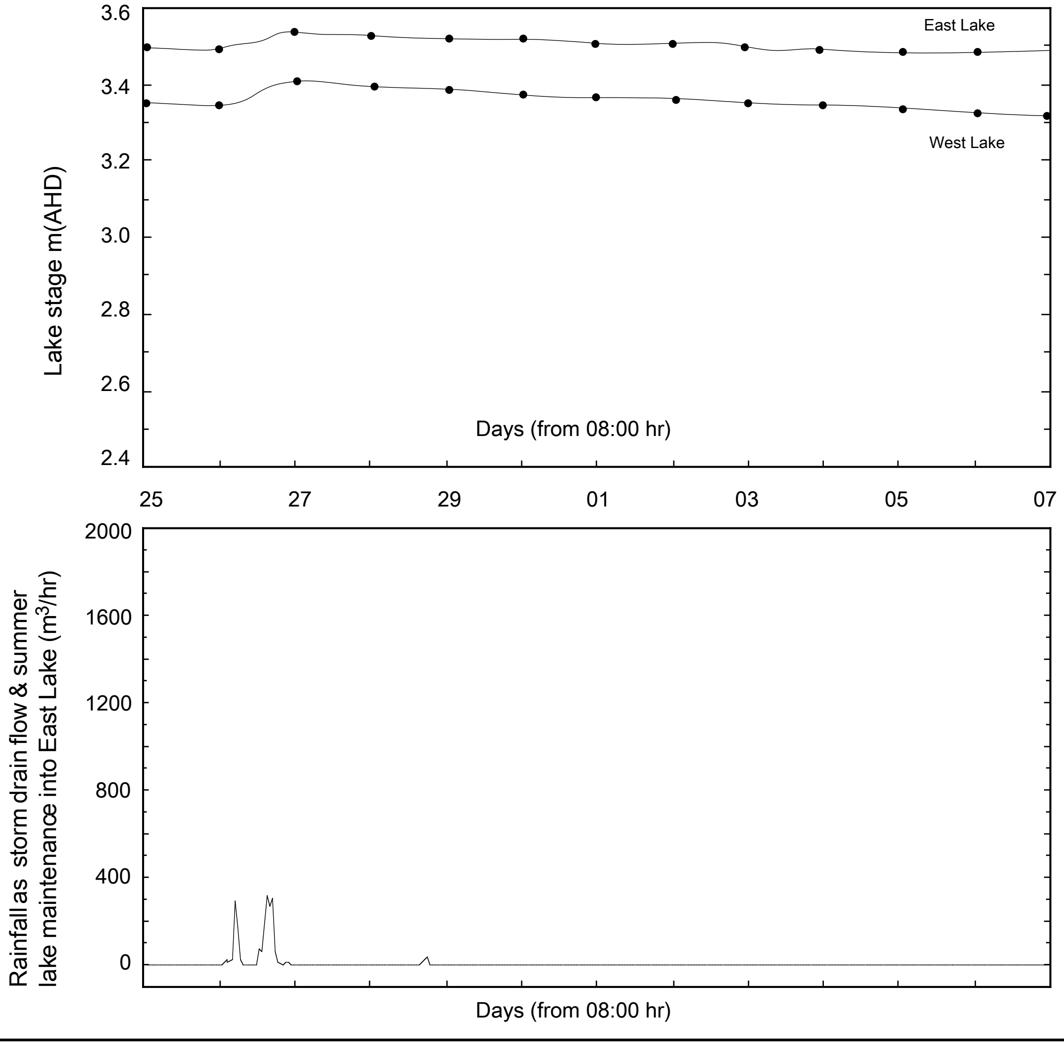
Balance 12 September 13 to September 25 1996



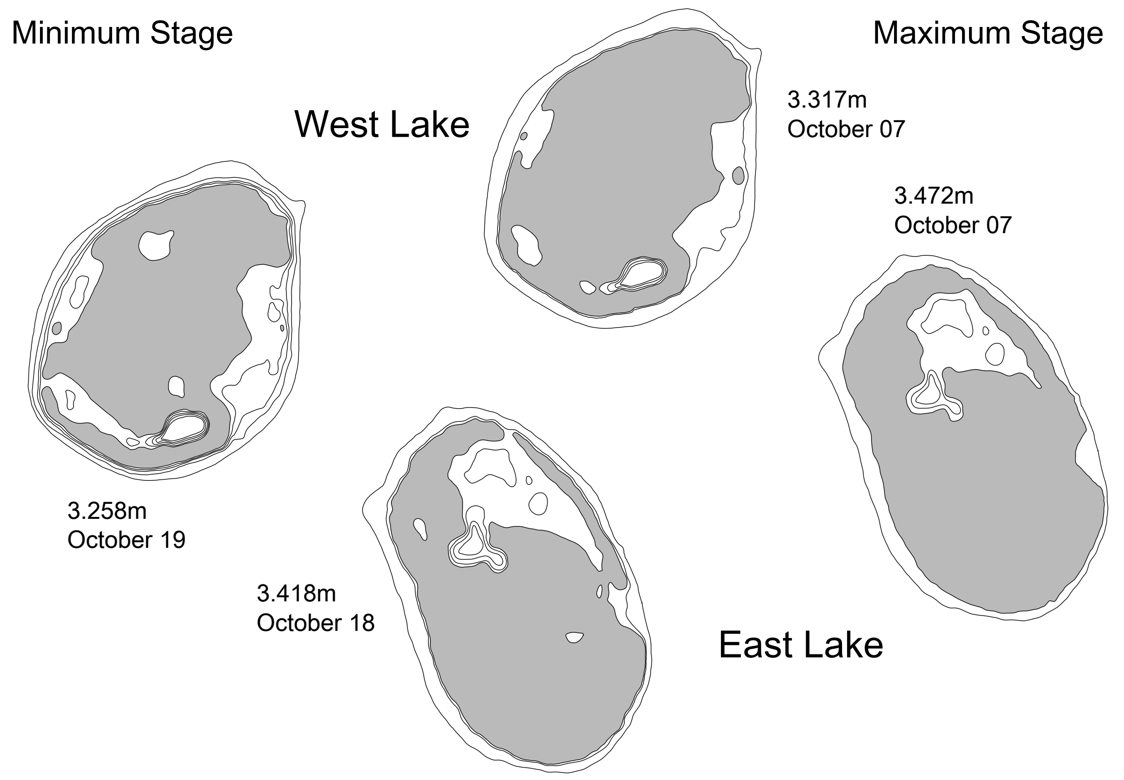


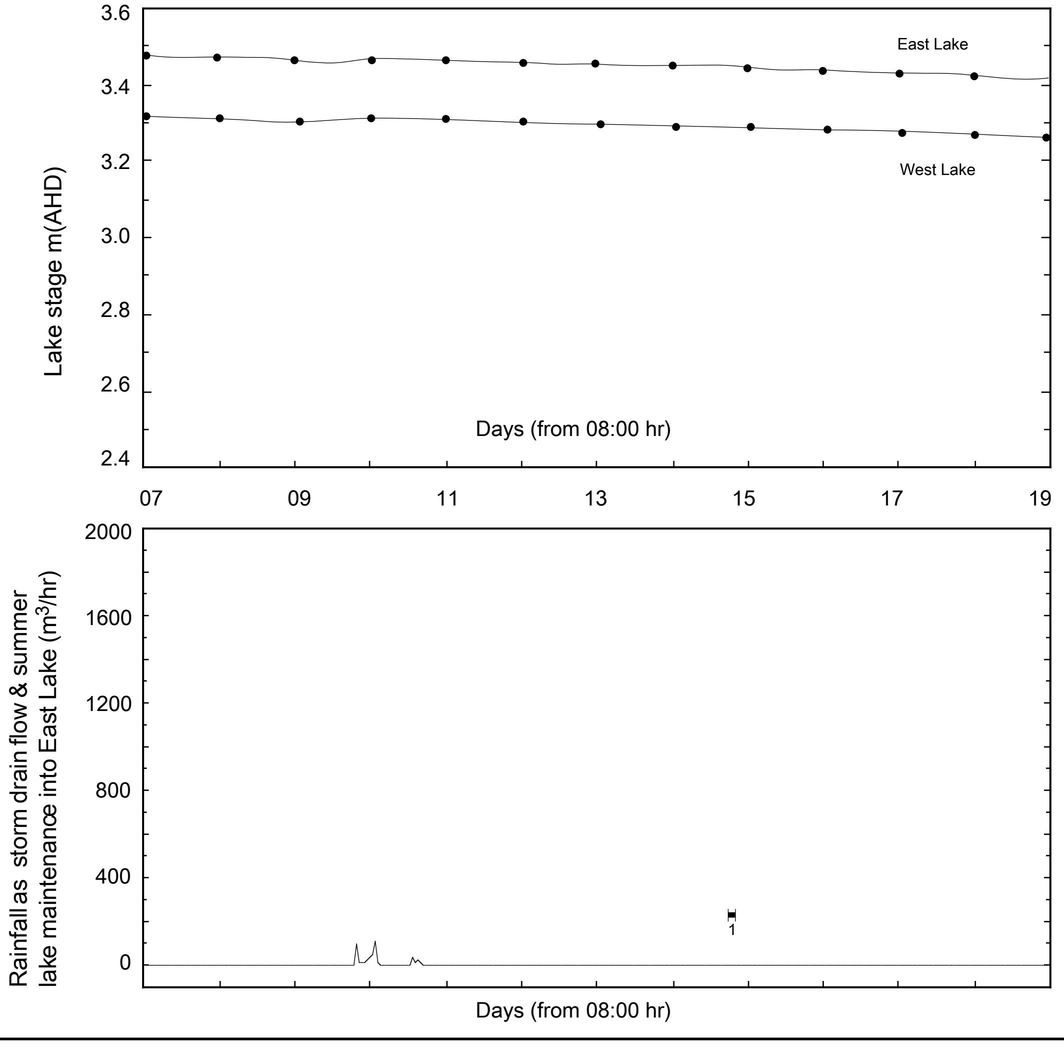
Balance 13 September 25 to October 07 1996



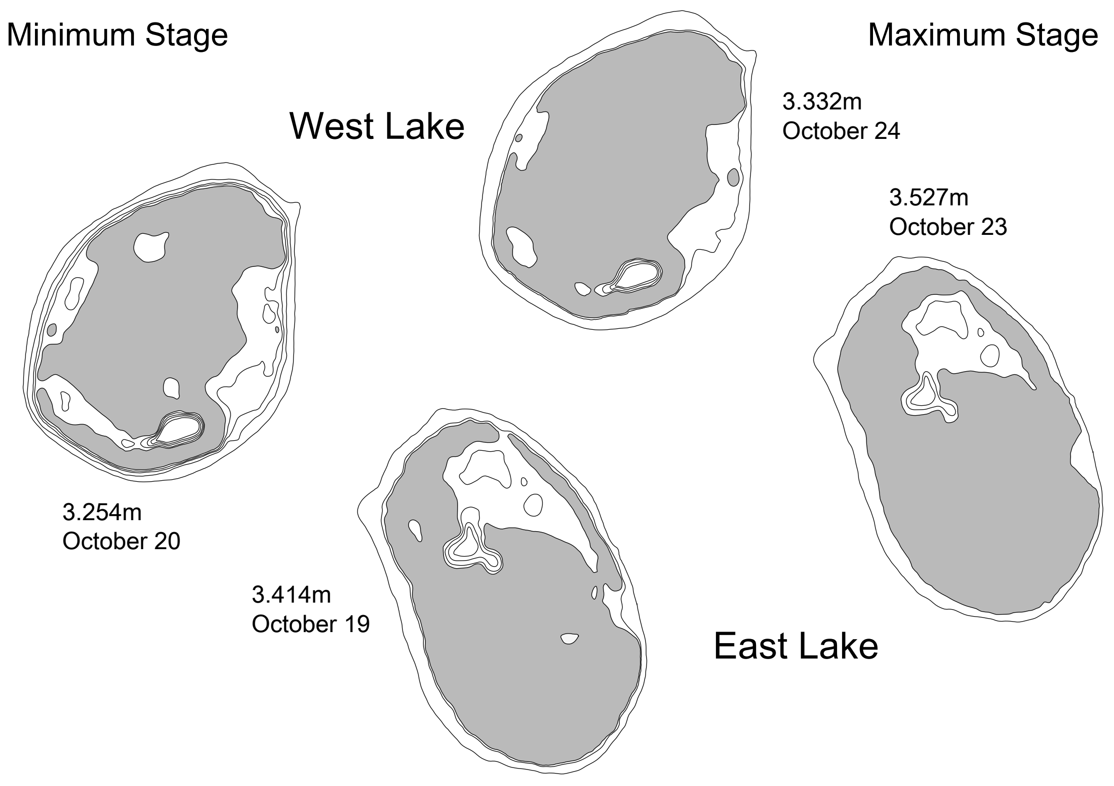


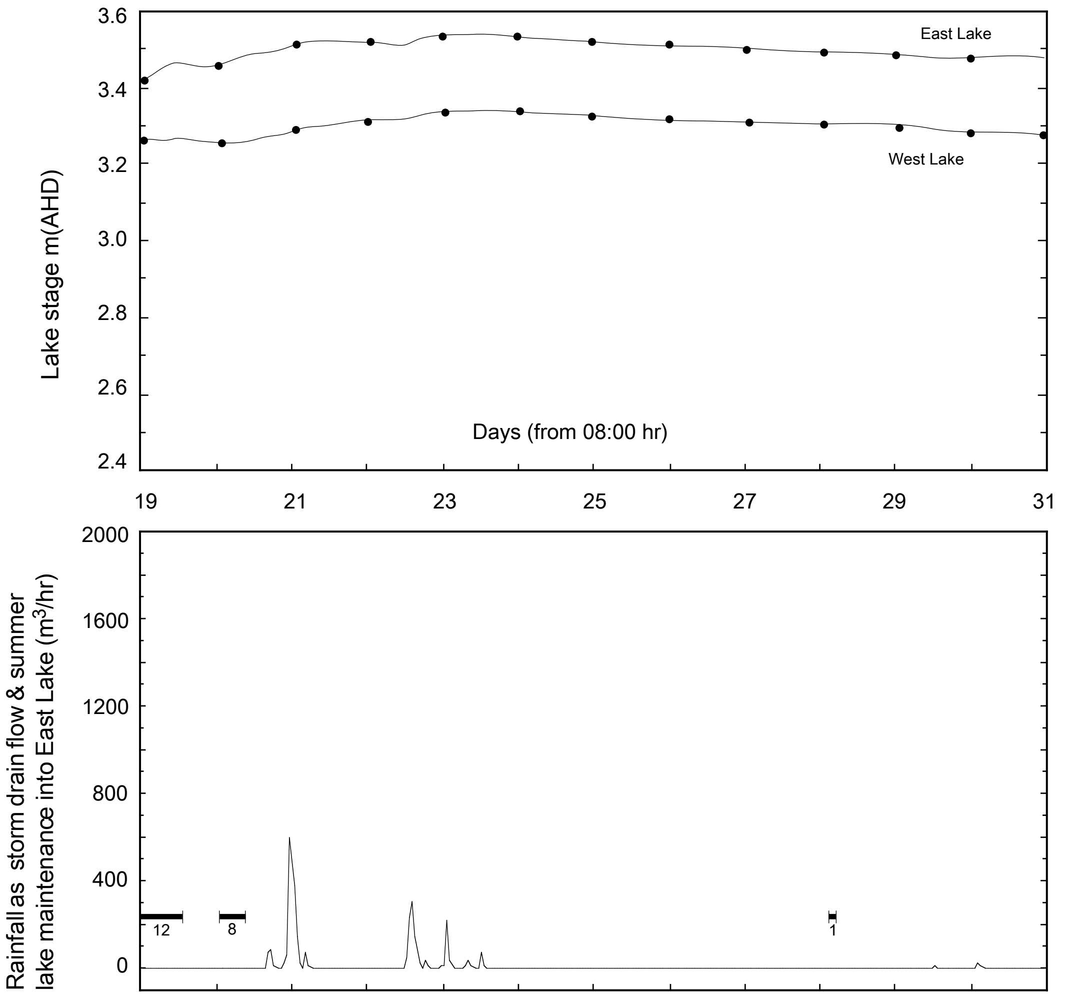
Balance 14 October 07 to October 19 1996



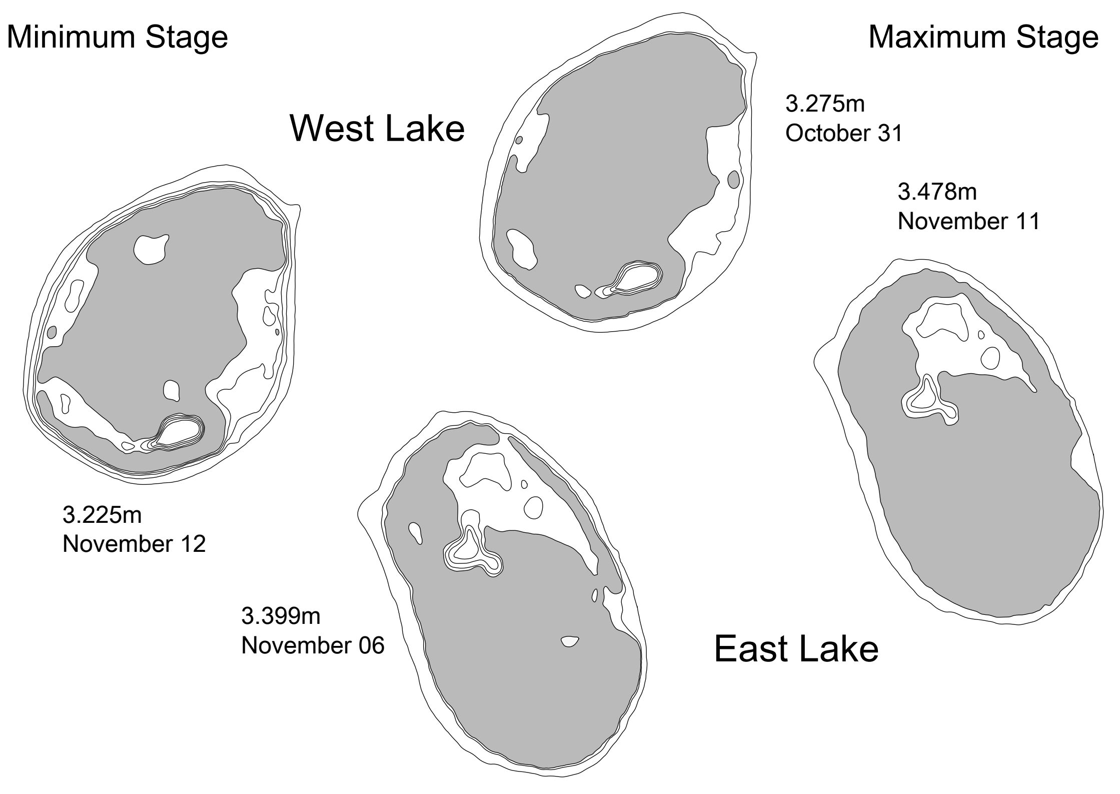


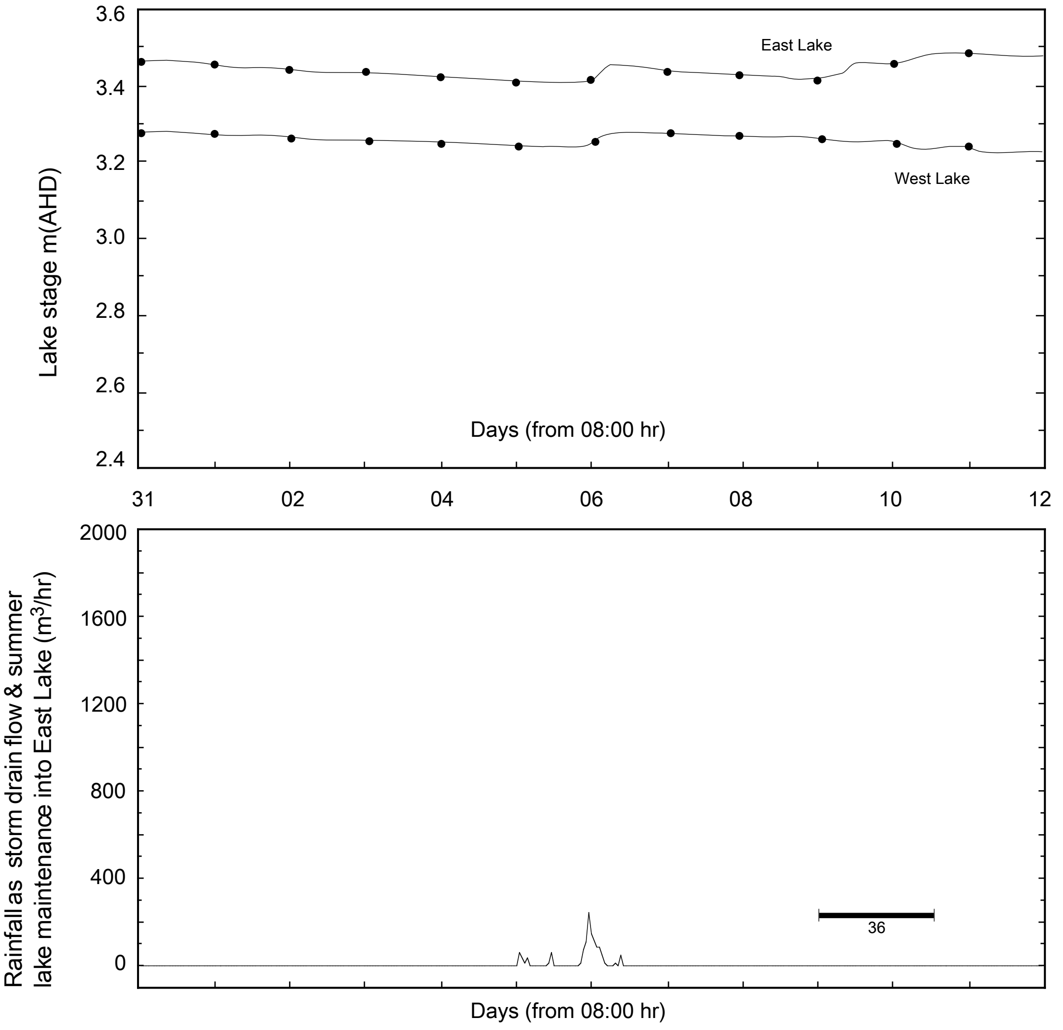
Balance 15 October 19 to October 31 1996



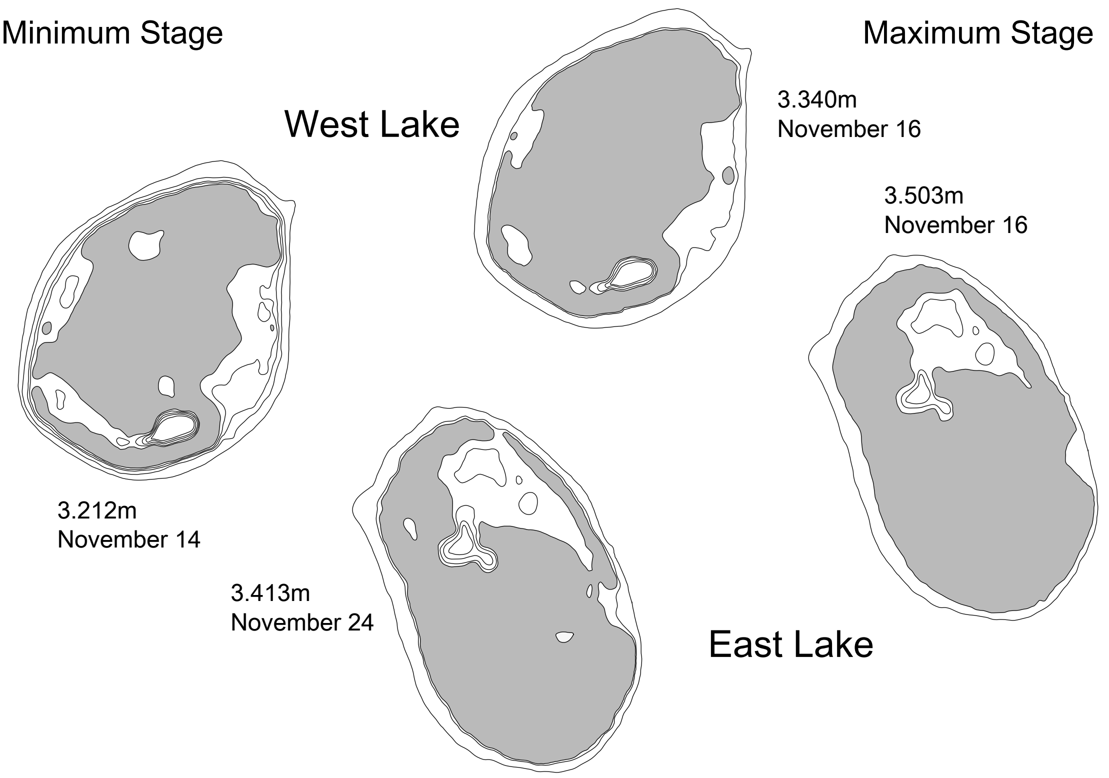


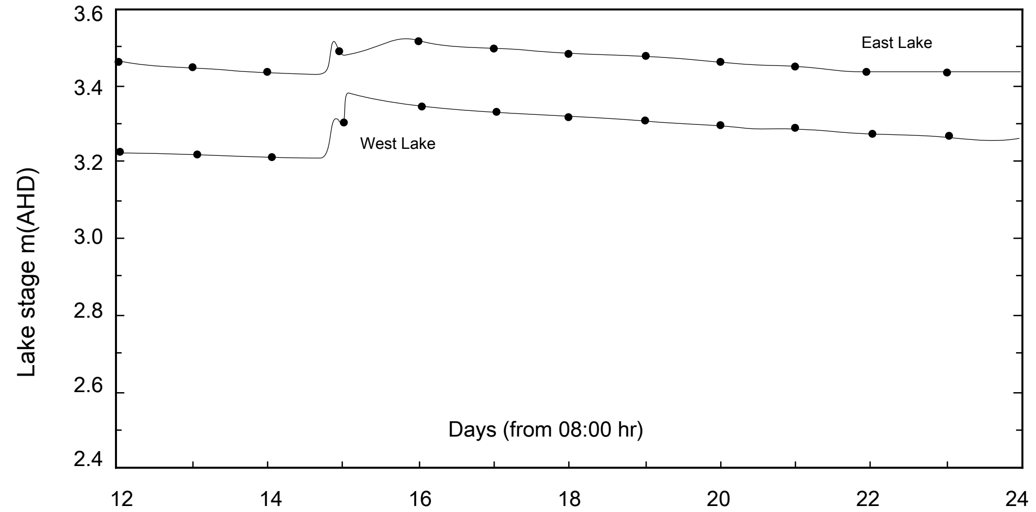
Balance 16 October 31 to November 12 1996

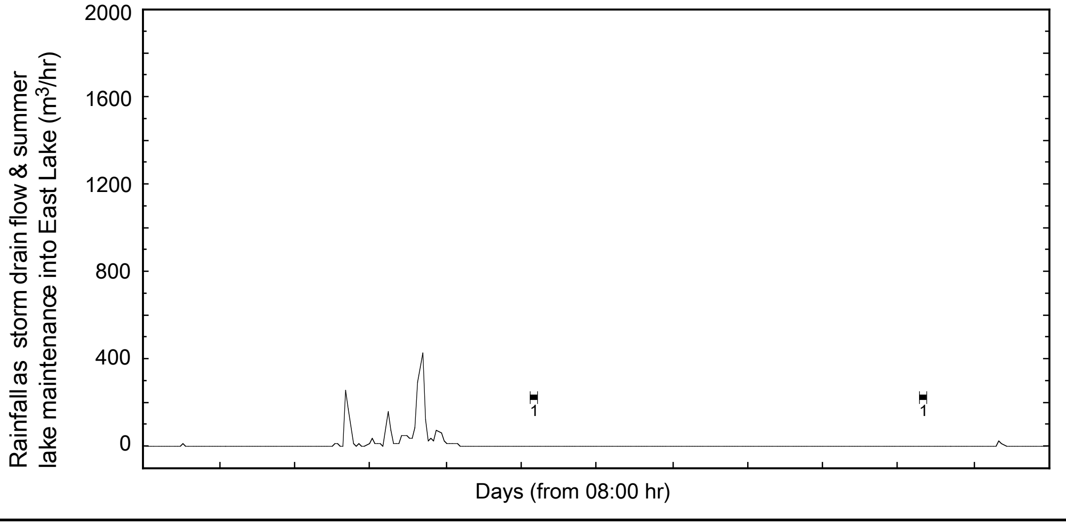




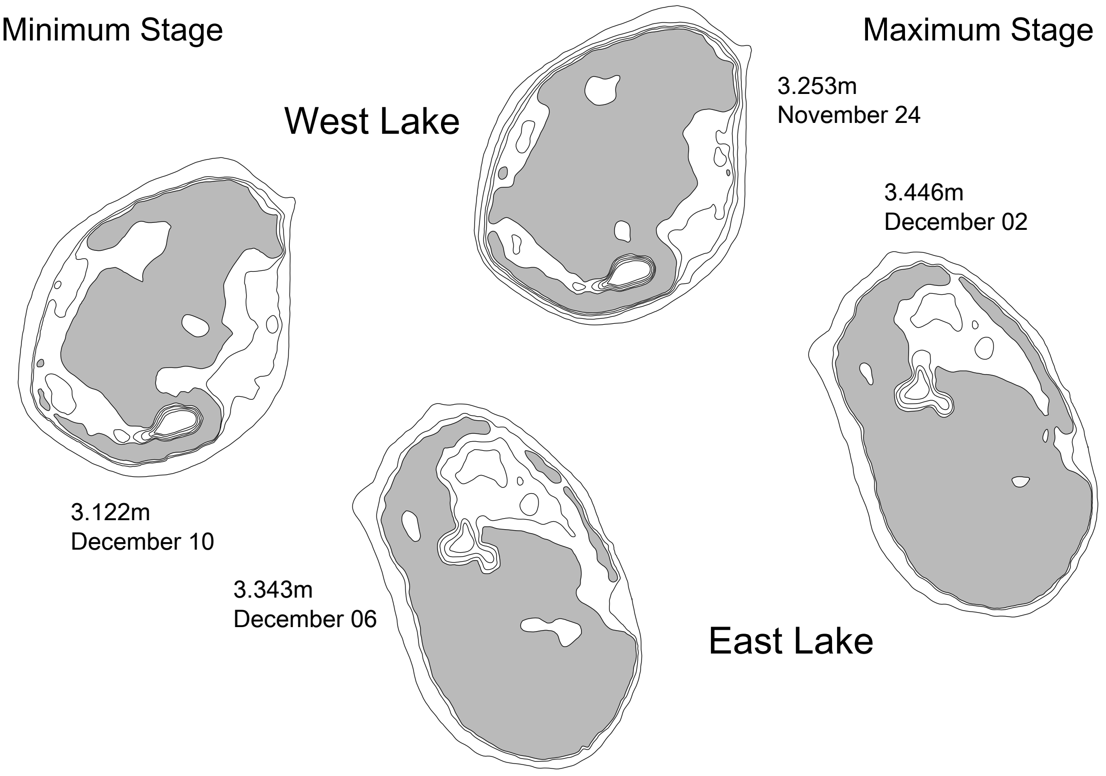
Balance 17 November 12 to November 24 1996

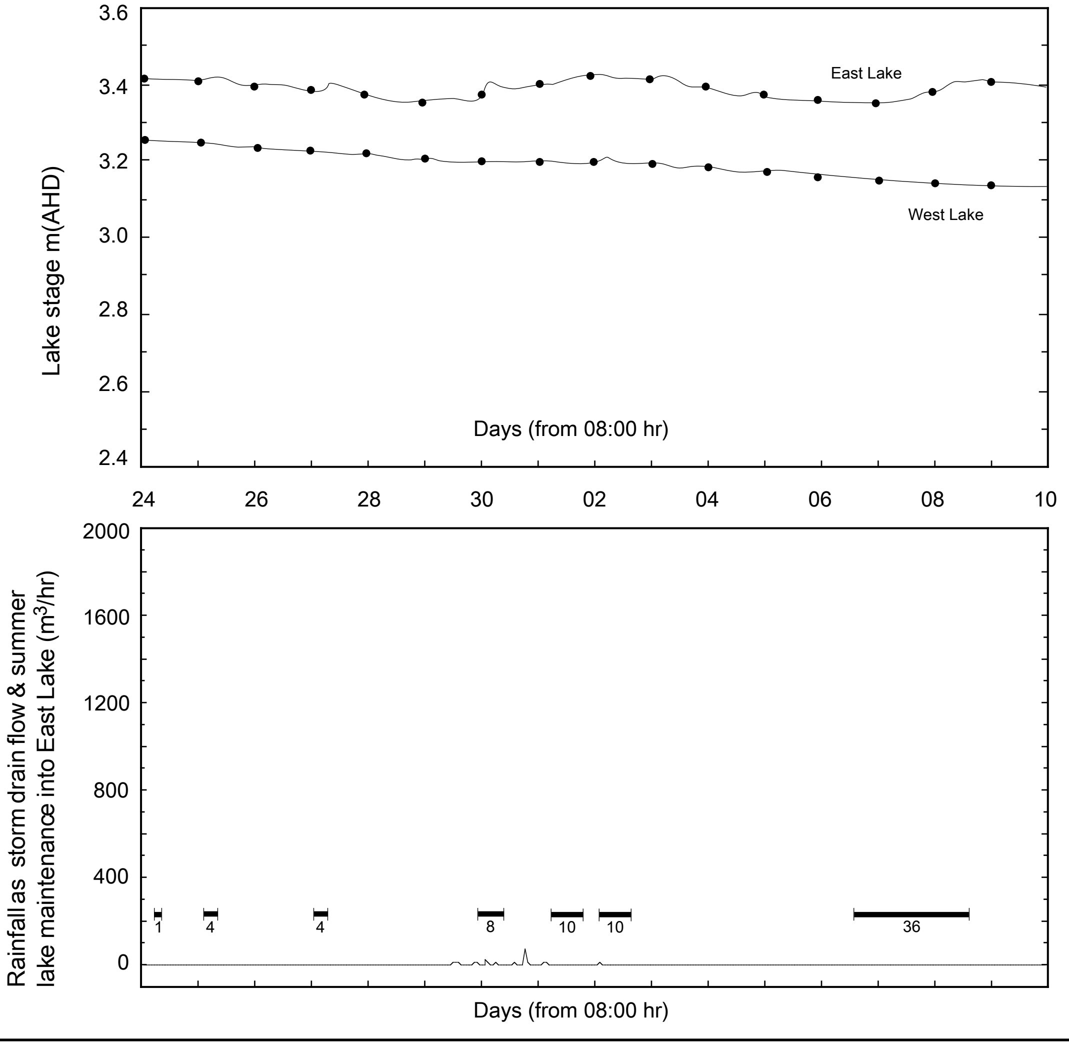




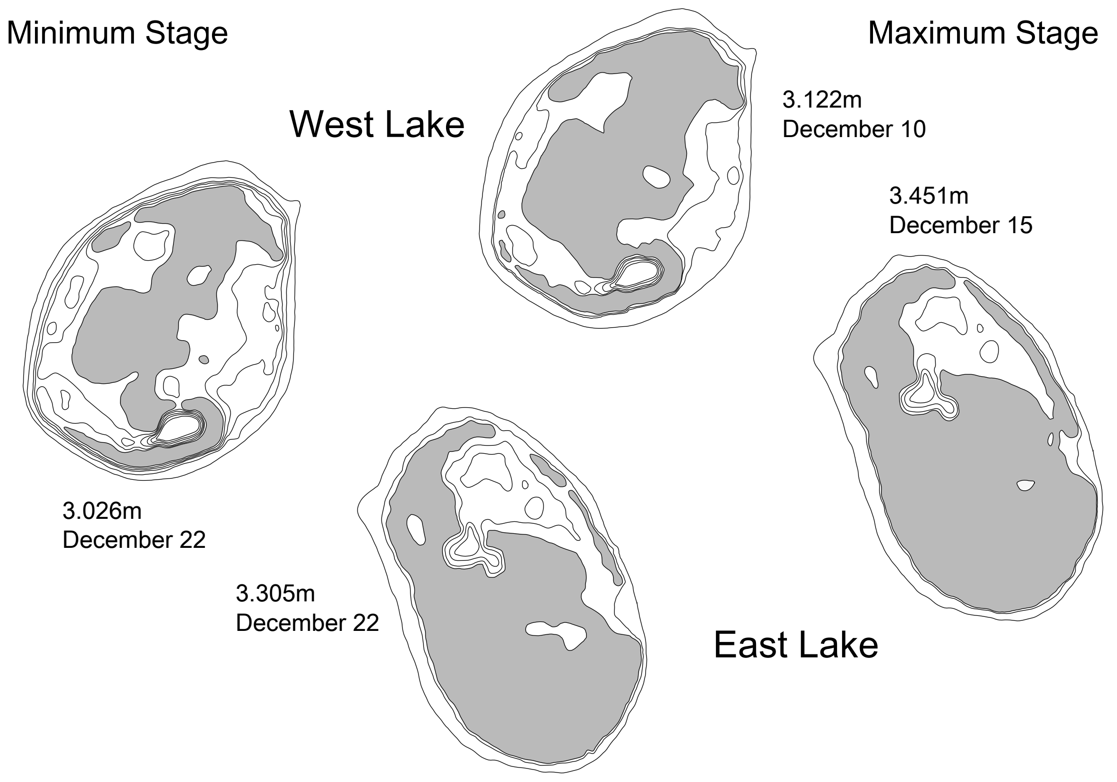


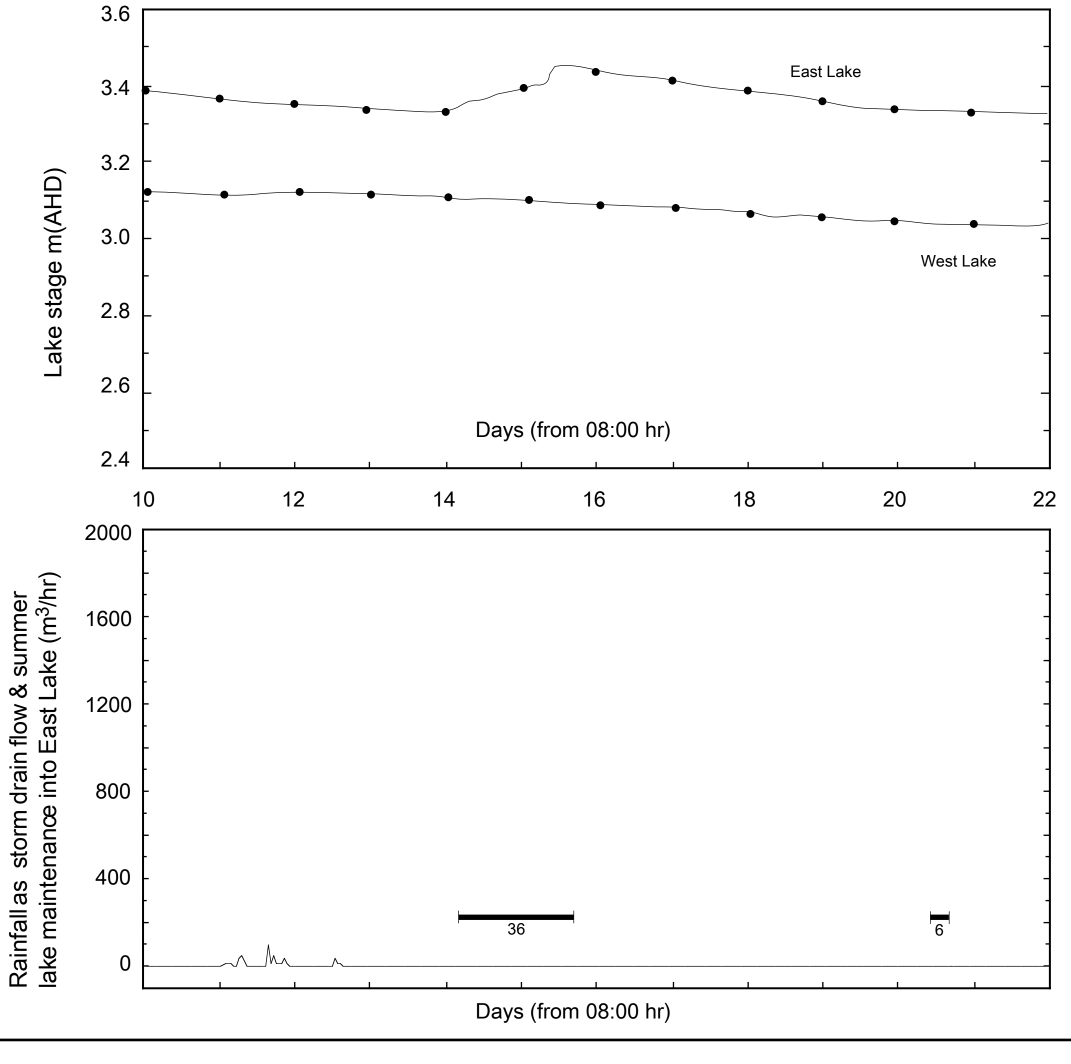
Balance 18 November 24 to December 10 1996



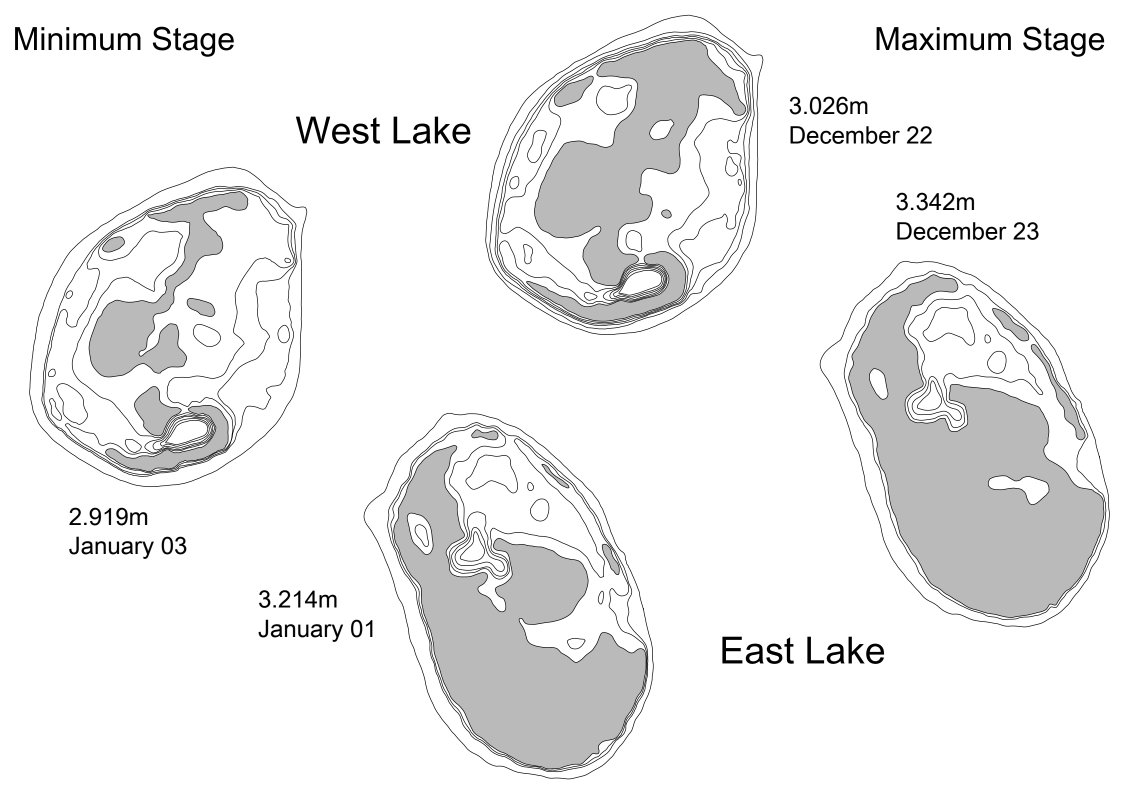


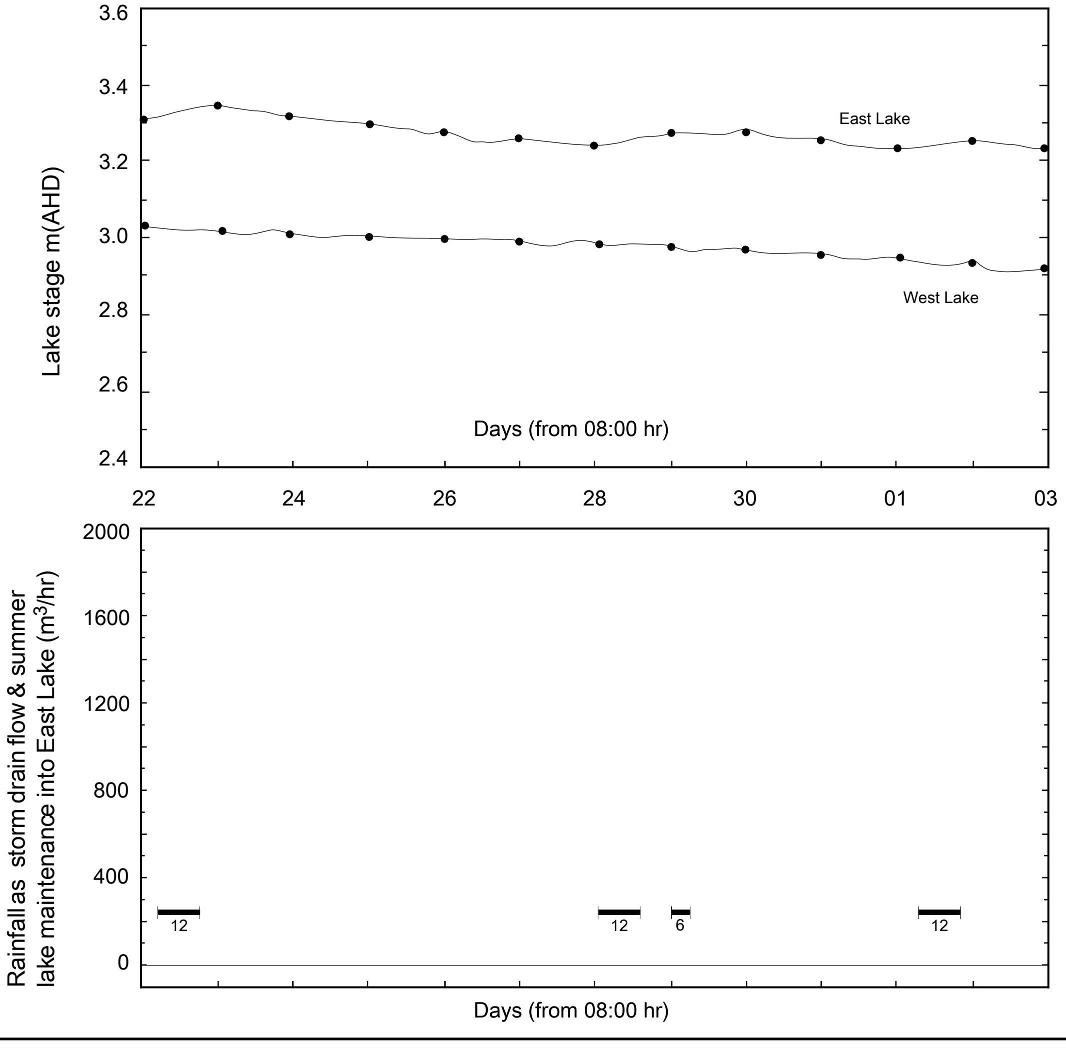
Balance 19 December 10 to December 22 1996



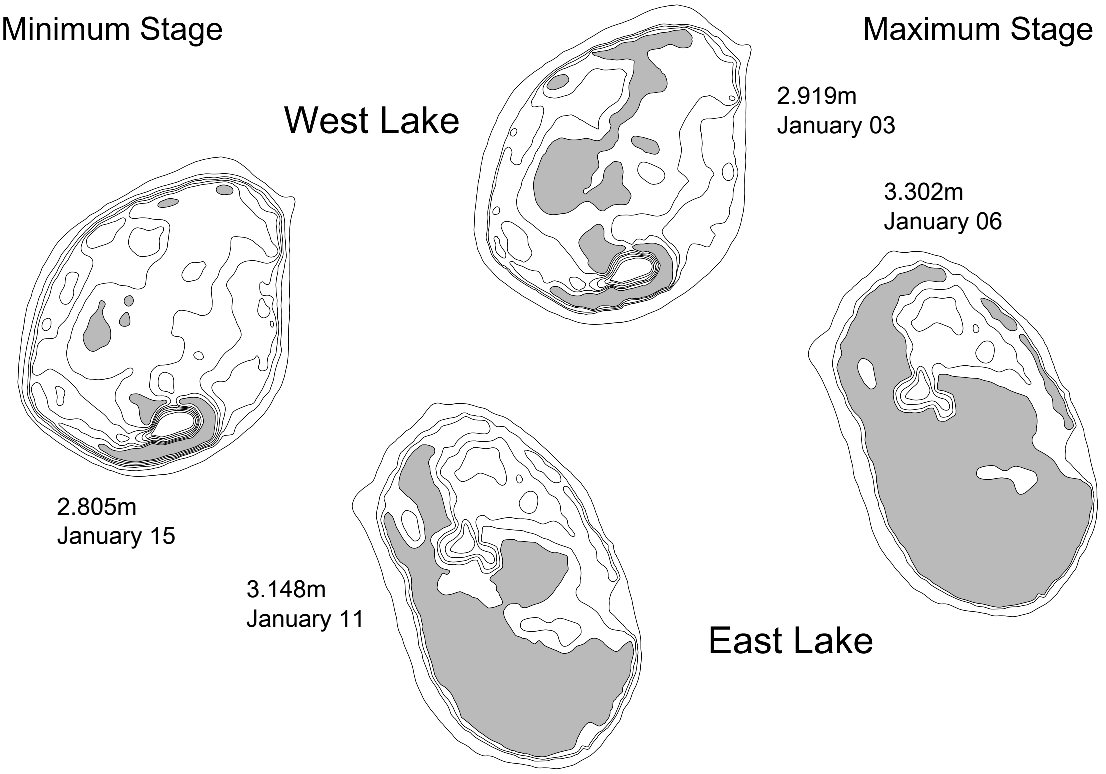


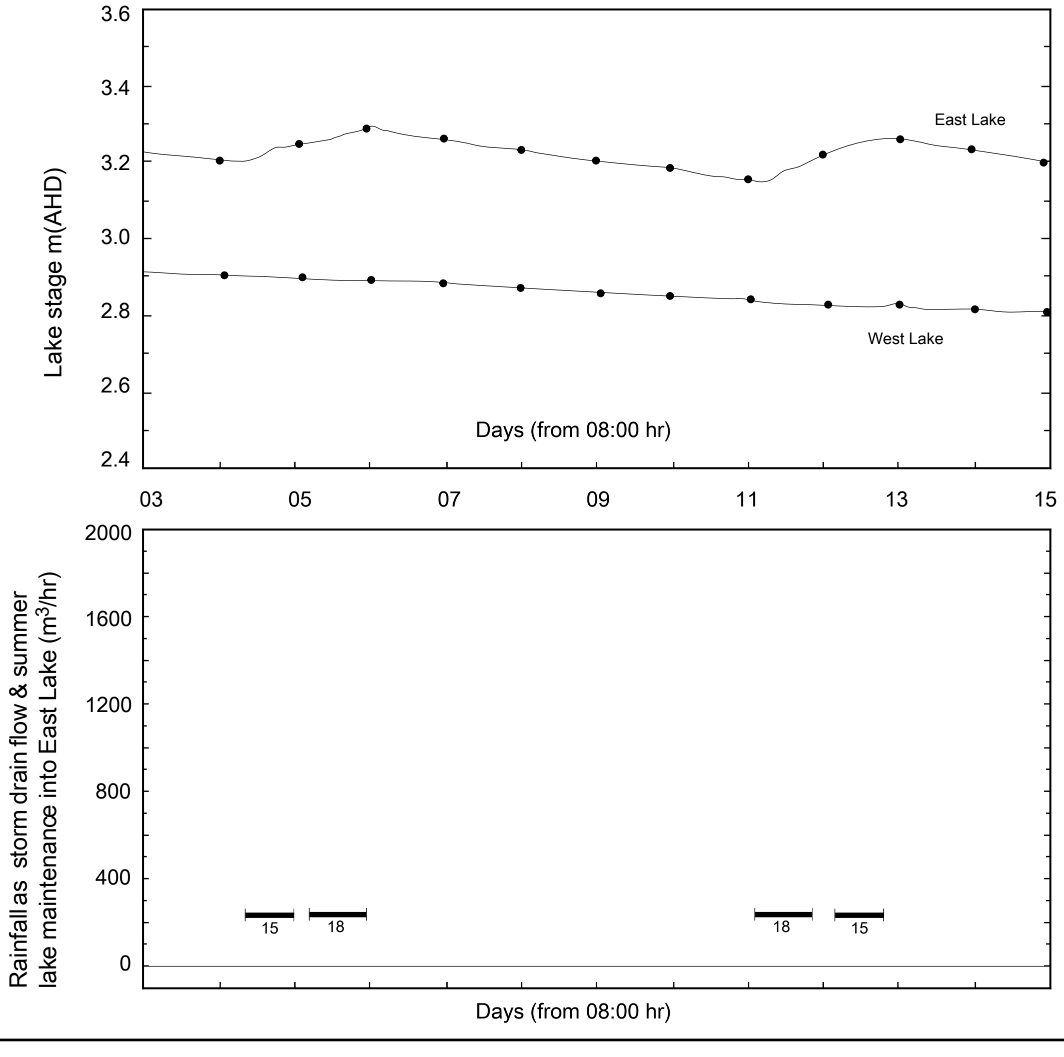
Balance 20 December 22 1996 to January 03 1997



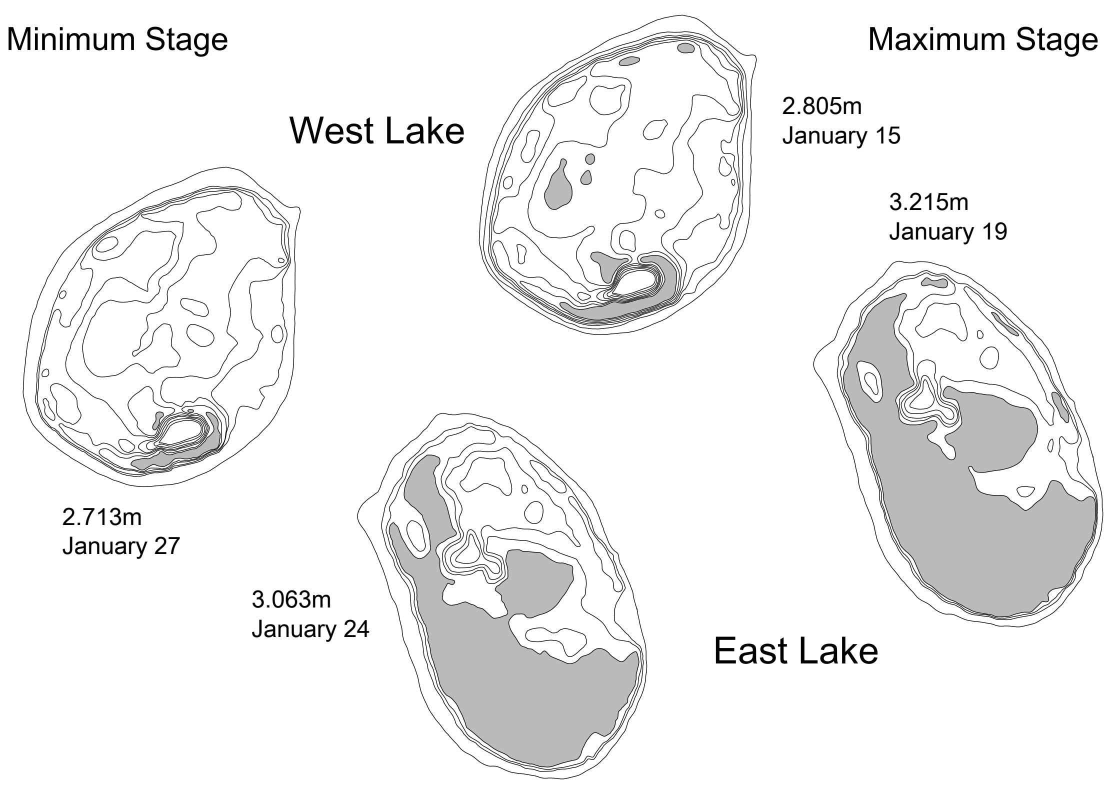


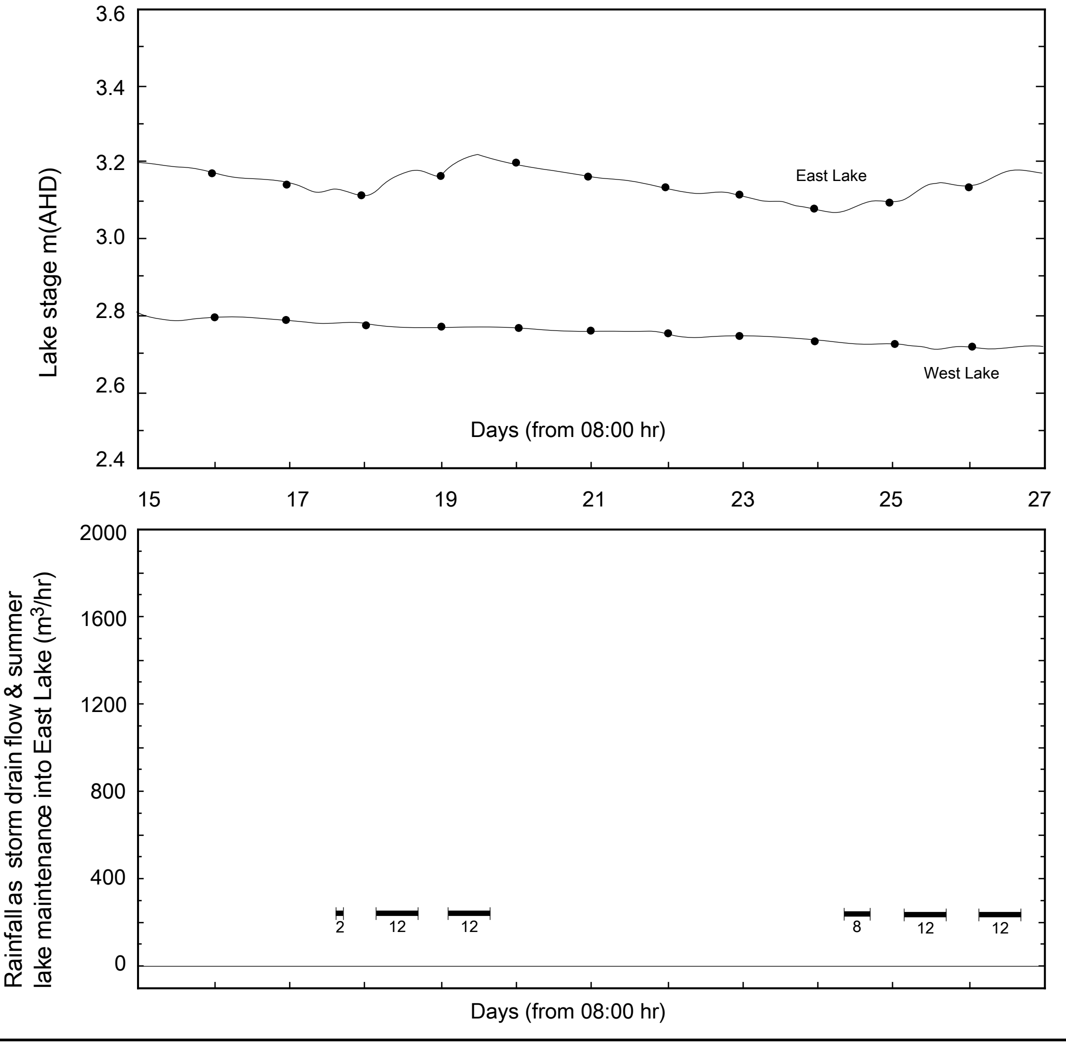
Balance 21 January 03 to January 15 1997



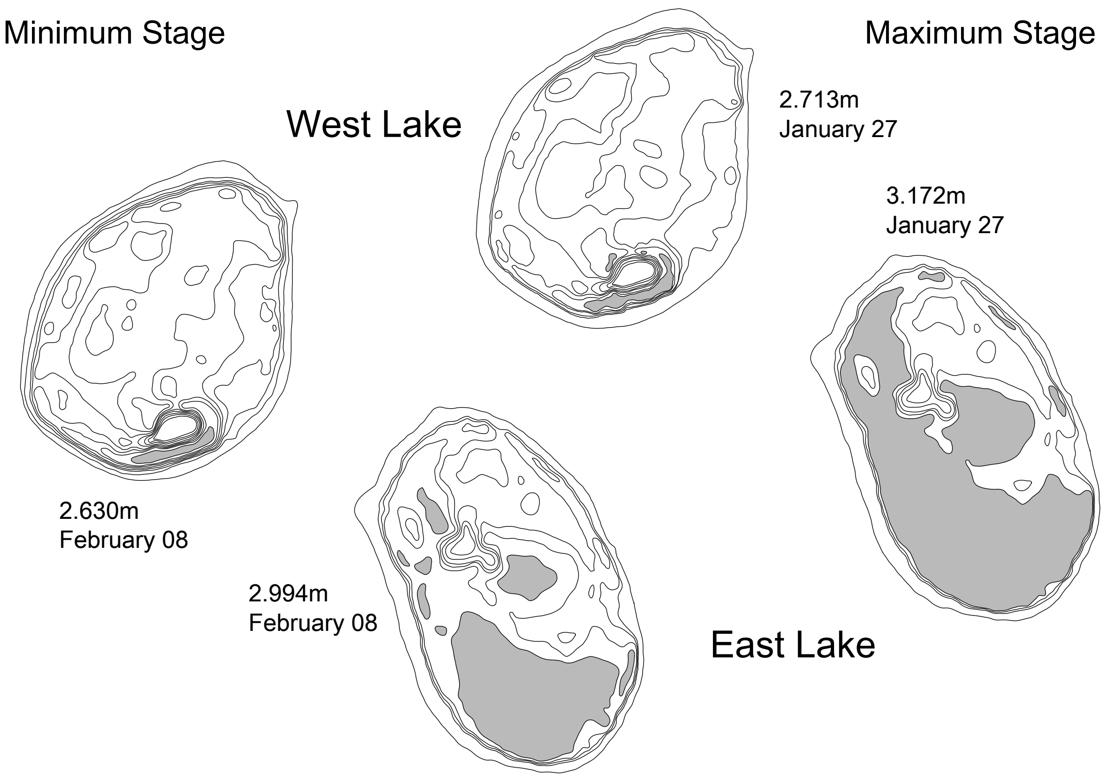


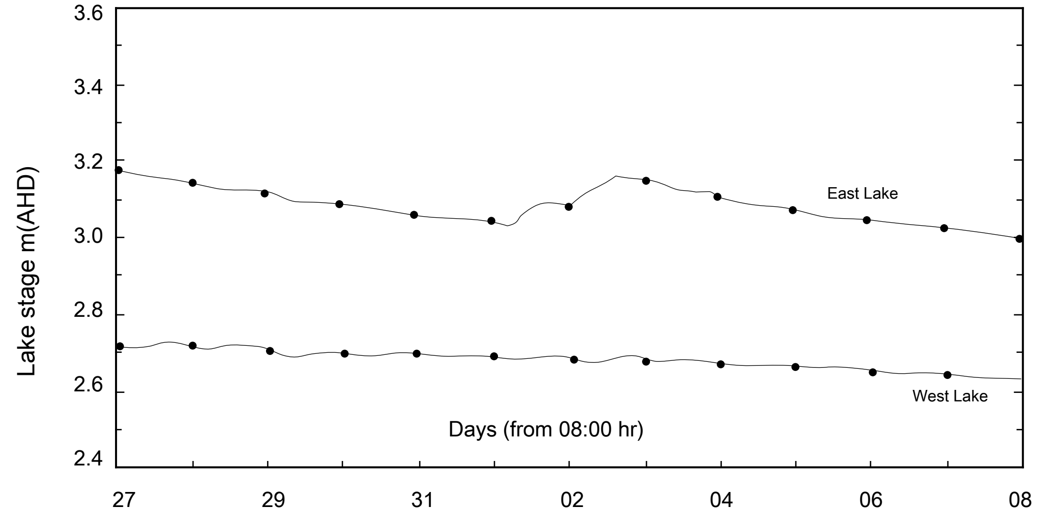
Balance 22 January 15 to January 27 1997

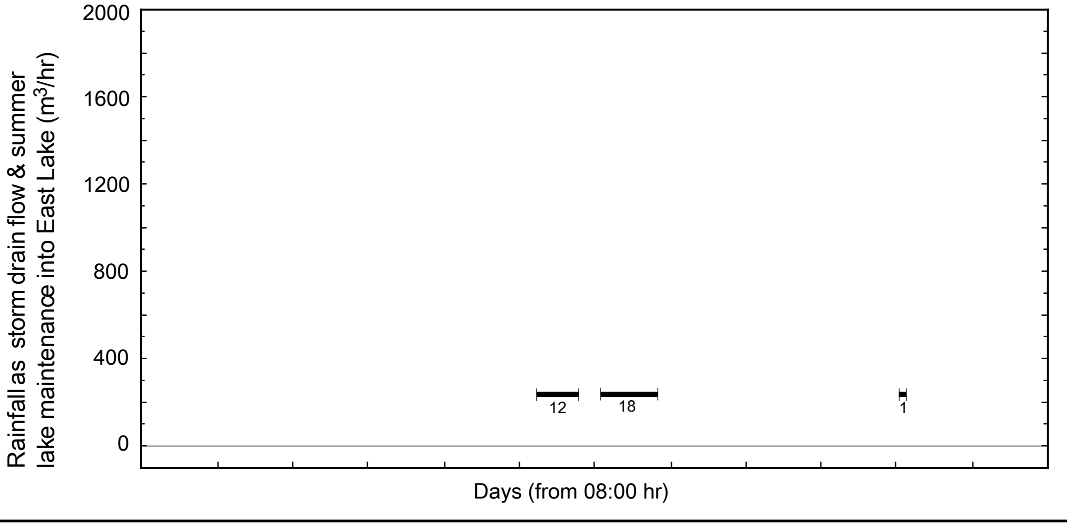




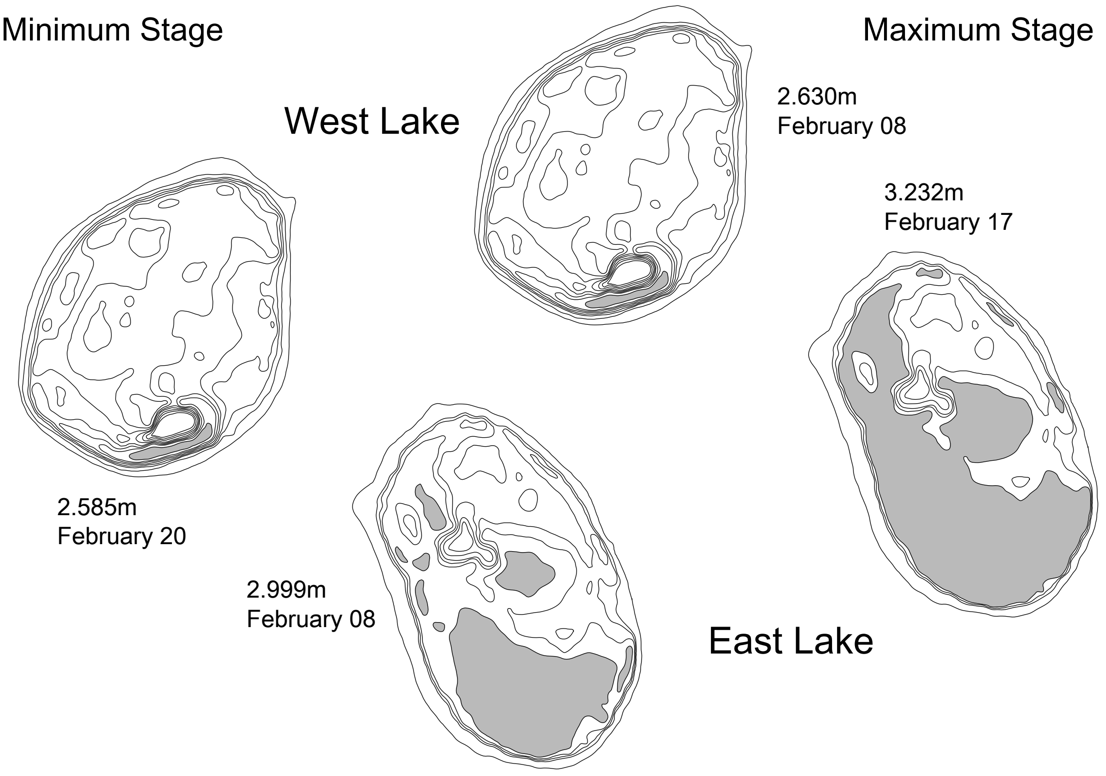
Balance 23 January 27 to February 08 1997

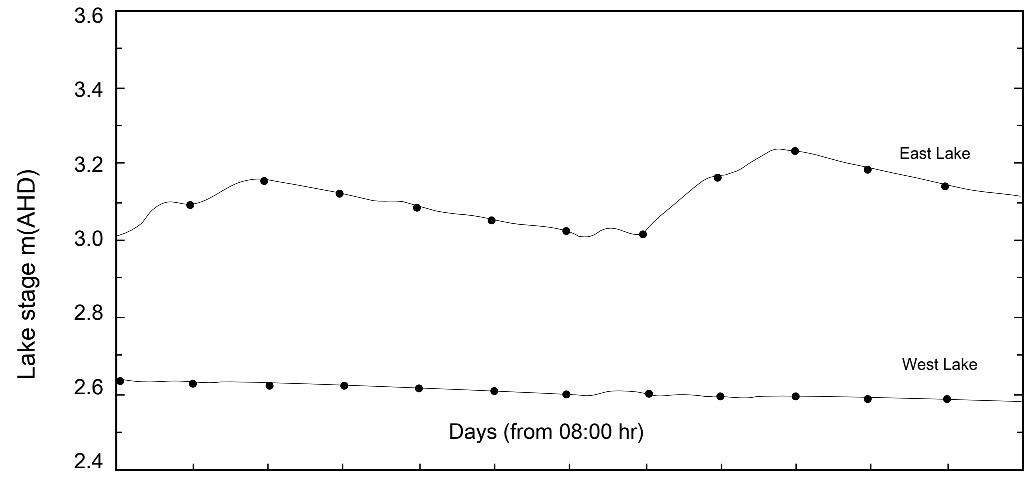


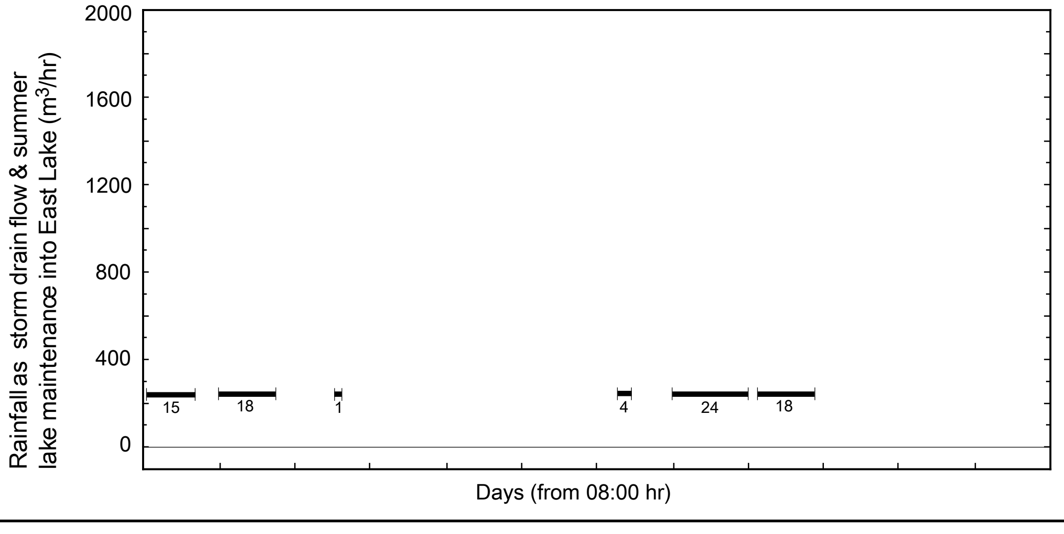




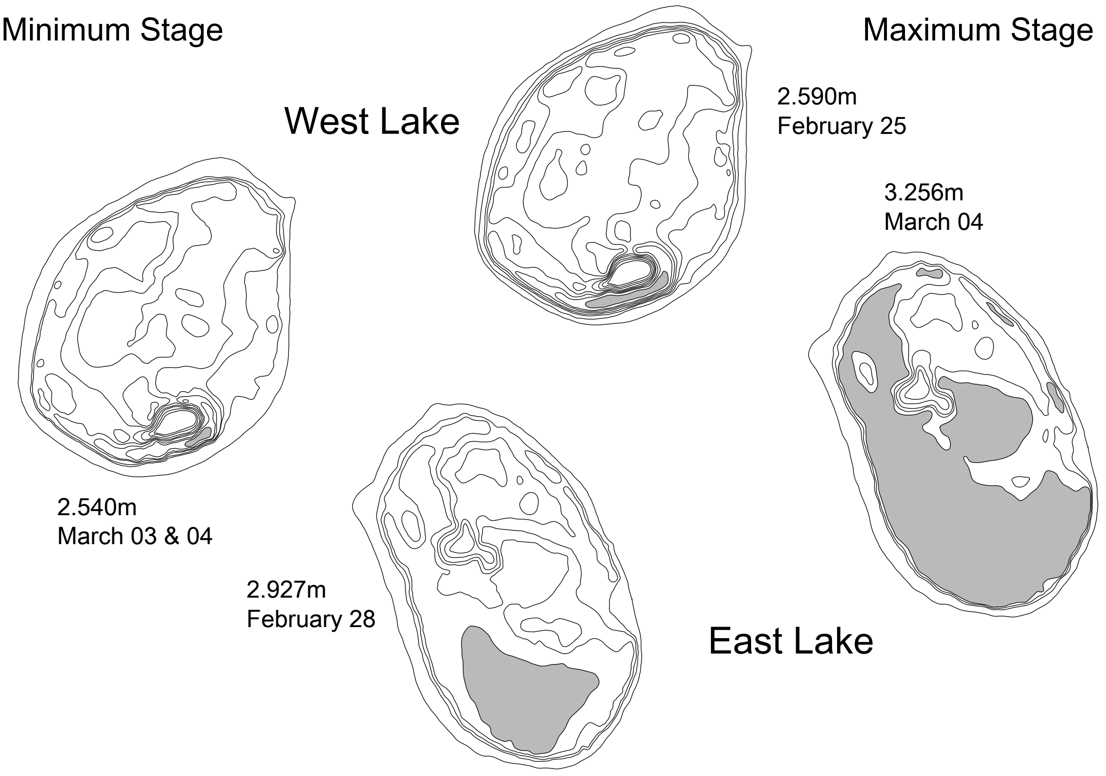
Balance 24 February 08 to February 20 1997

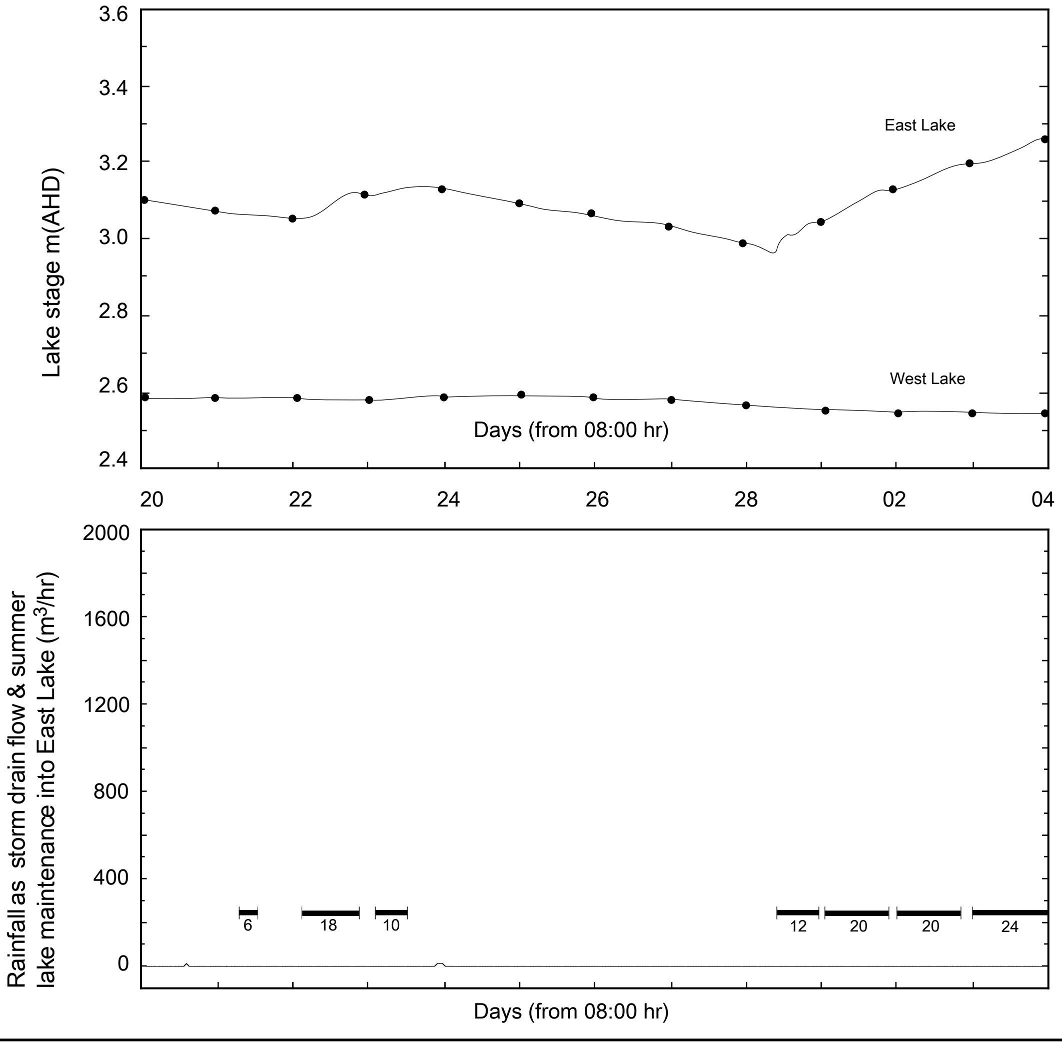




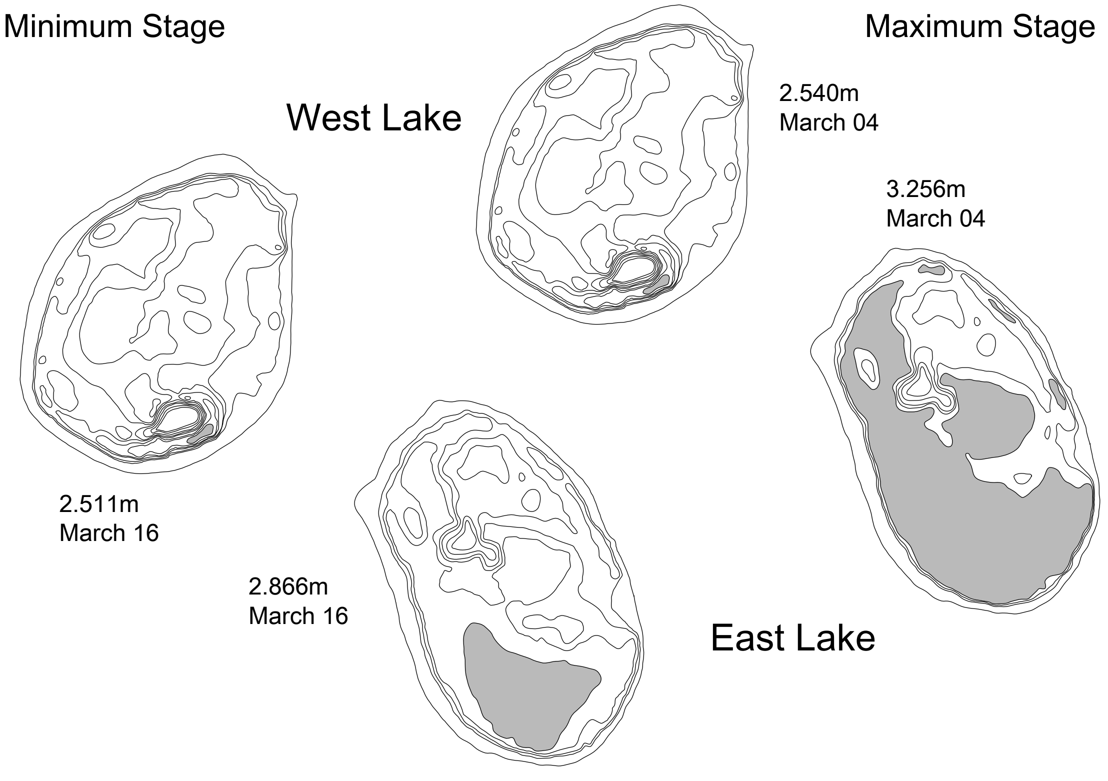


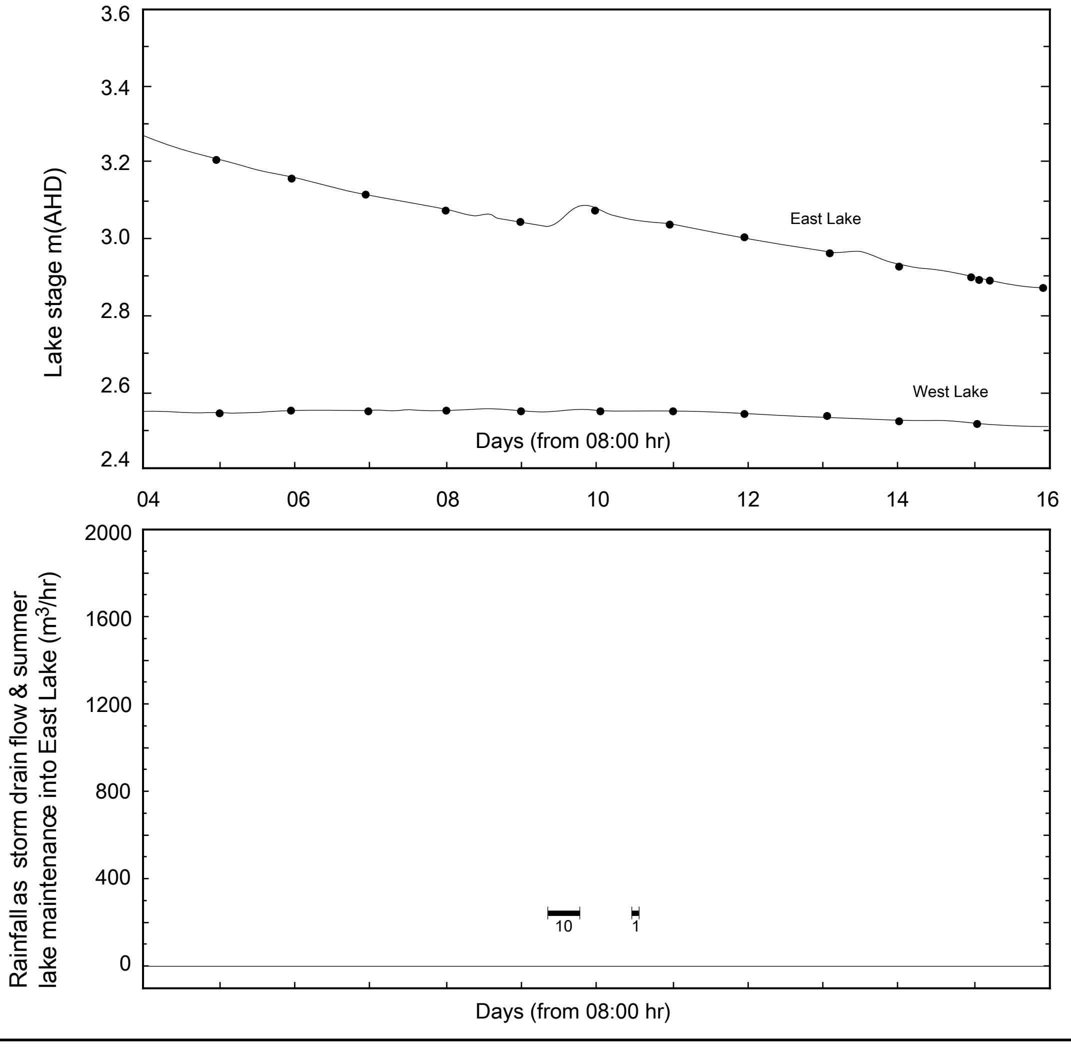
Balance 25 February 20 to March 04 1997



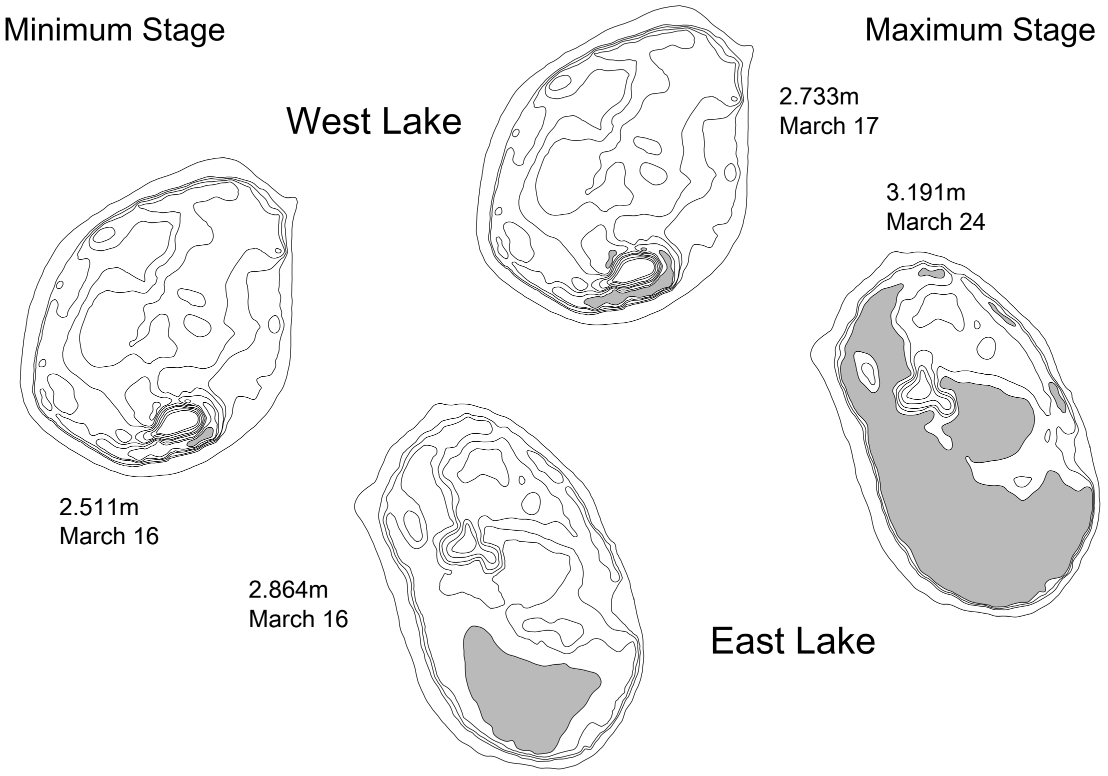


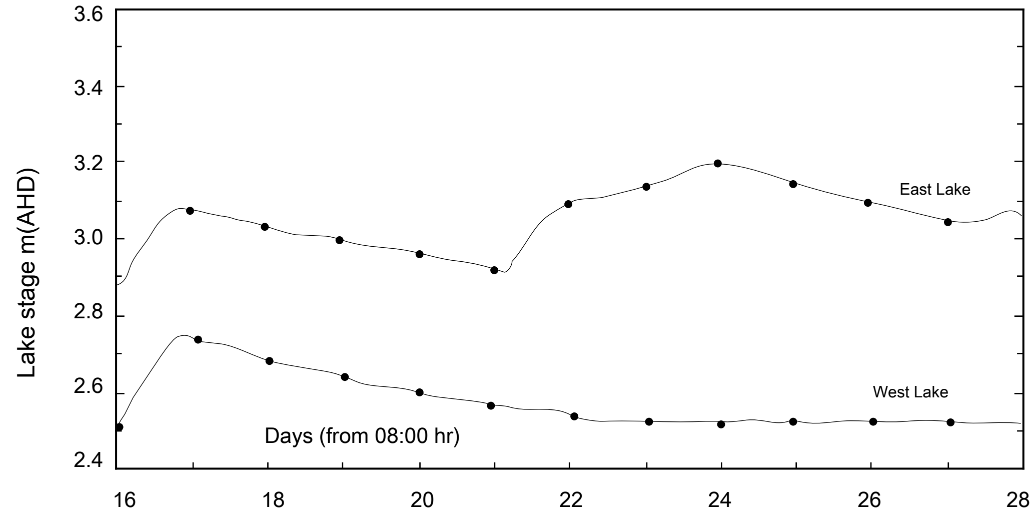
Balance 26 March 04 to March 16 1997

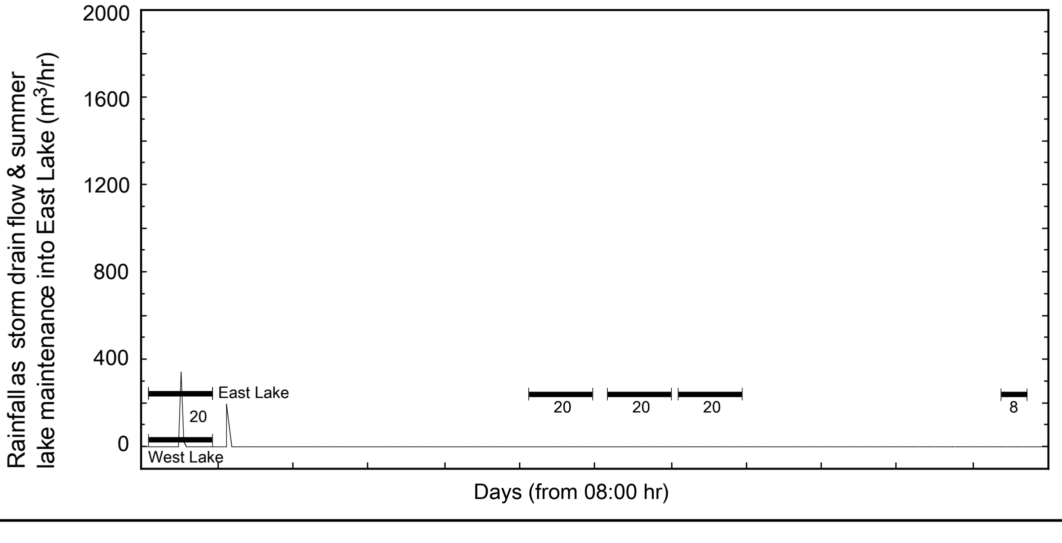




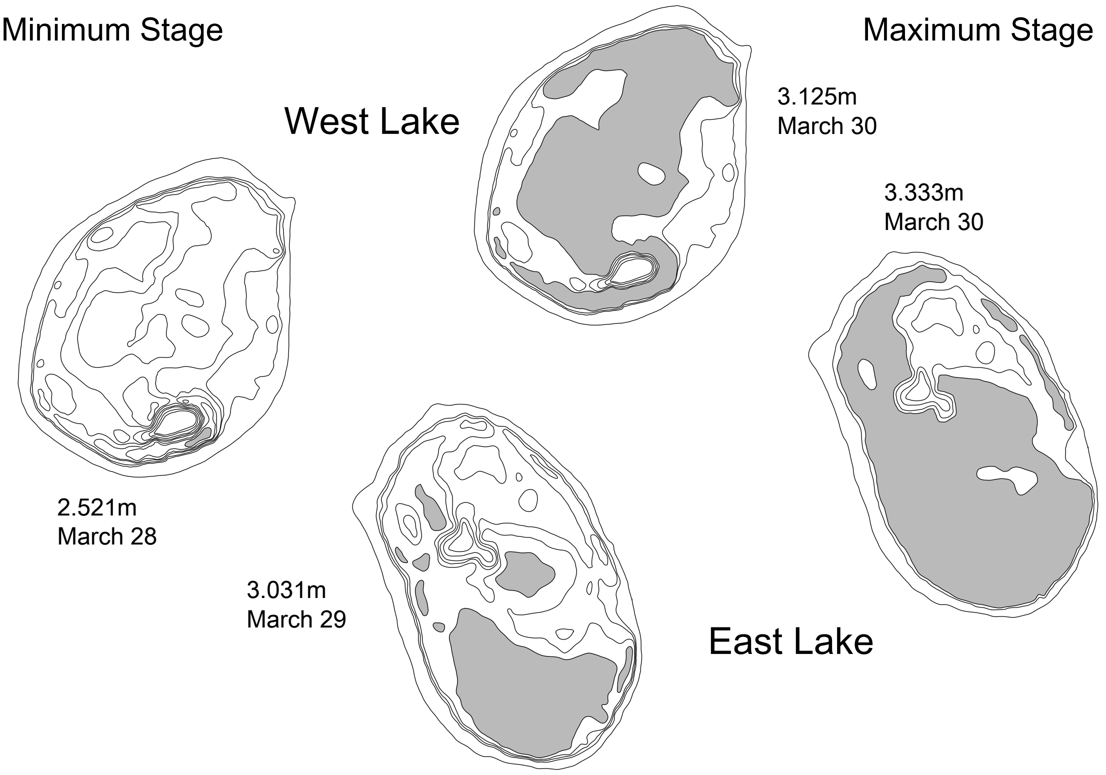
Balance 27 — March 16 to March 28 1997

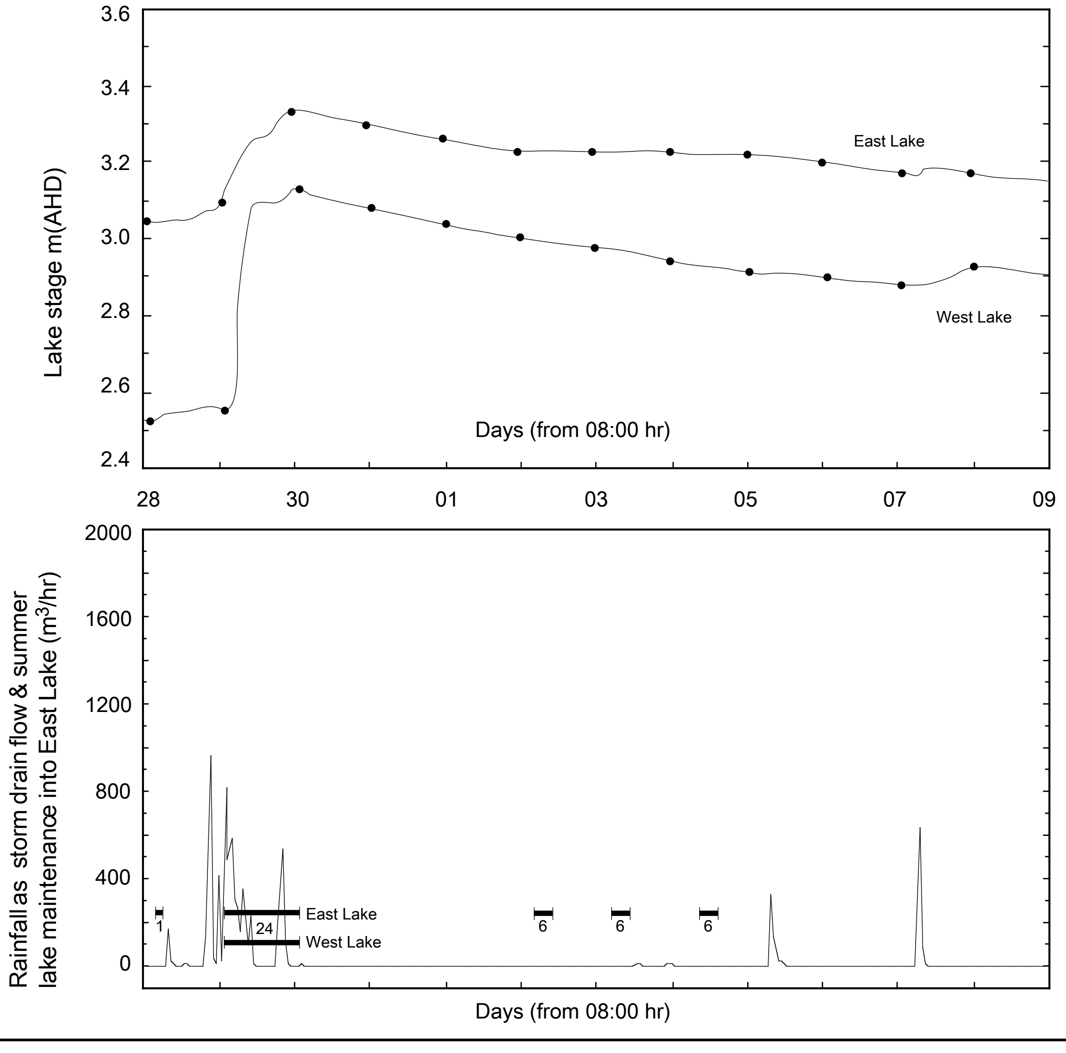




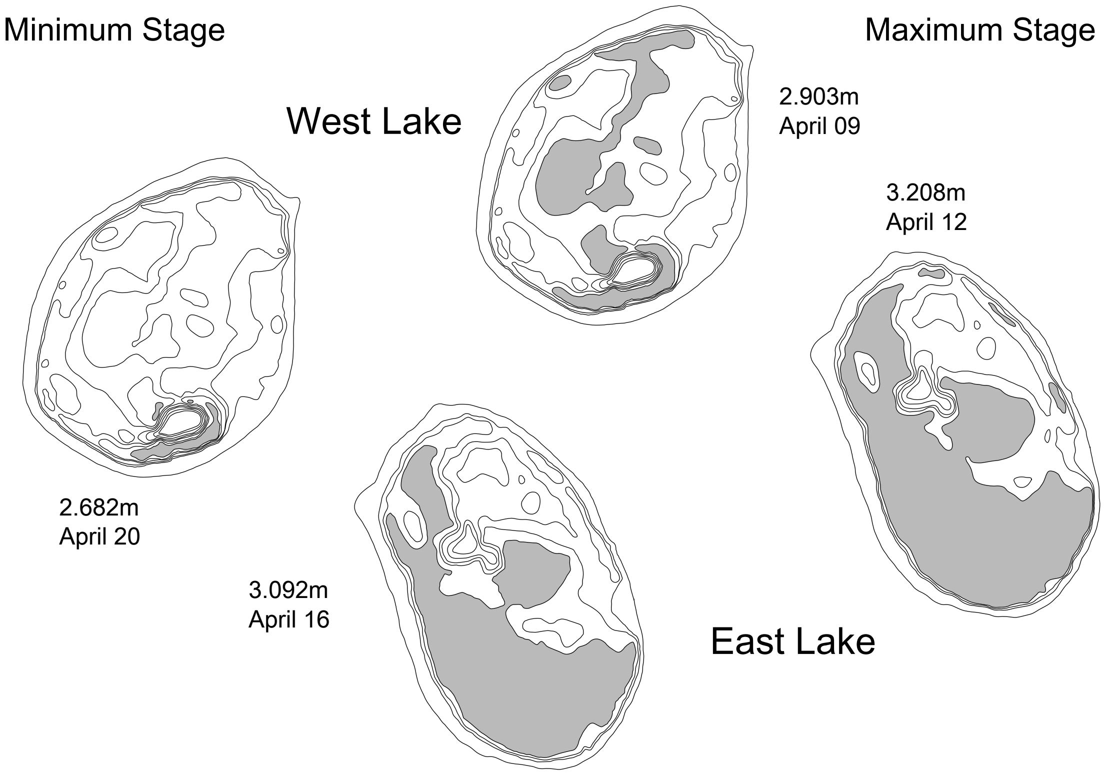


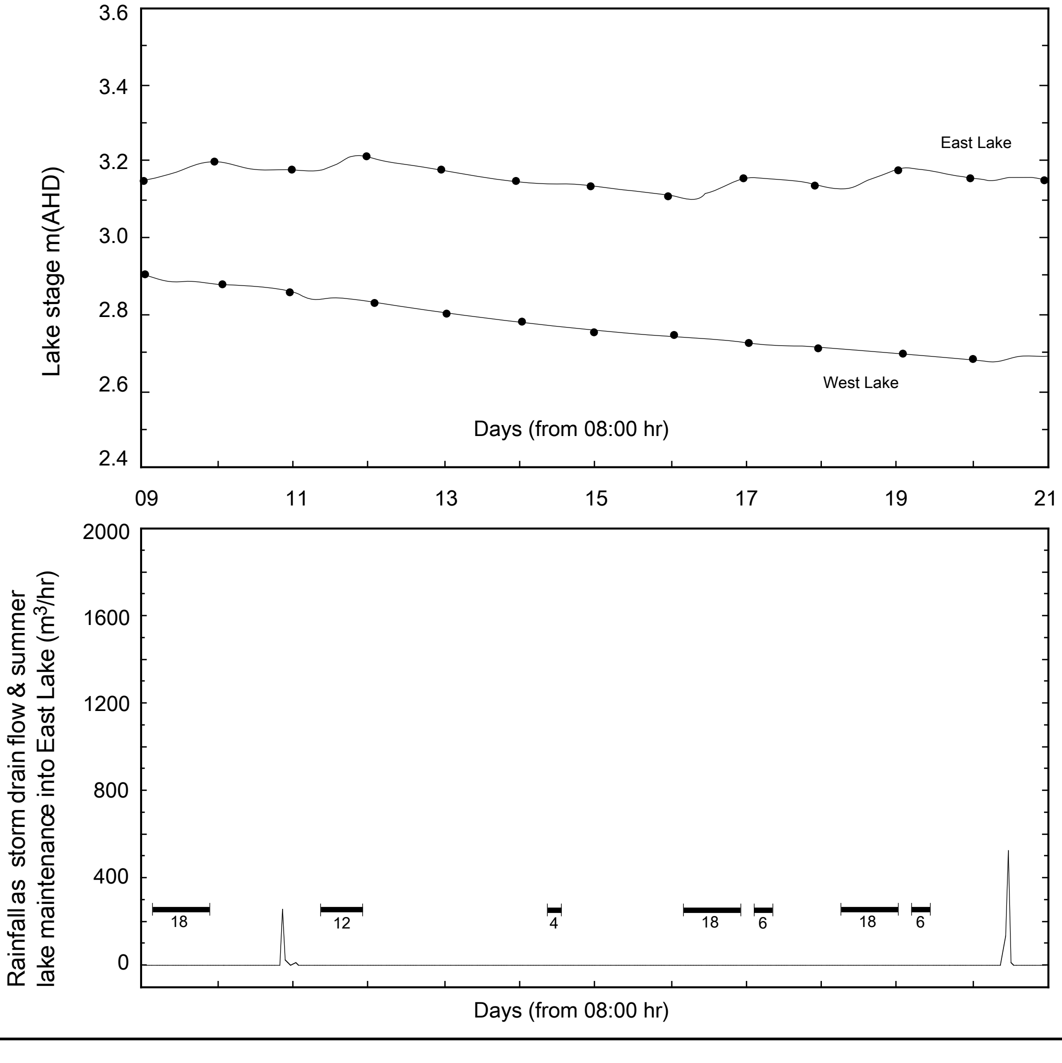
Balance 28 March 28 to April 09 1997





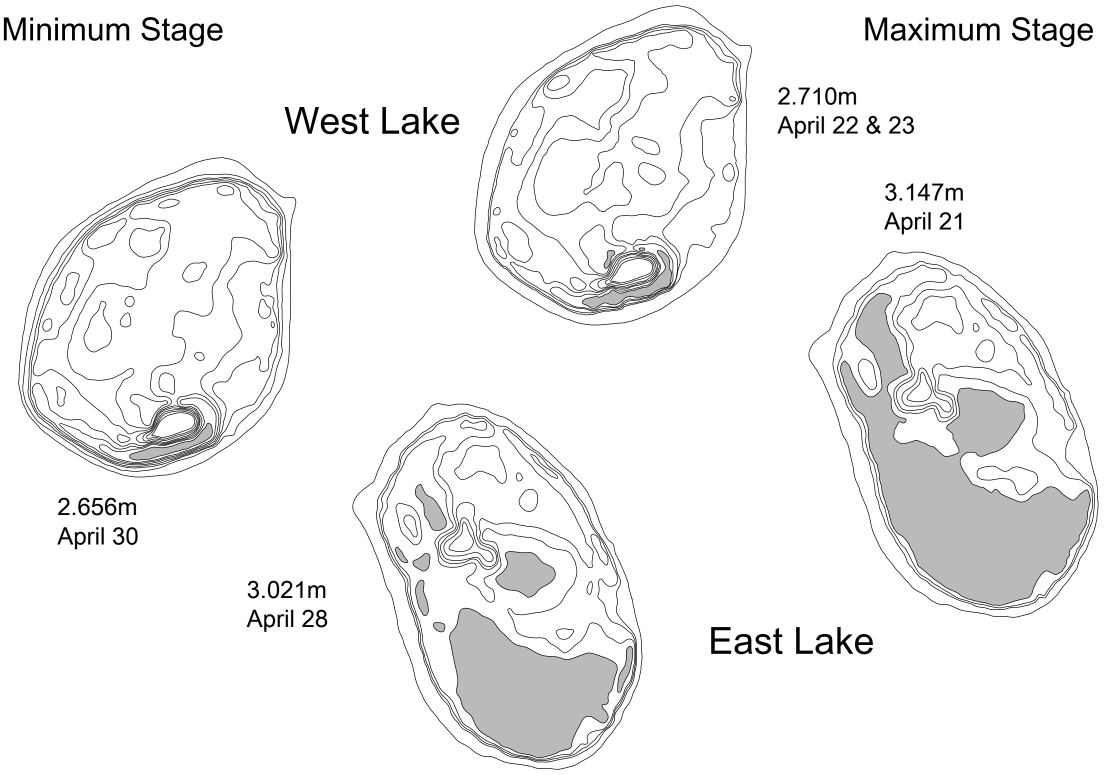
Balance 29 April 09 to April 21 1997

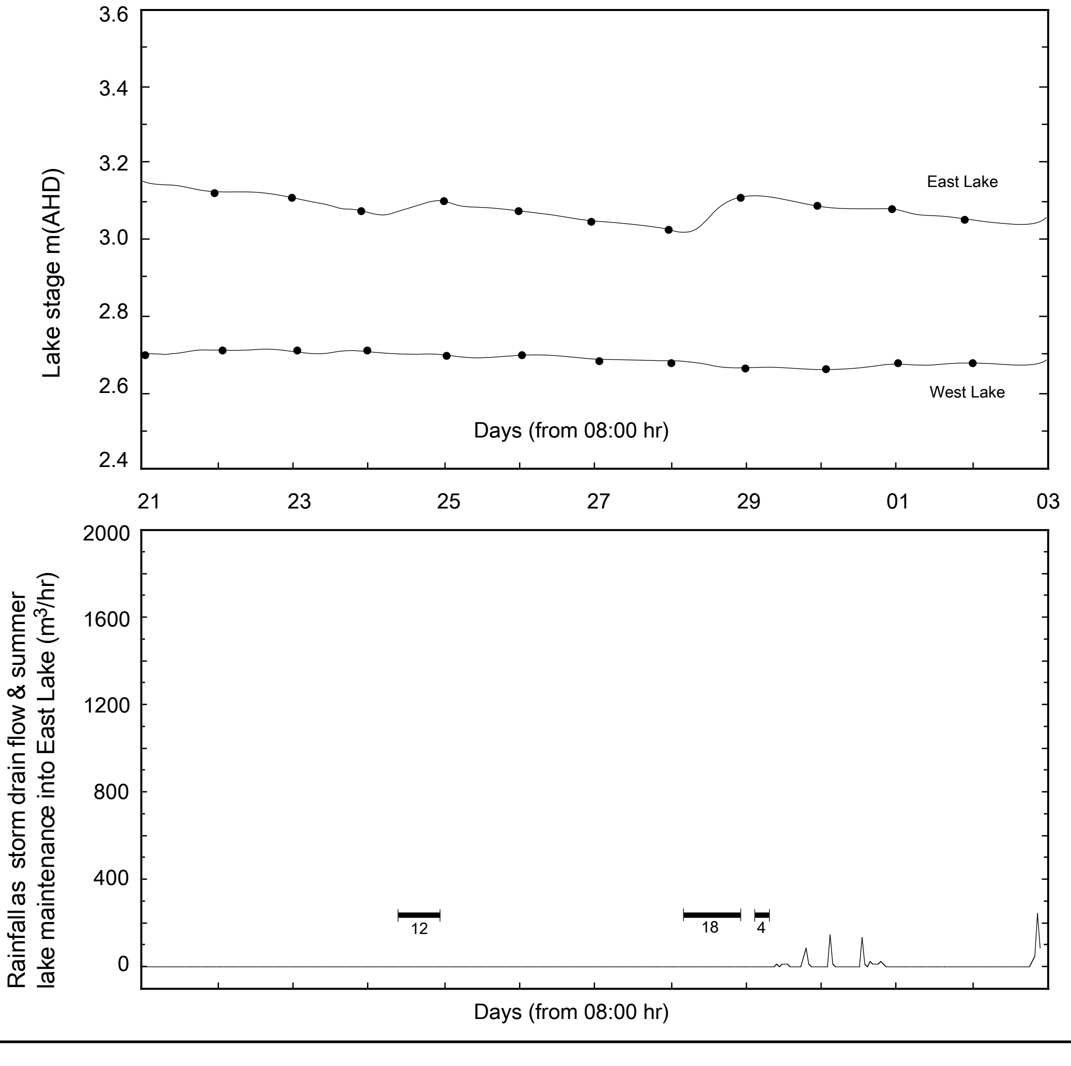




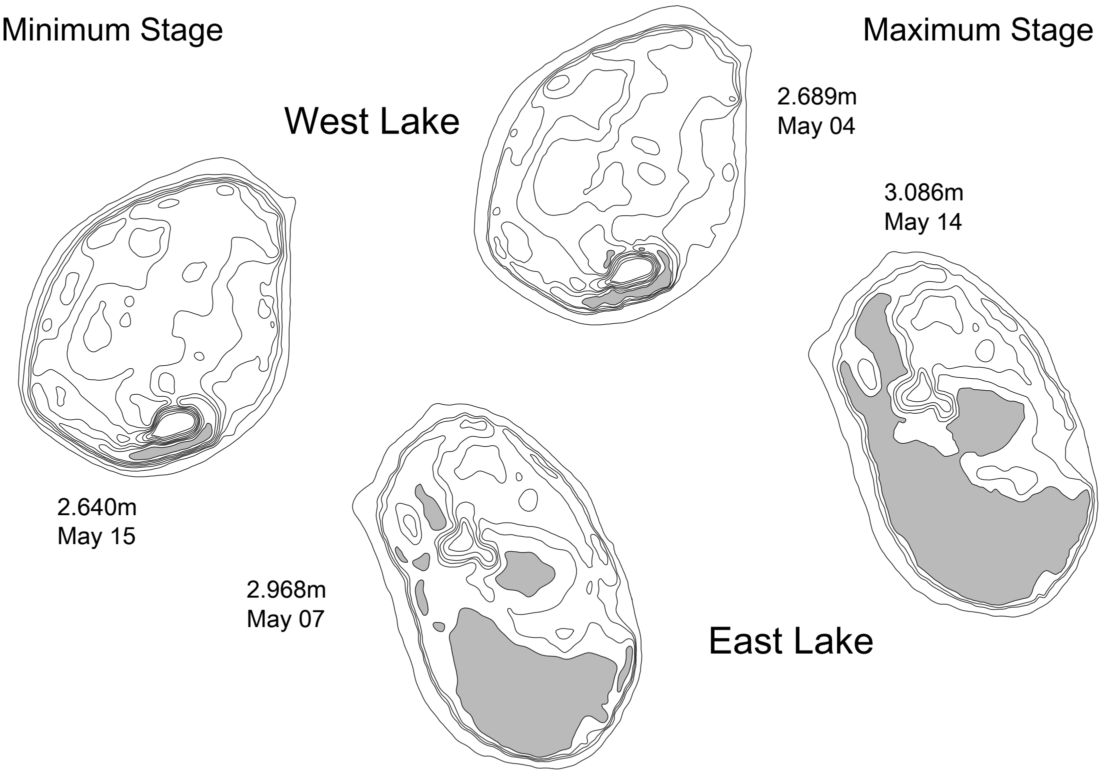
Balance 30

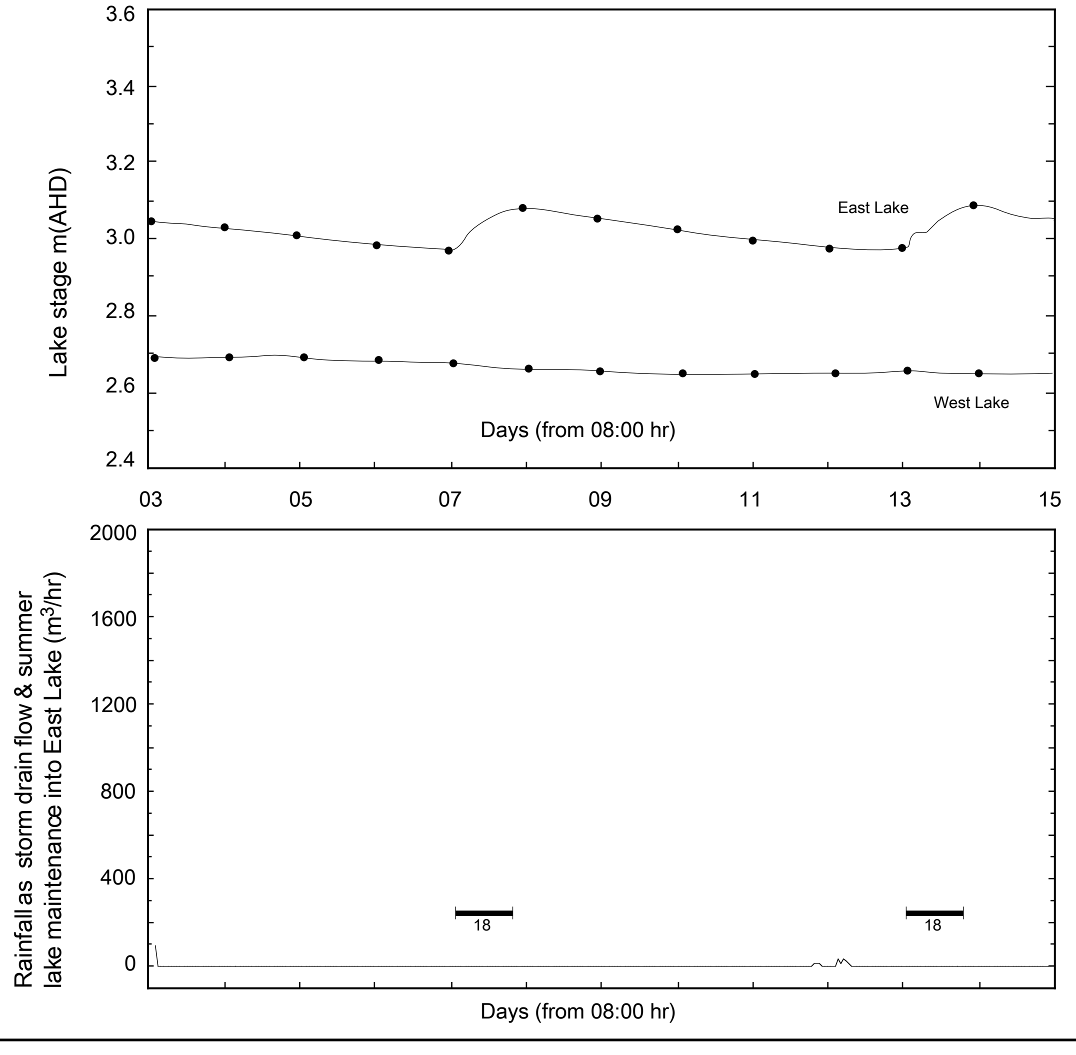
April 21 to May 03 1997



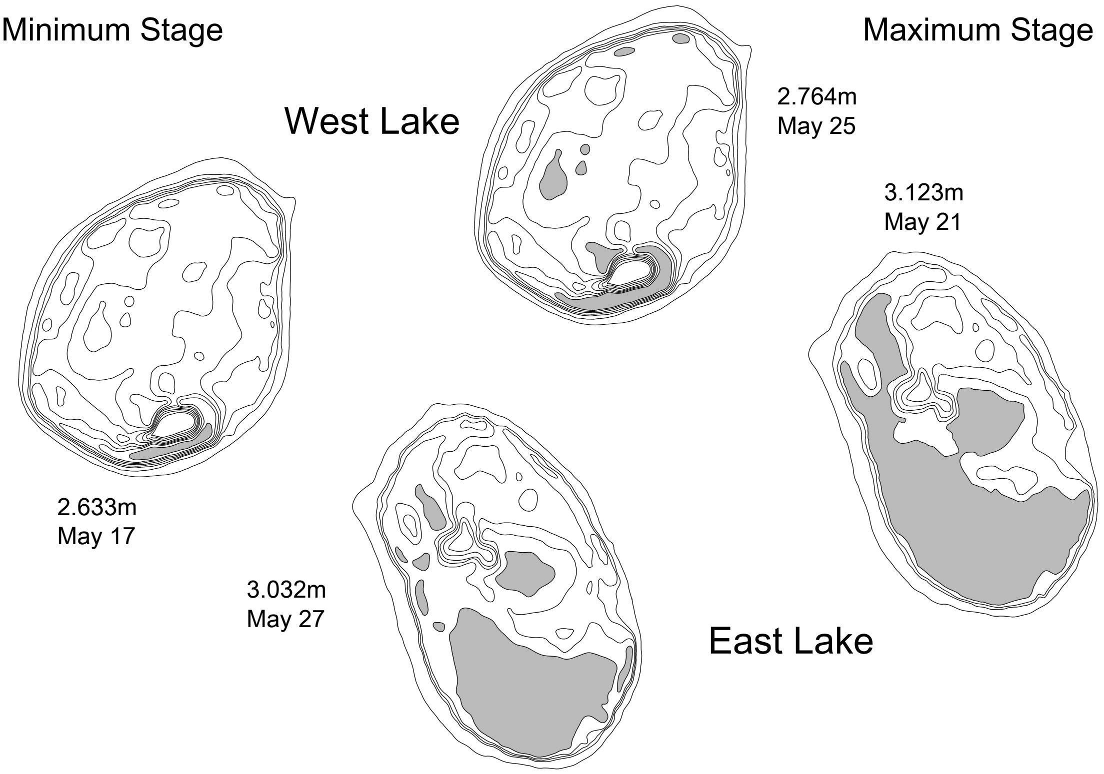


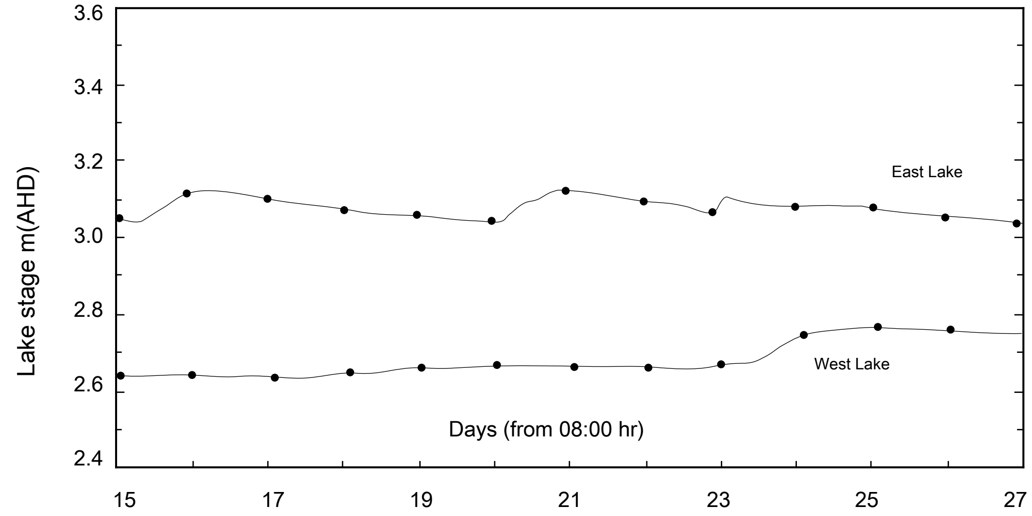
Balance 31 May 03 to May 15 1997

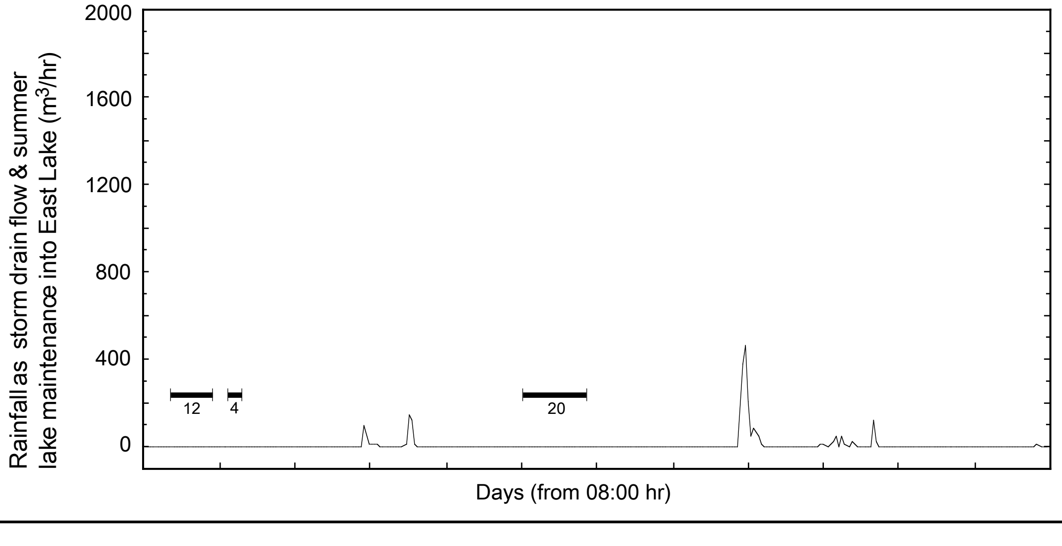




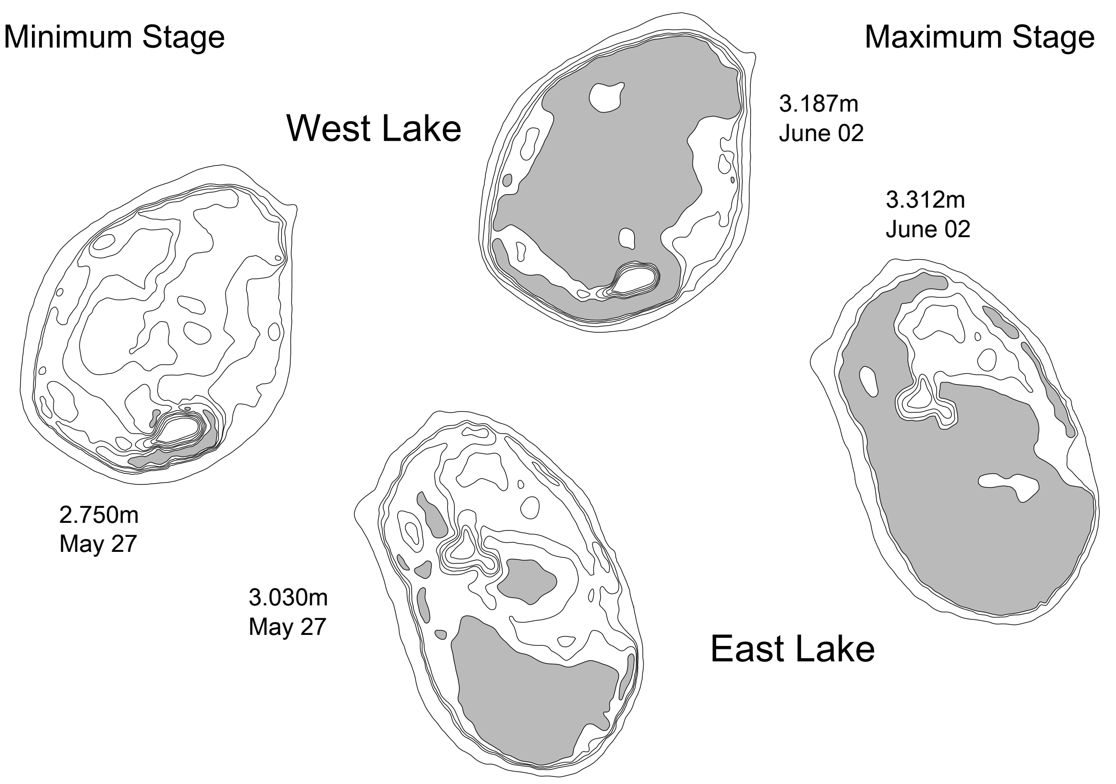
Balance 32 May 15 to May 27 1997

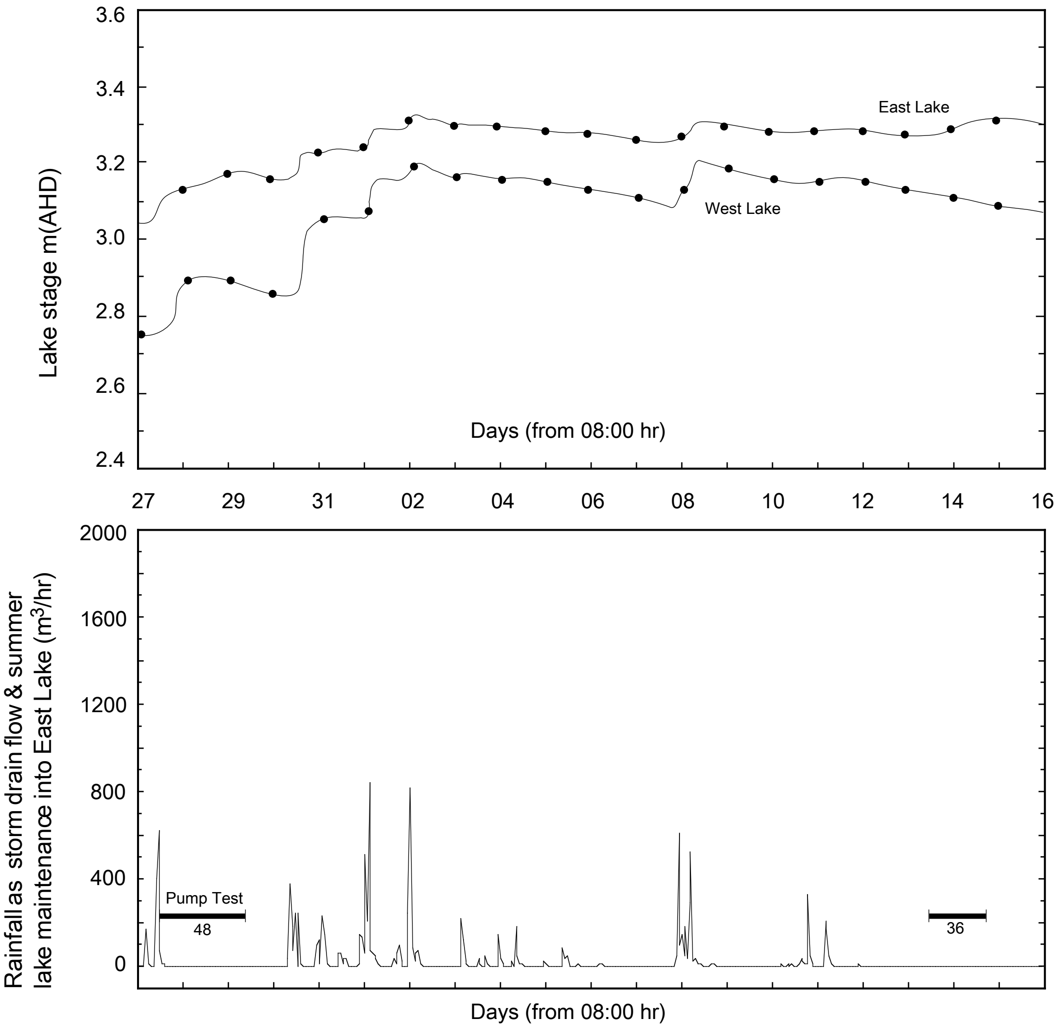






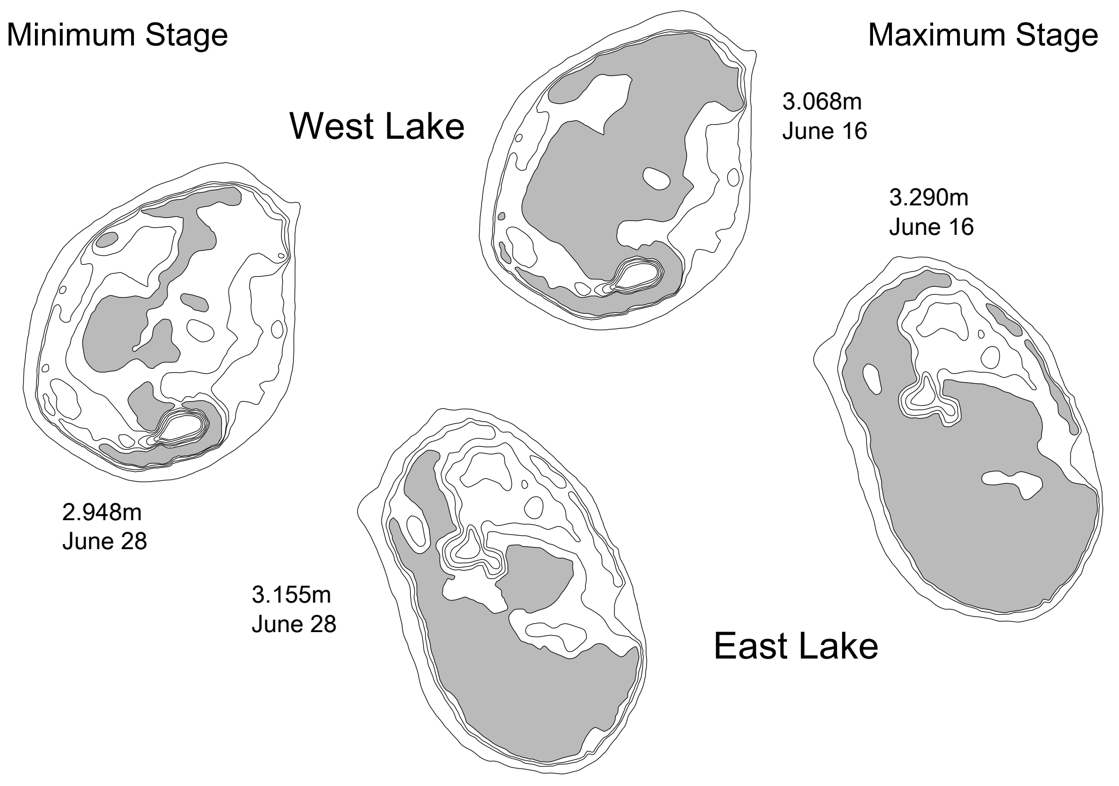
Balance 33 May 27 to June 16 1997

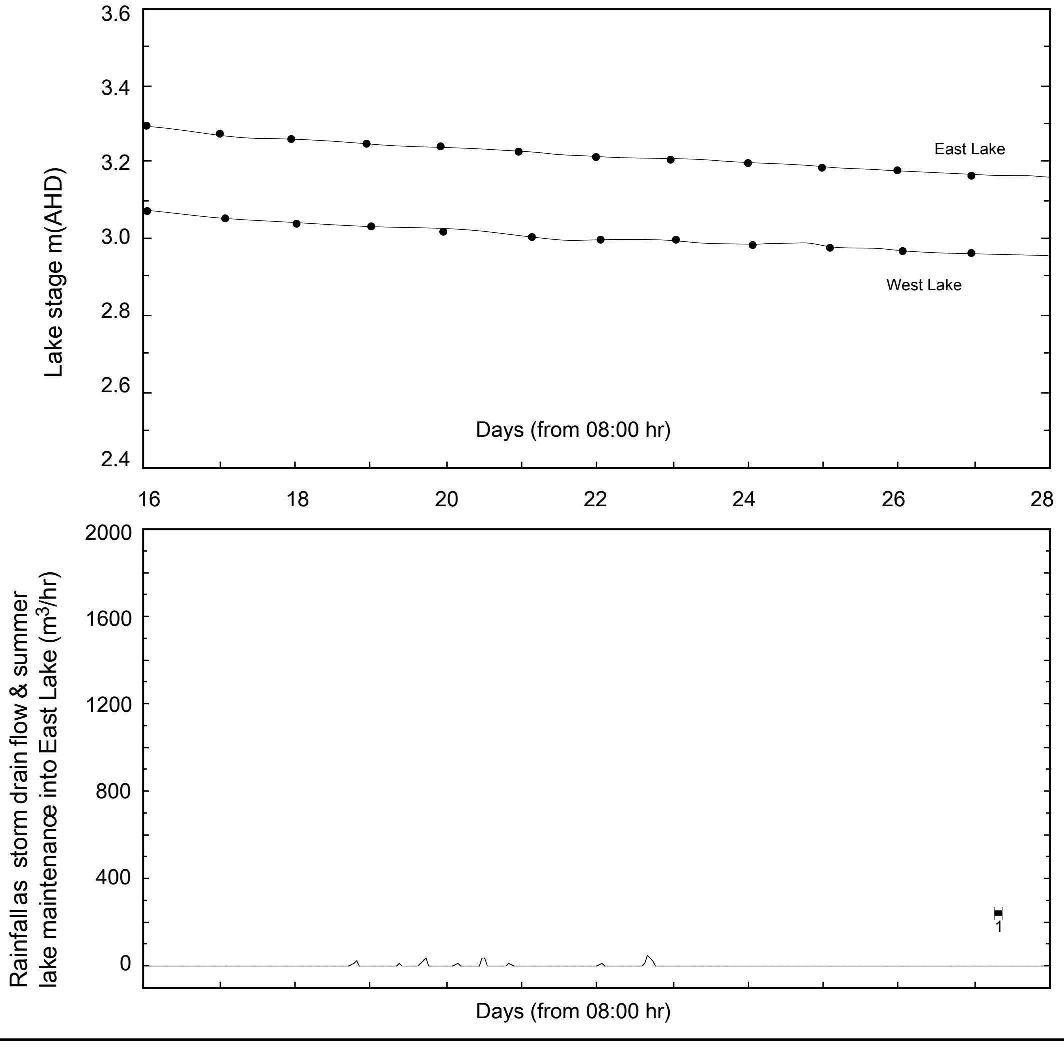




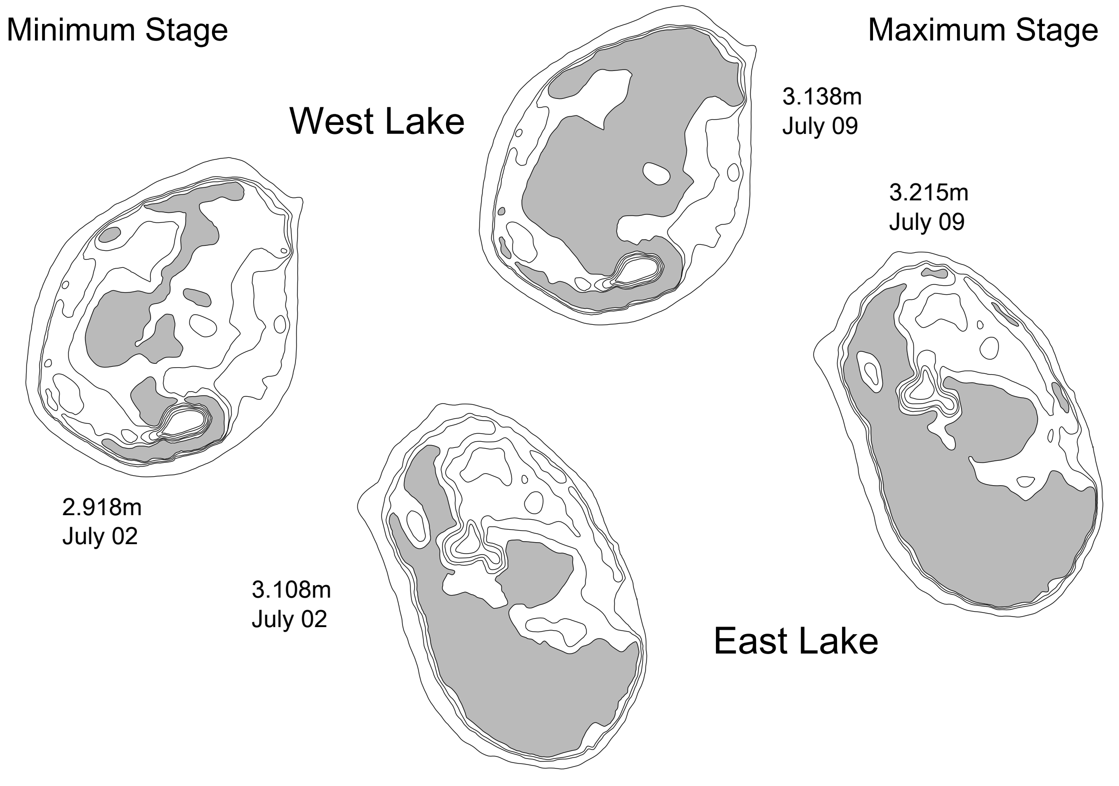
Balance 34

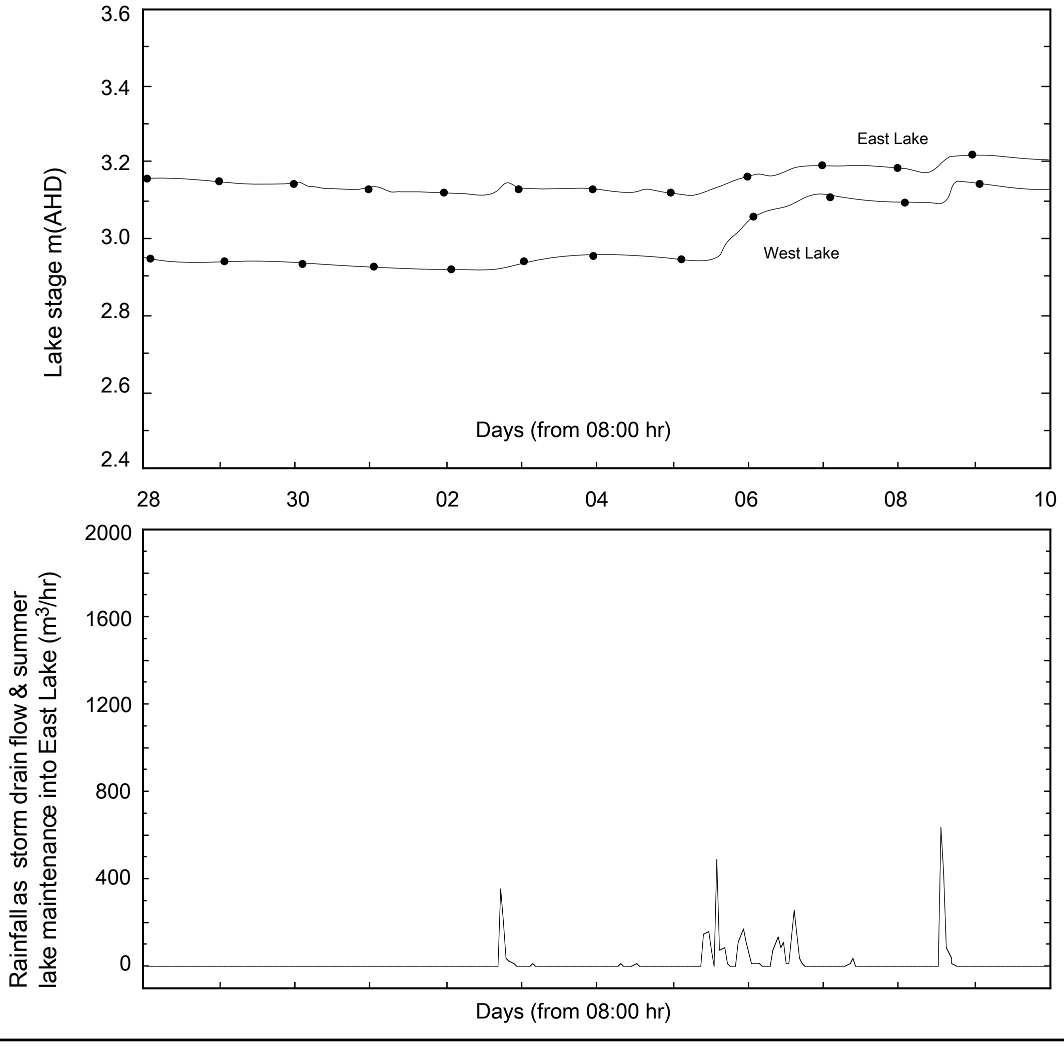
June 16 to June 28 1997



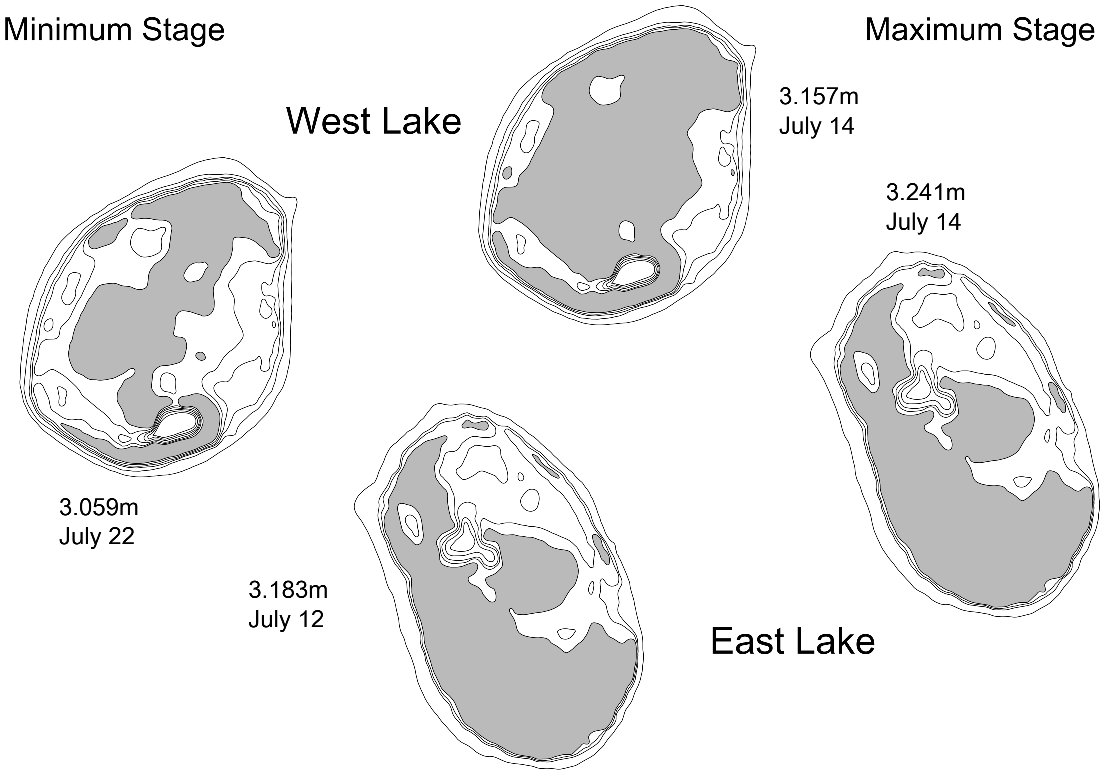


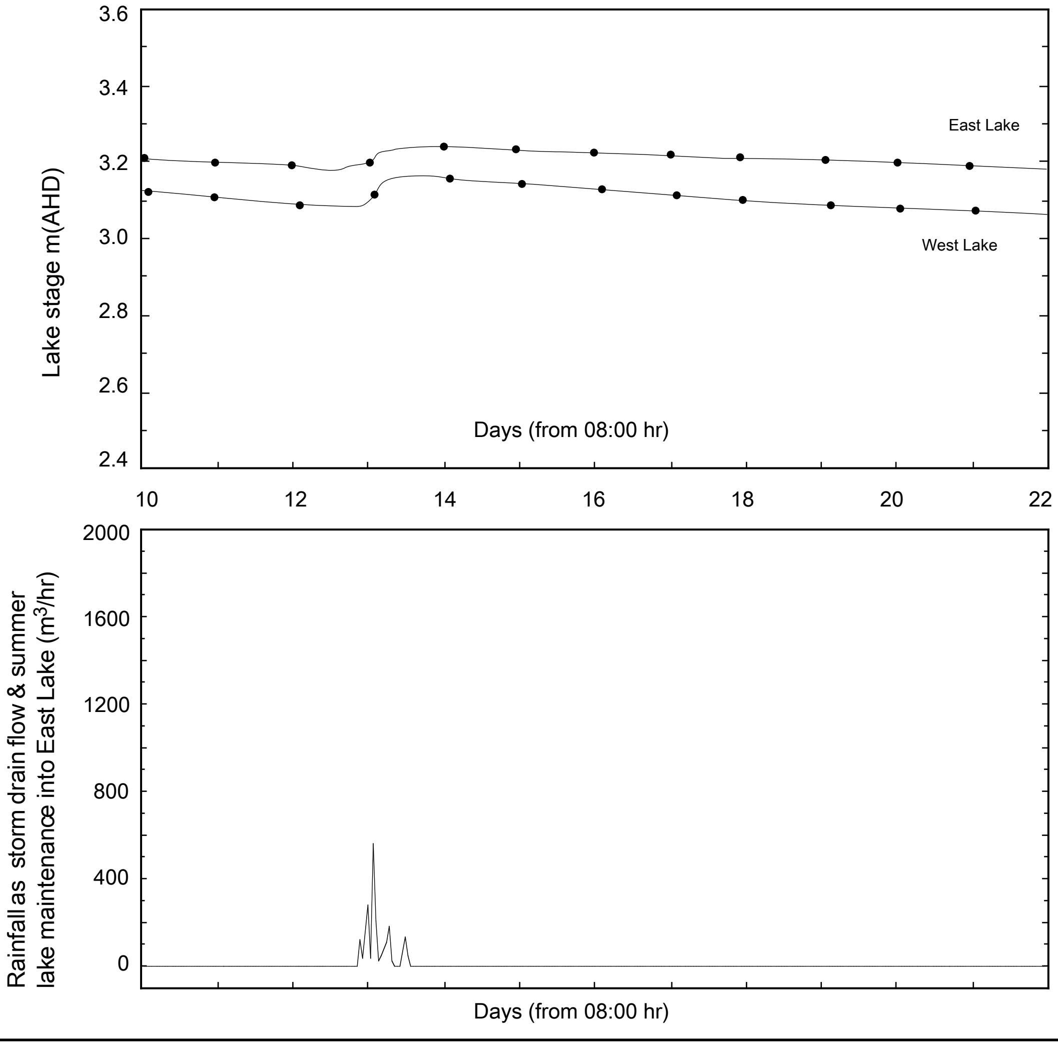
Balance 35 June 28 to July 10 1997



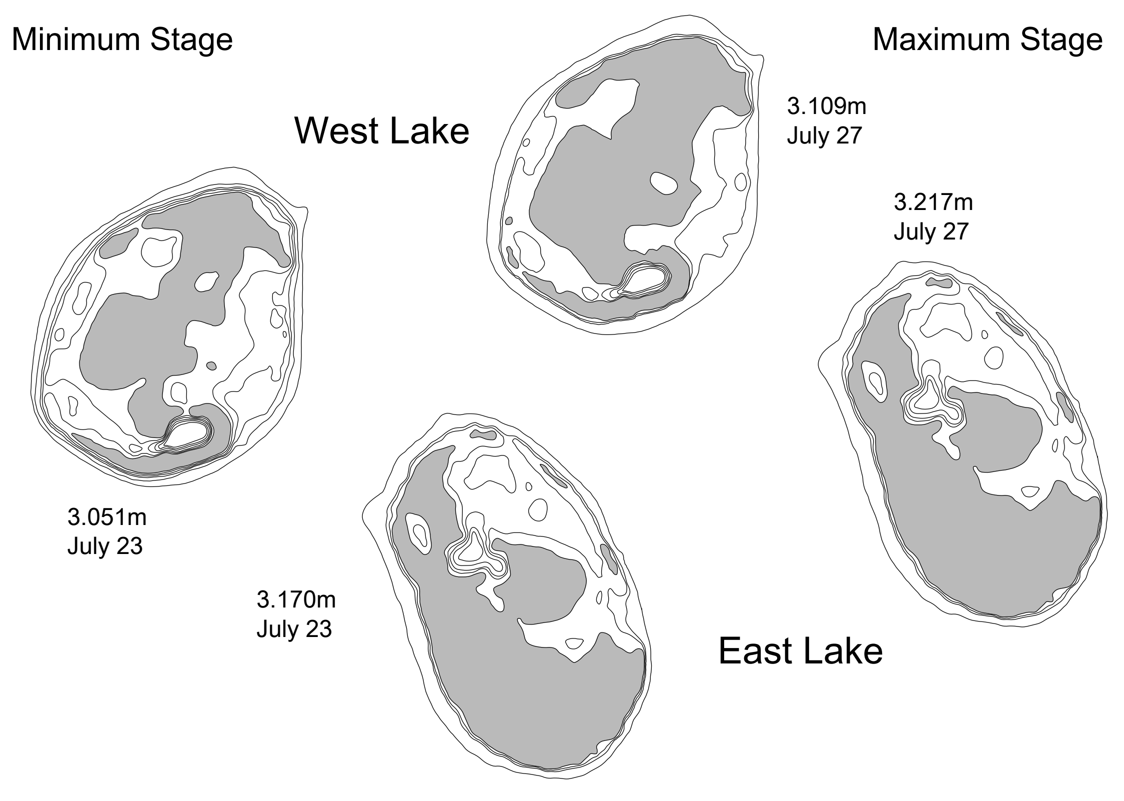


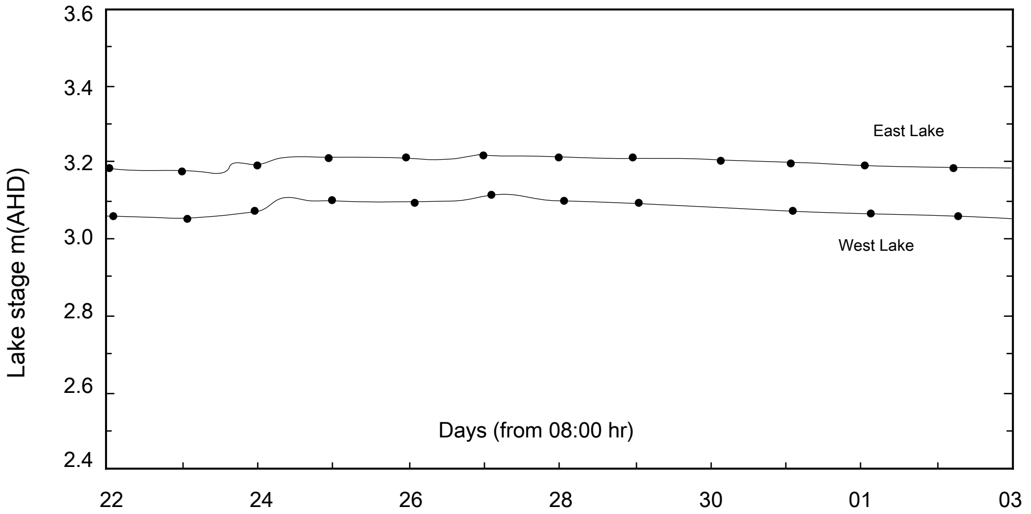
Balance 36 July 10 to July 22 1997

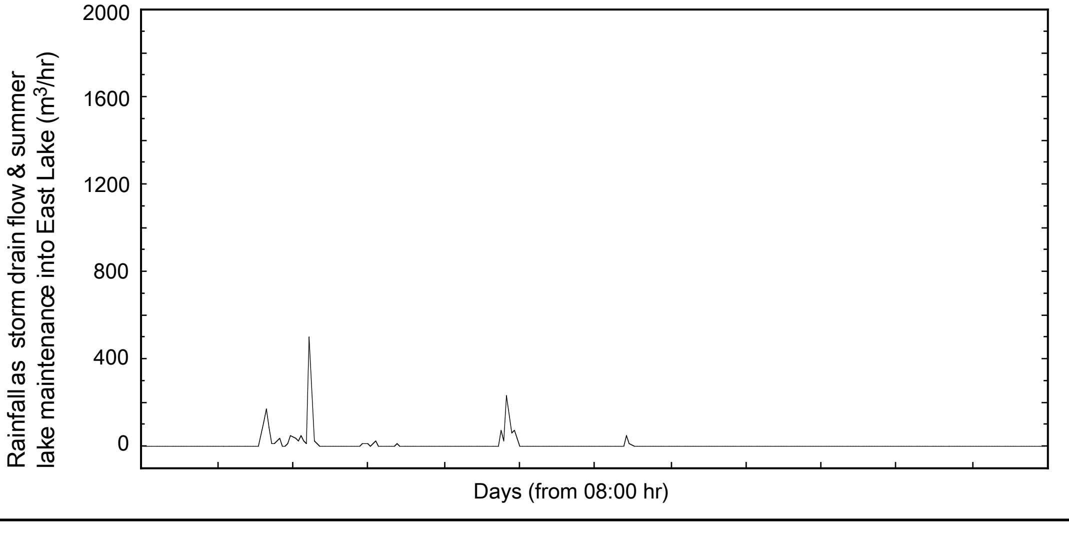




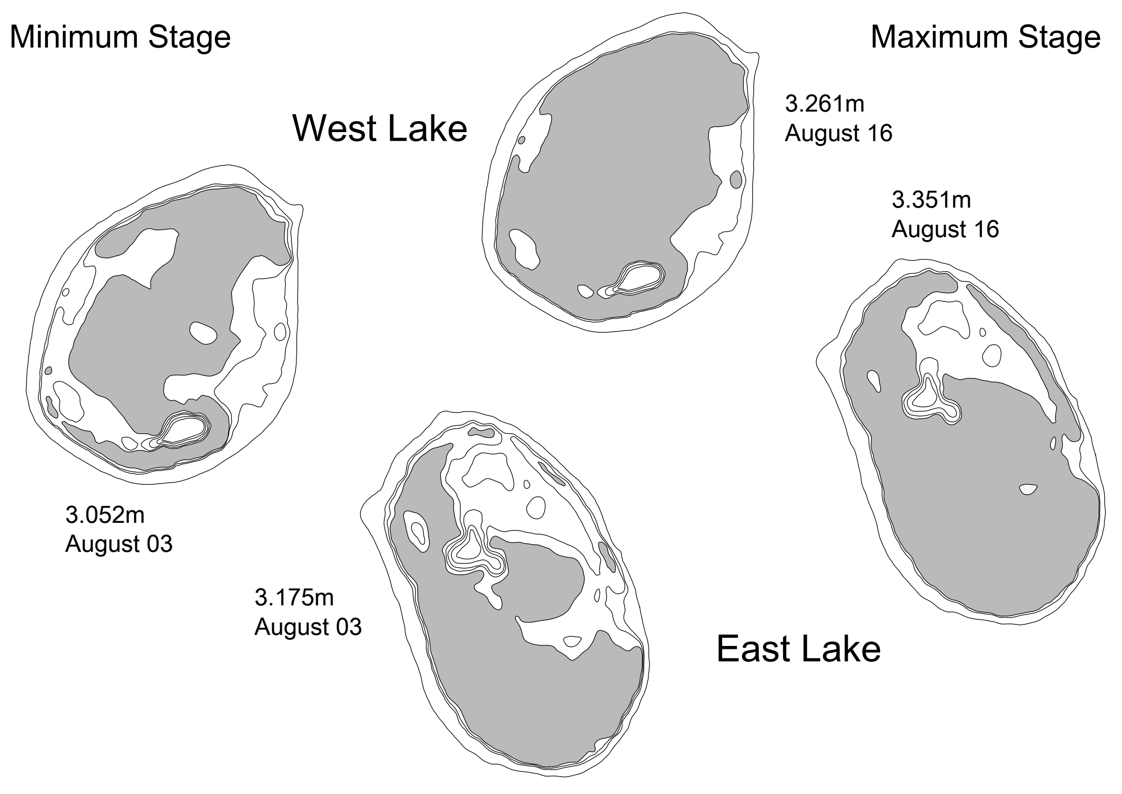
Balance 37 July 22 to August 03 1997

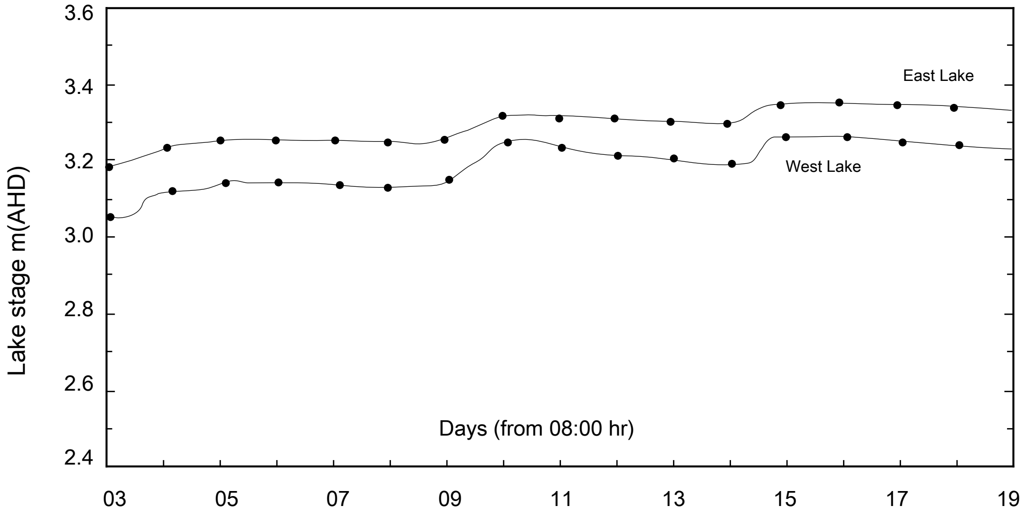


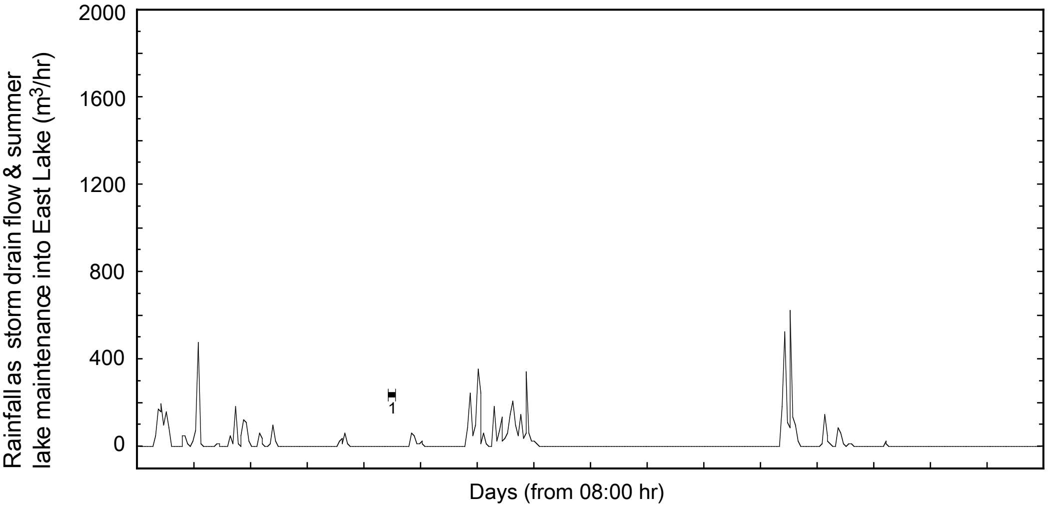




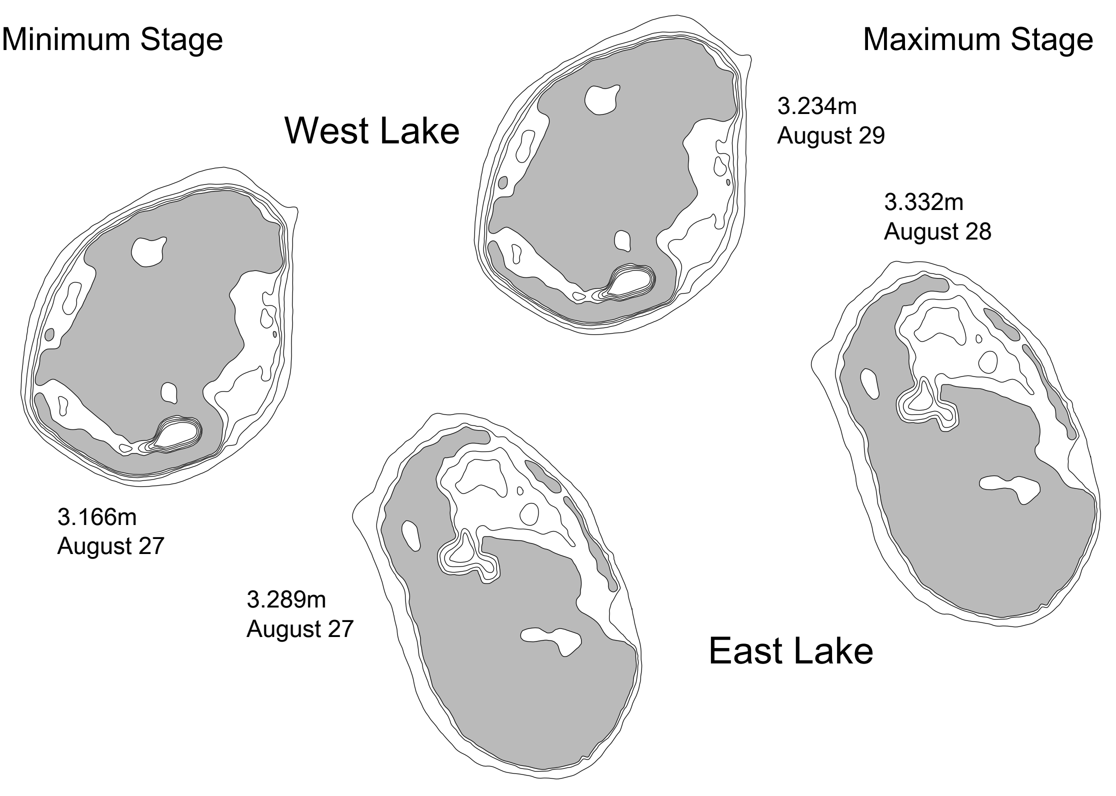
Balance 38 August 03 to August 19 1997

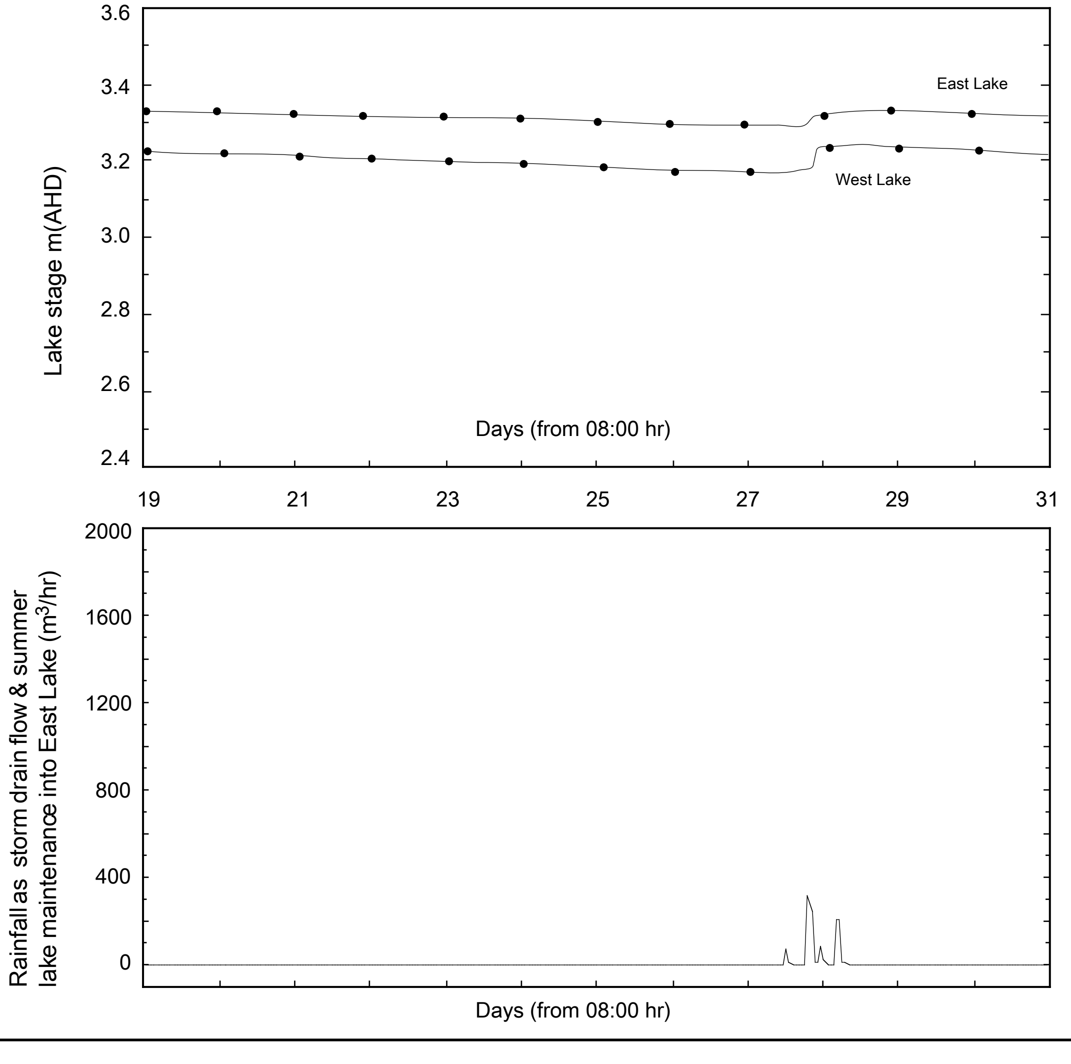




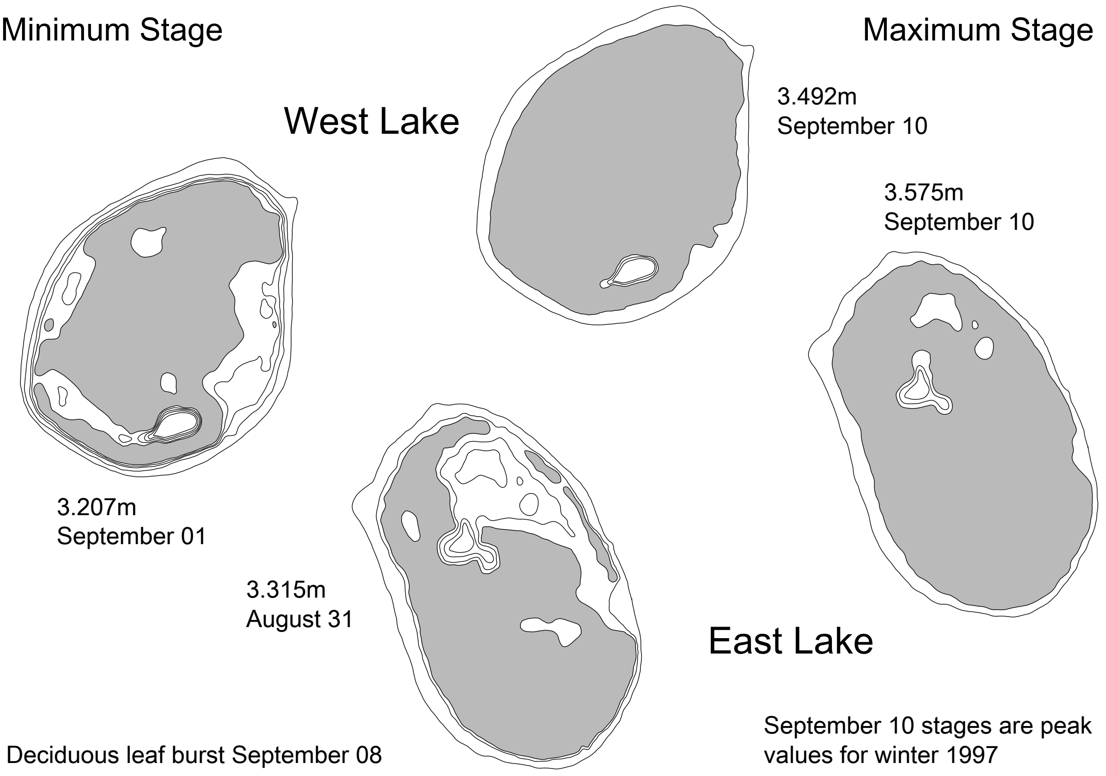


Balance 39 August 19 to August 31 1997



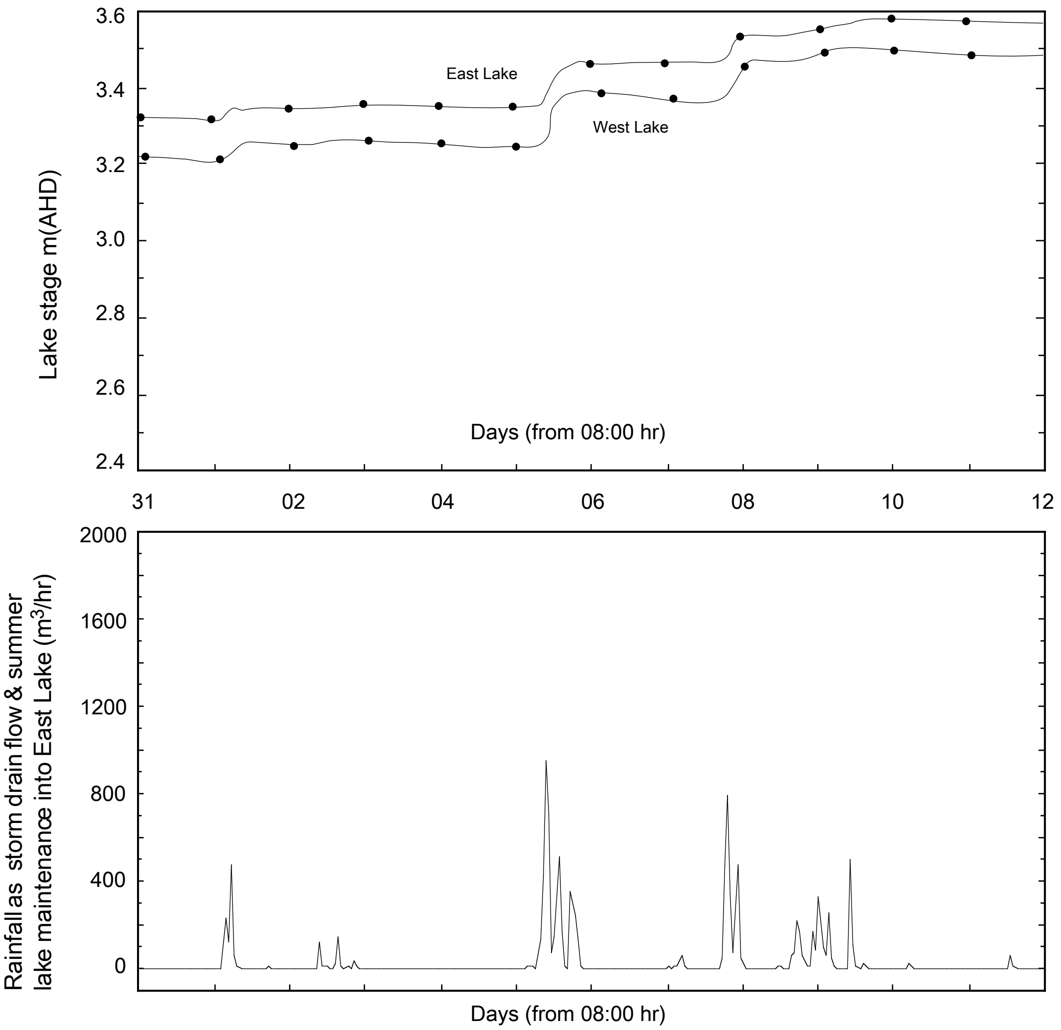


Balance 40 August 31 to September 12 1997

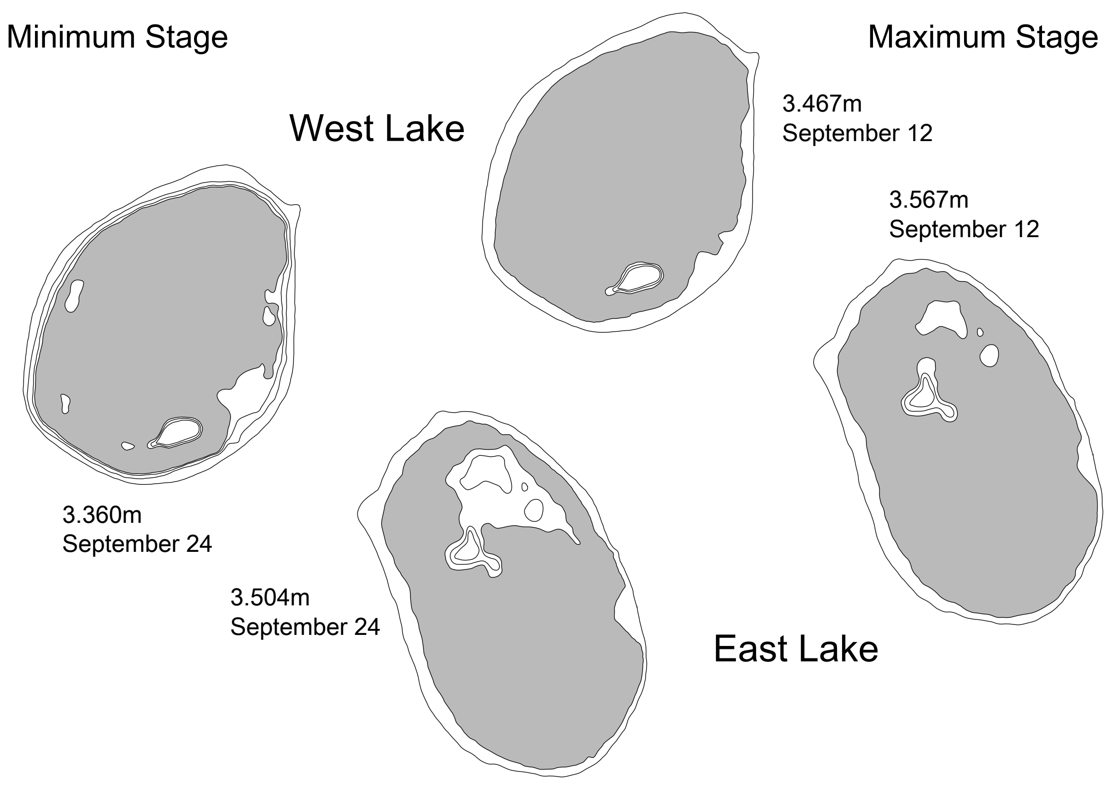


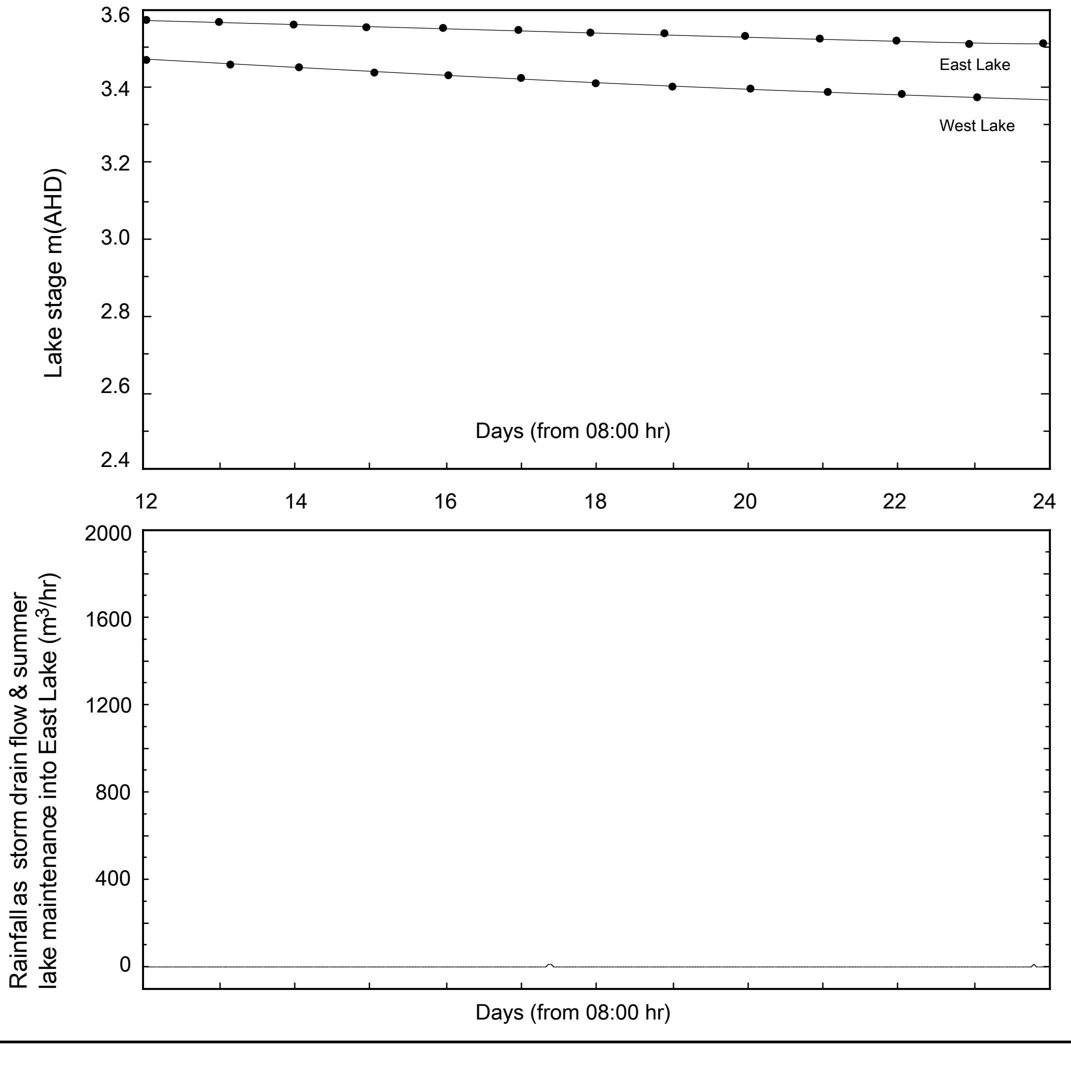
Deciduous leaf burst September 08

September 10 stages are peak values for winter 1997

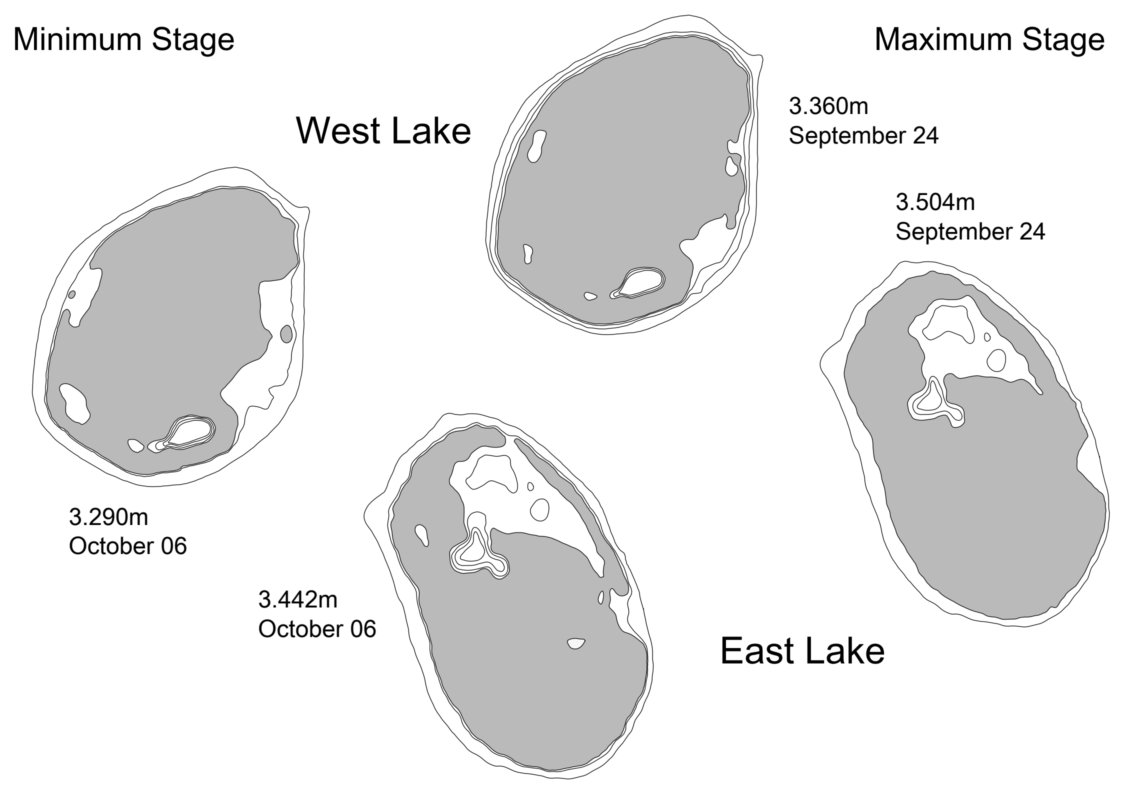


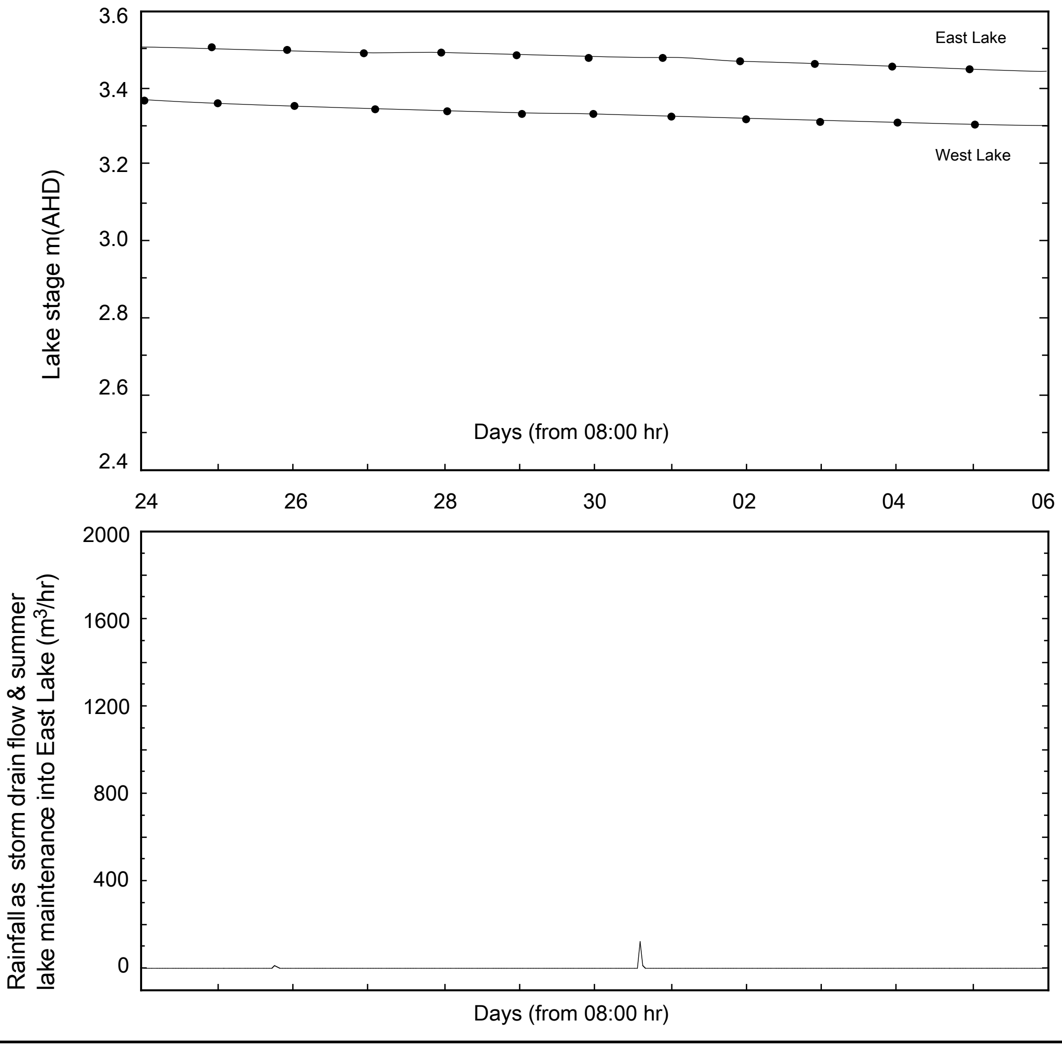
Balance 41 September 12 to September 24 1997



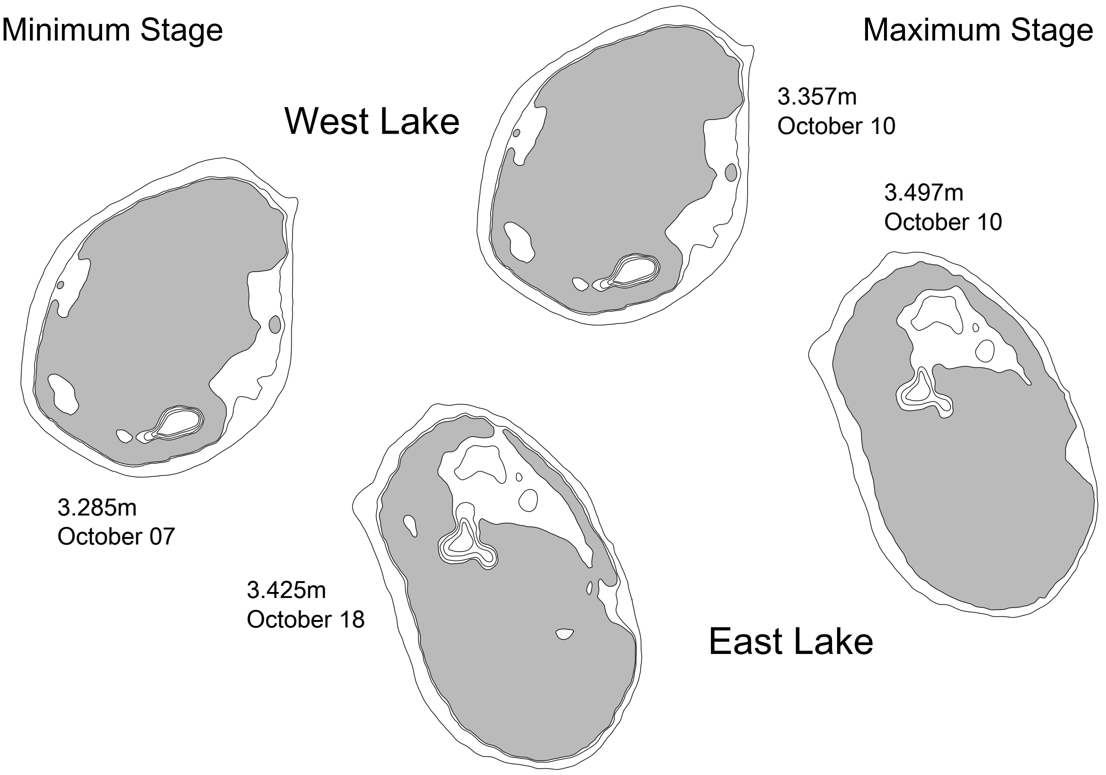


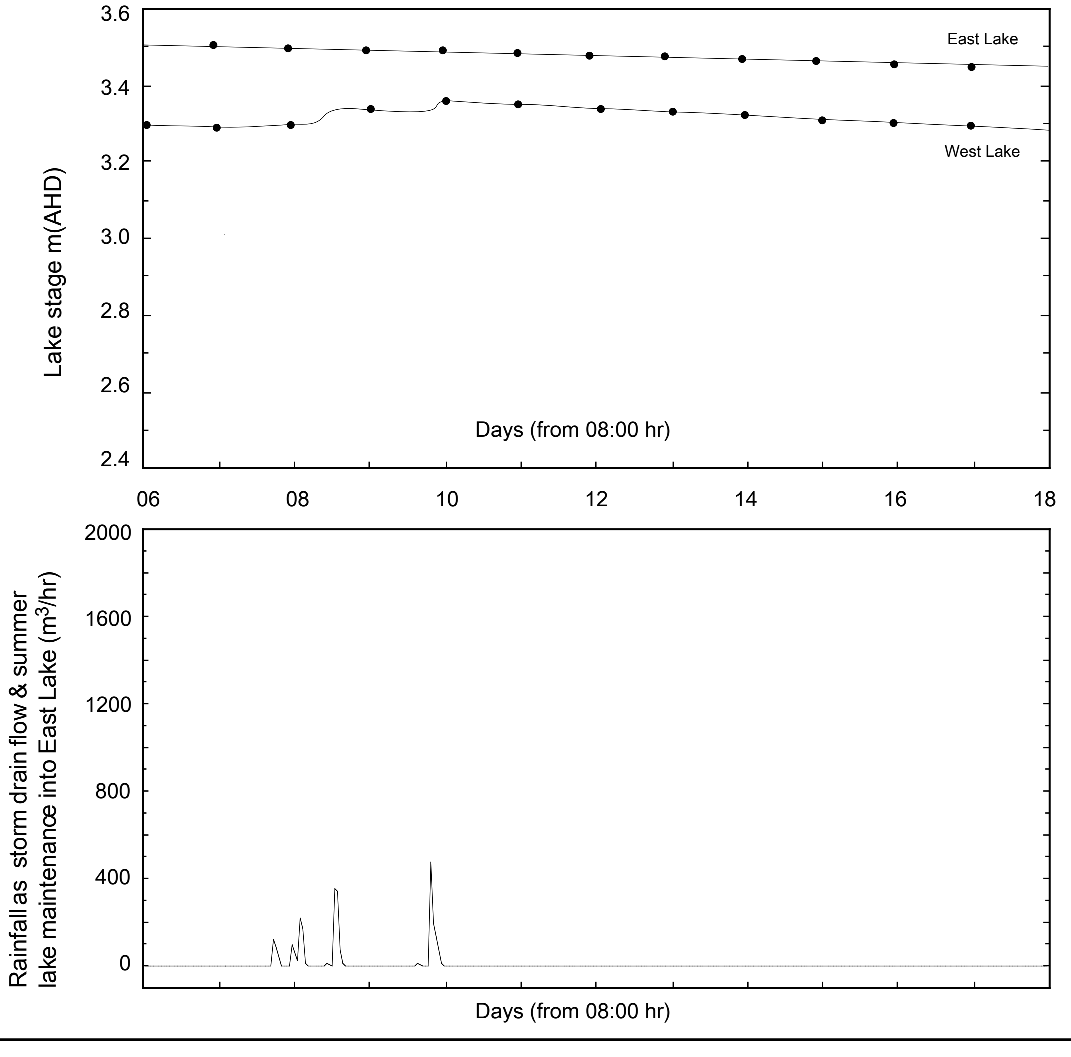
Balance 42 September 24 to October 06 1997



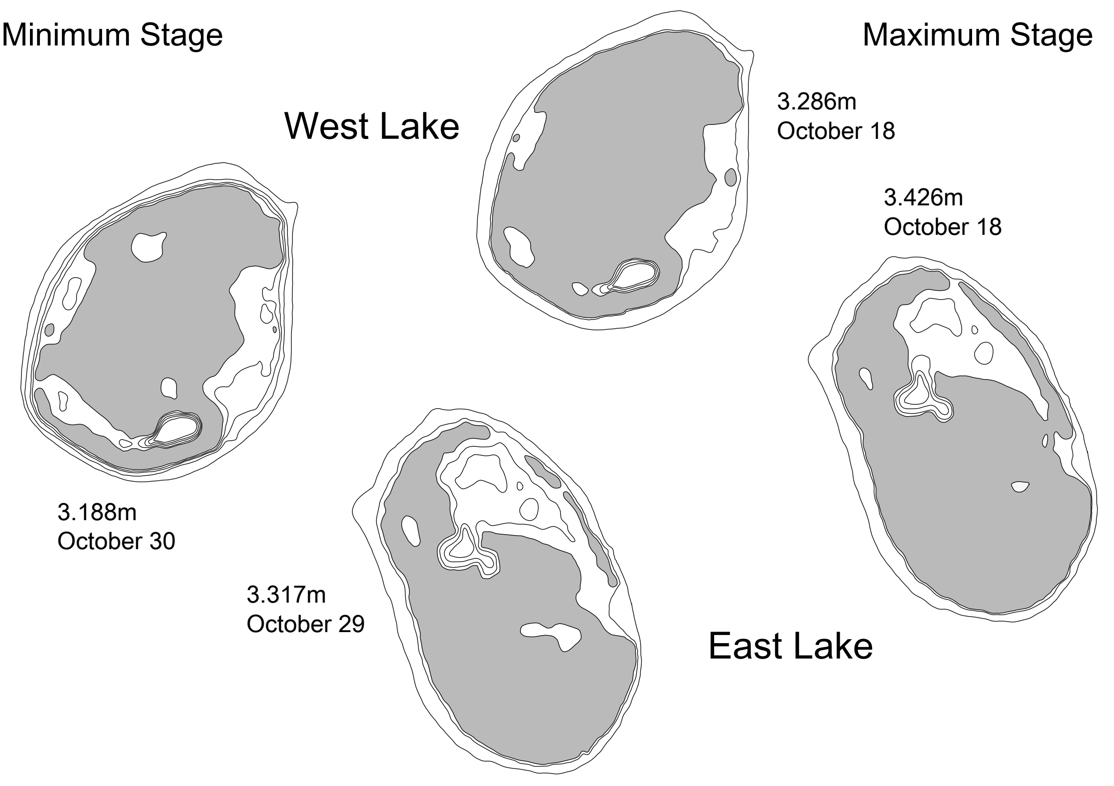


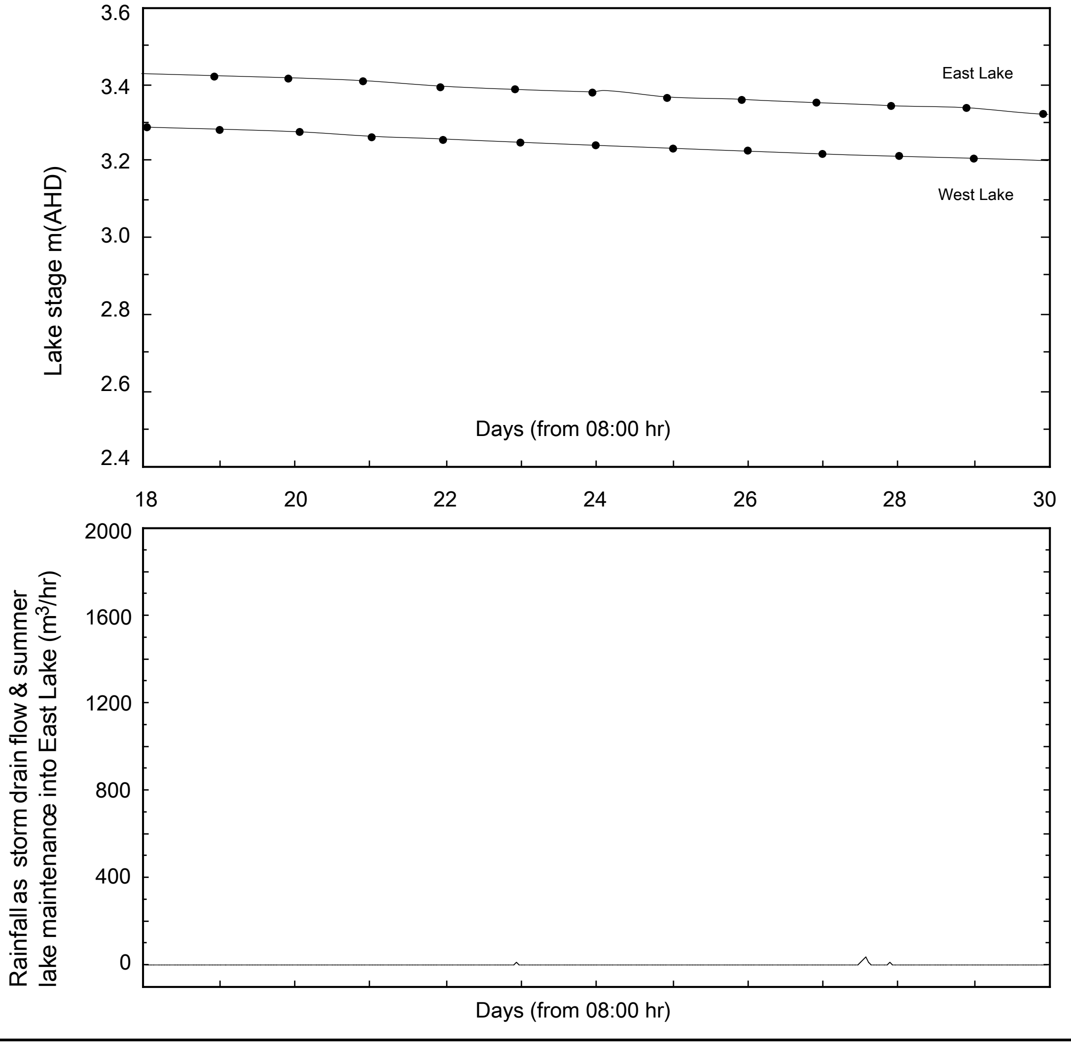
Balance 43 October 06 to October 18 1997



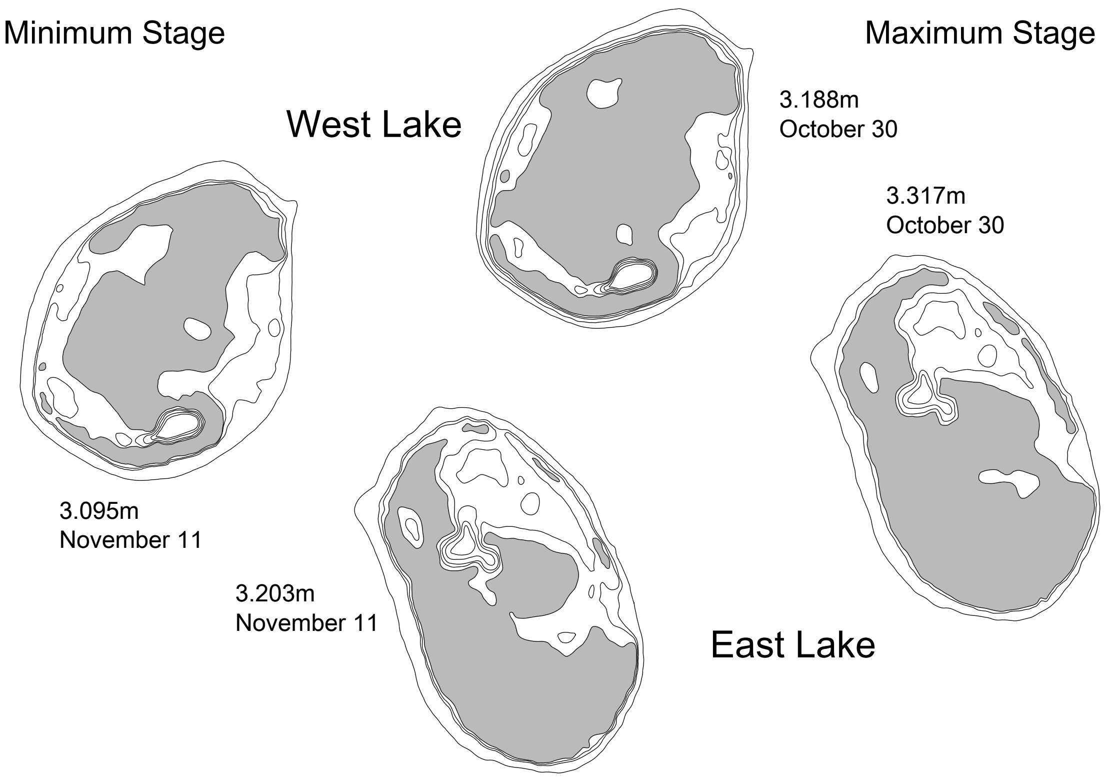


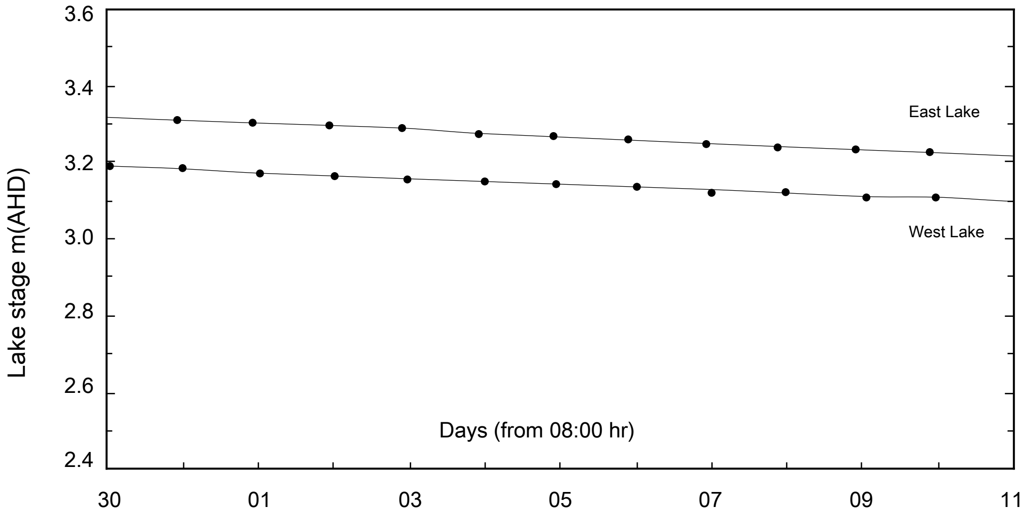
Balance 44 October 18 to October 30 1997

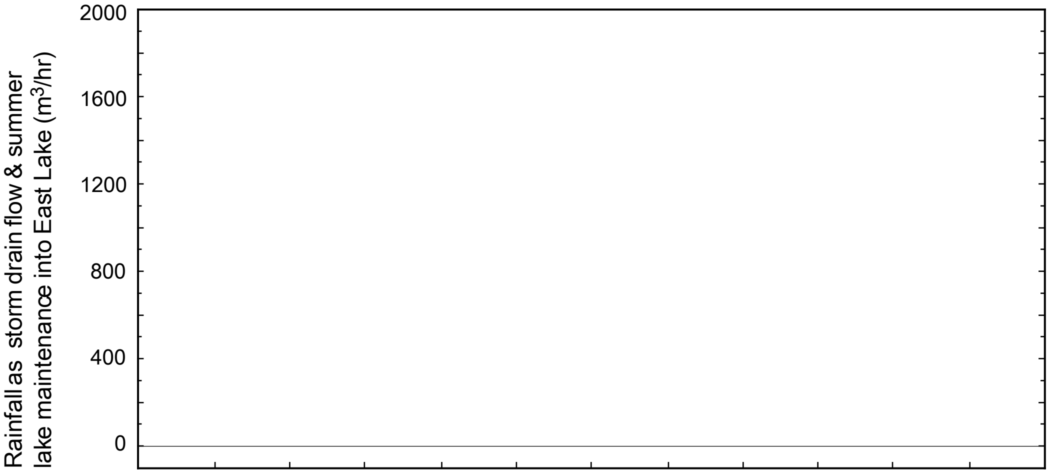




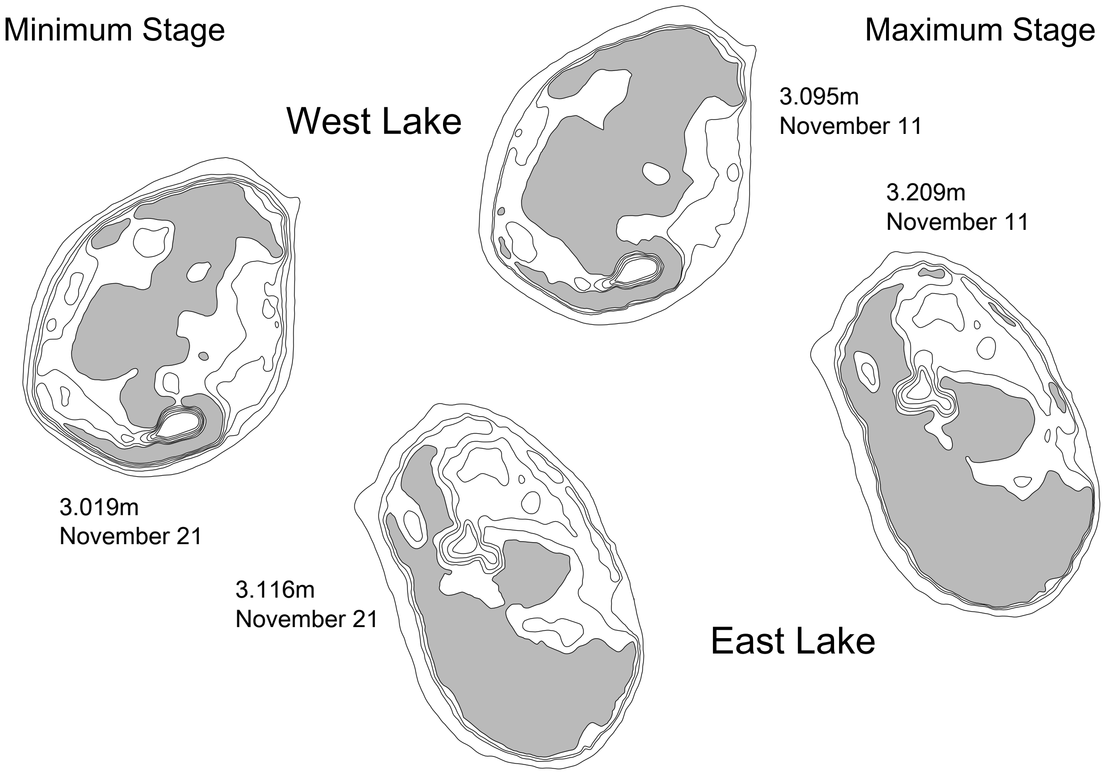
Balance 45 October 30 to November 11 1997

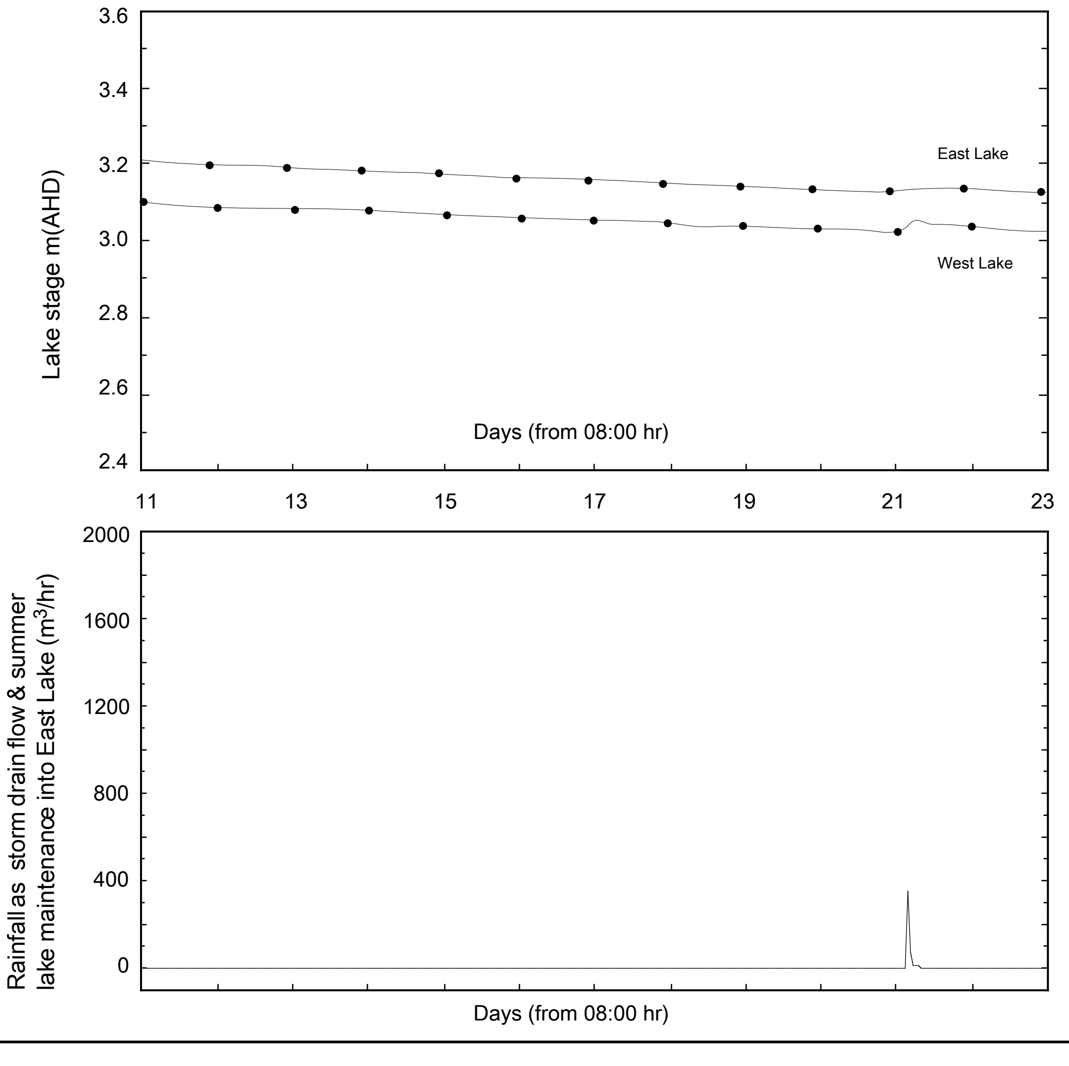




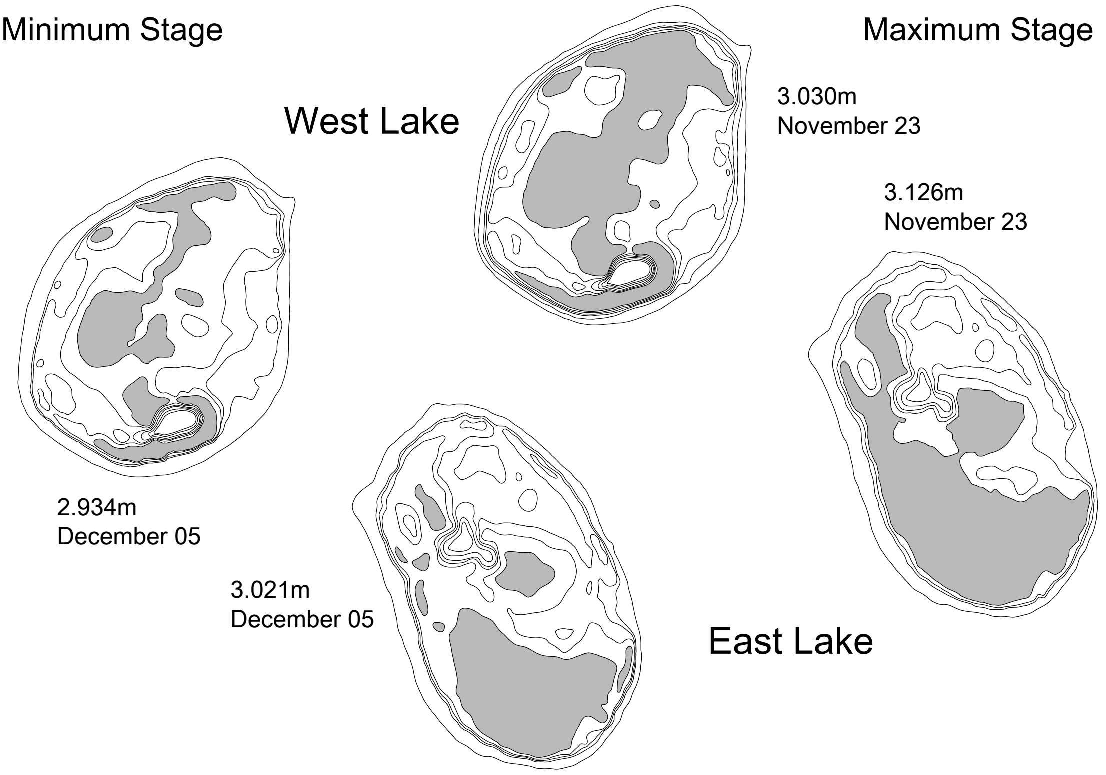


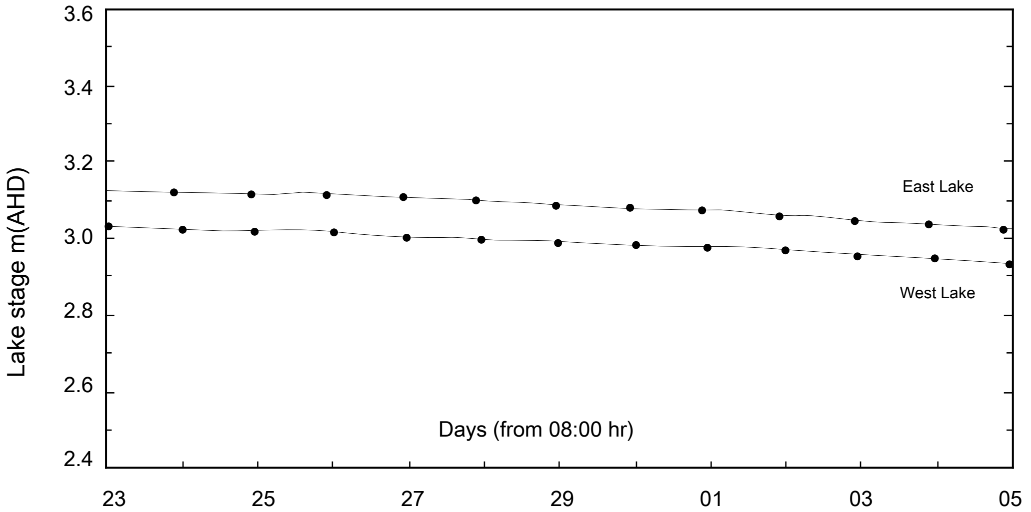
Balance 46 November 11 to November 23 1997

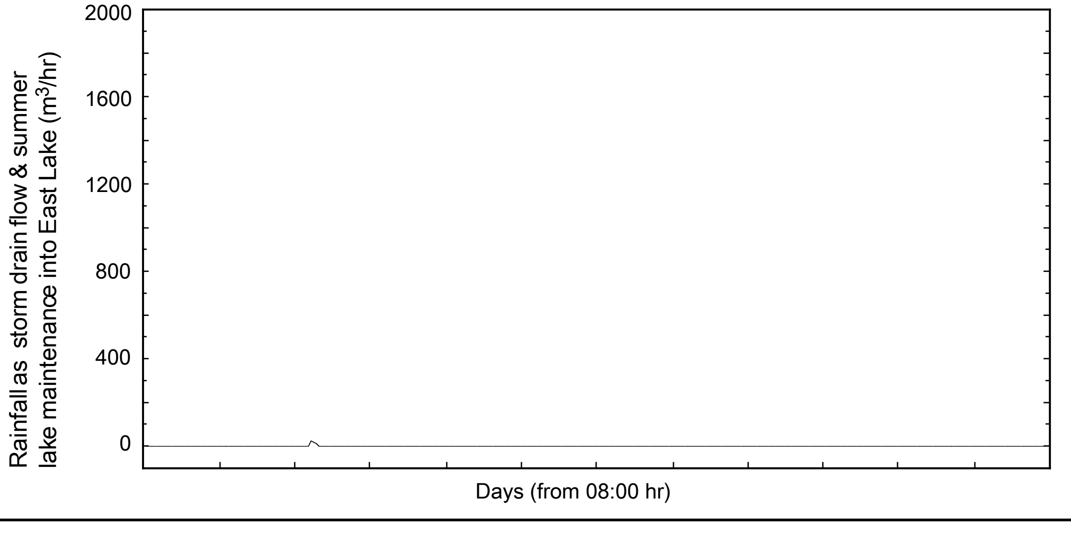




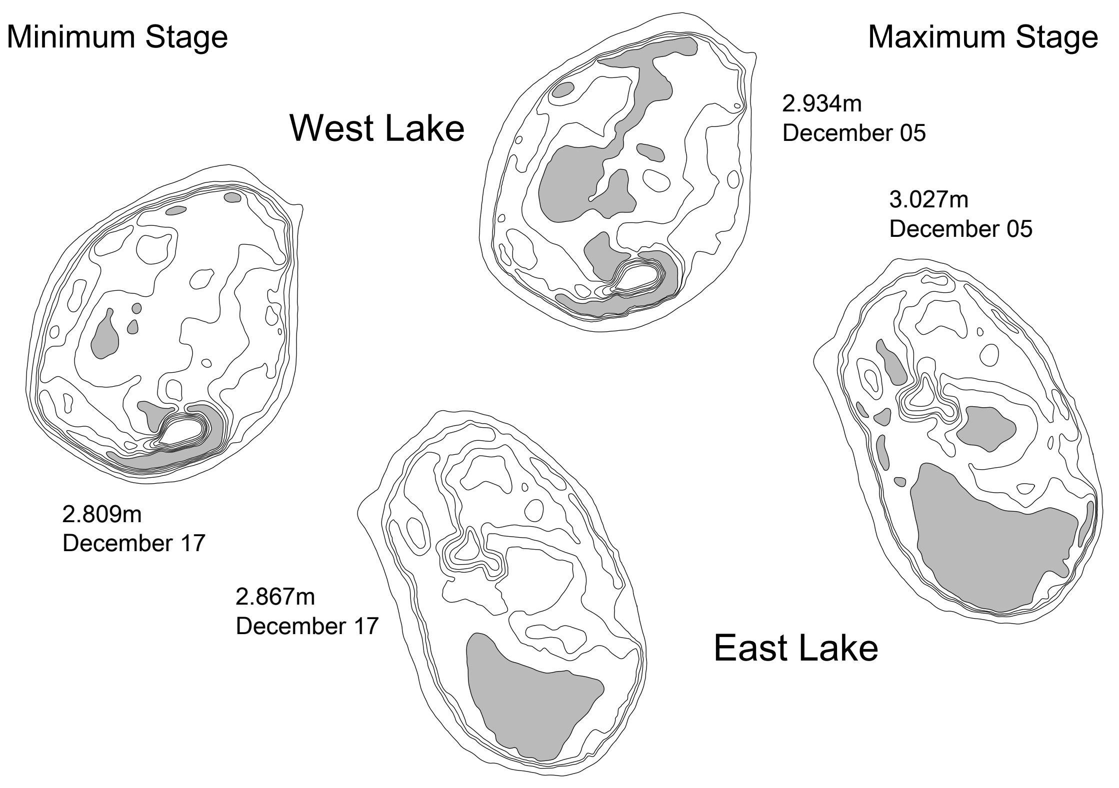
Balance 47 November 23 to December 05 1997

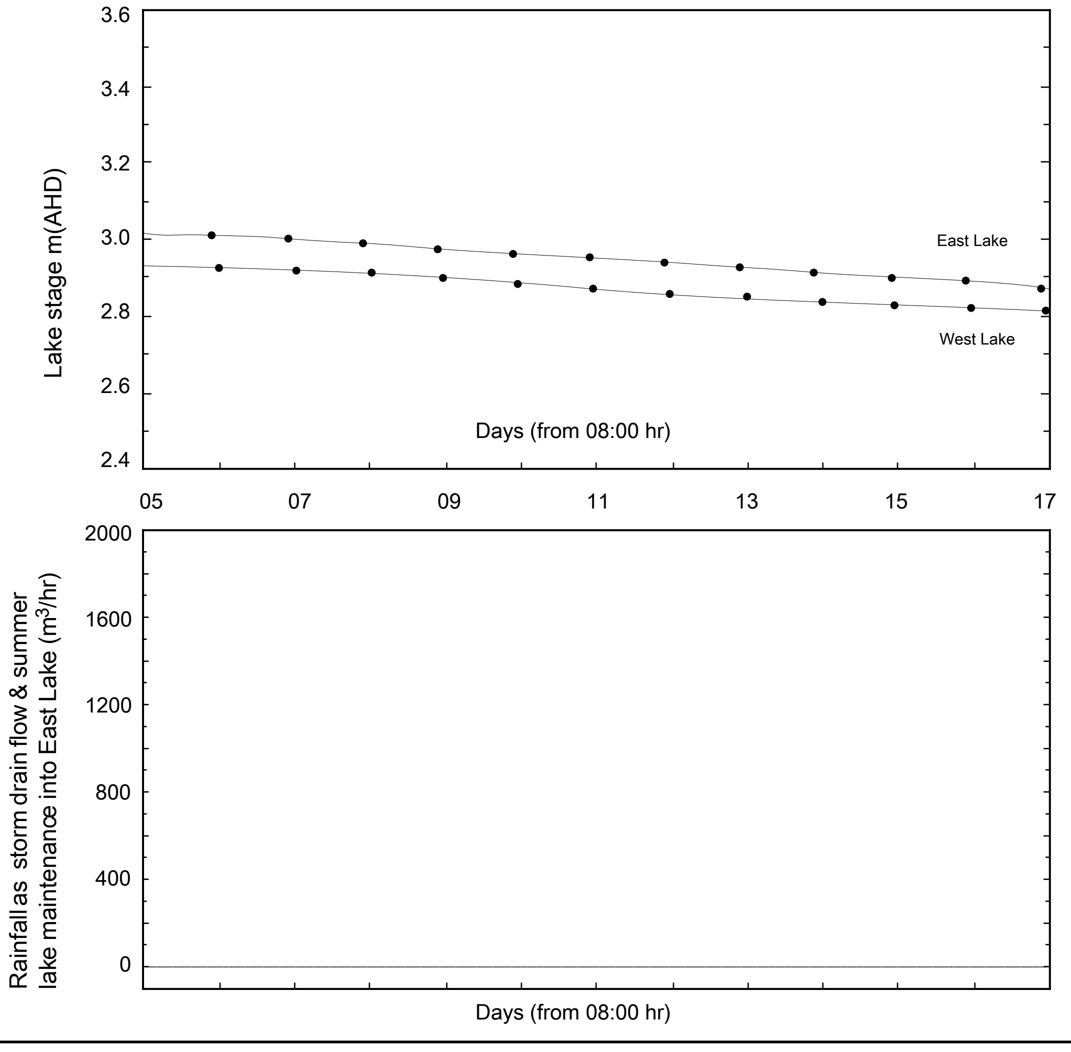




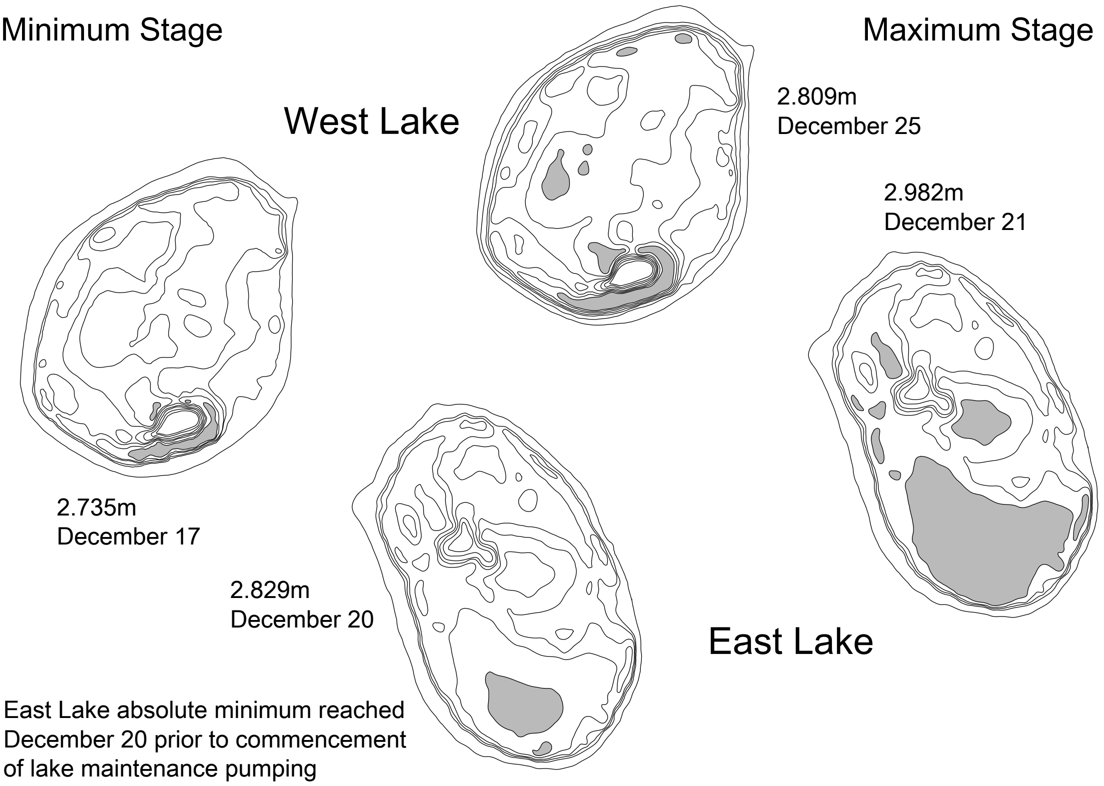


Balance 48 December 05 to December 17 1997

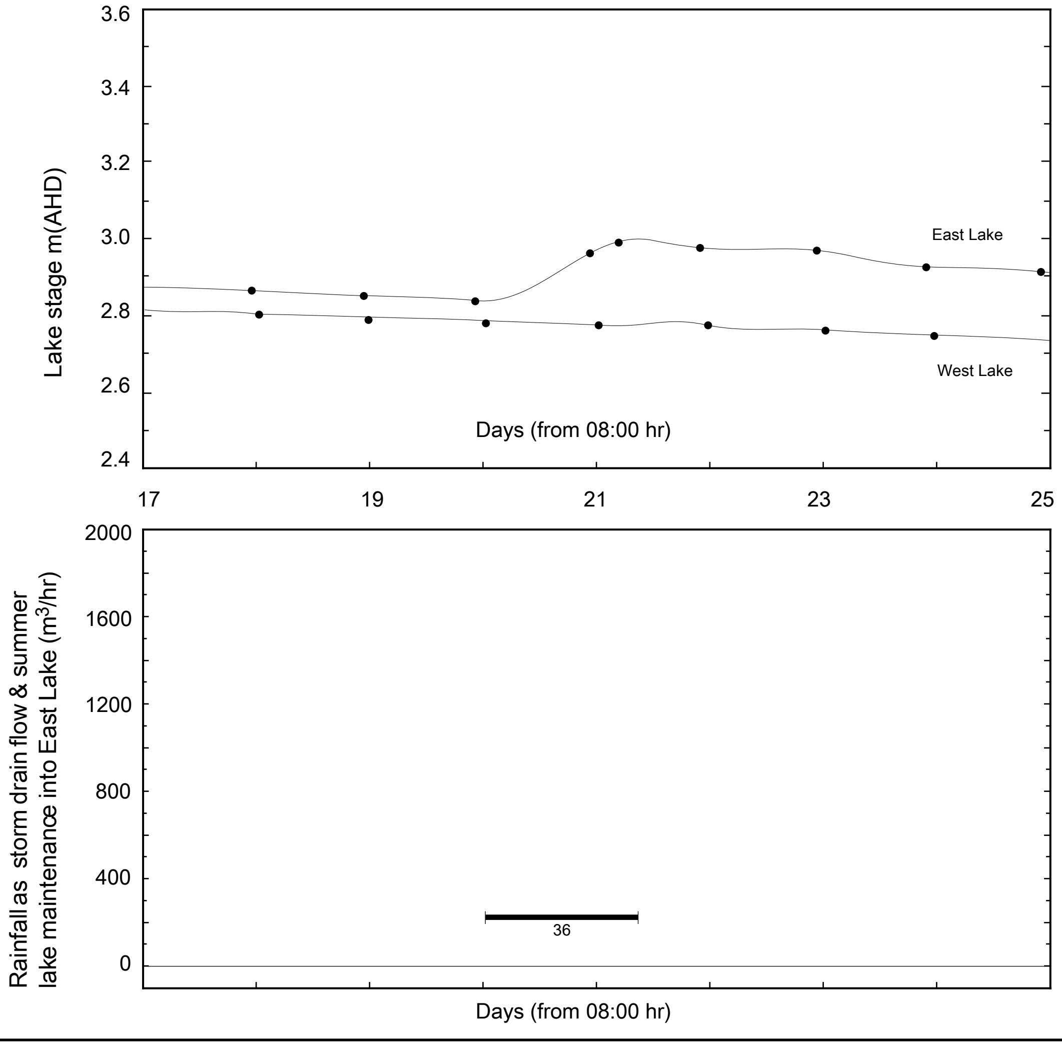




Balance 49 December 17 to December 25 1997

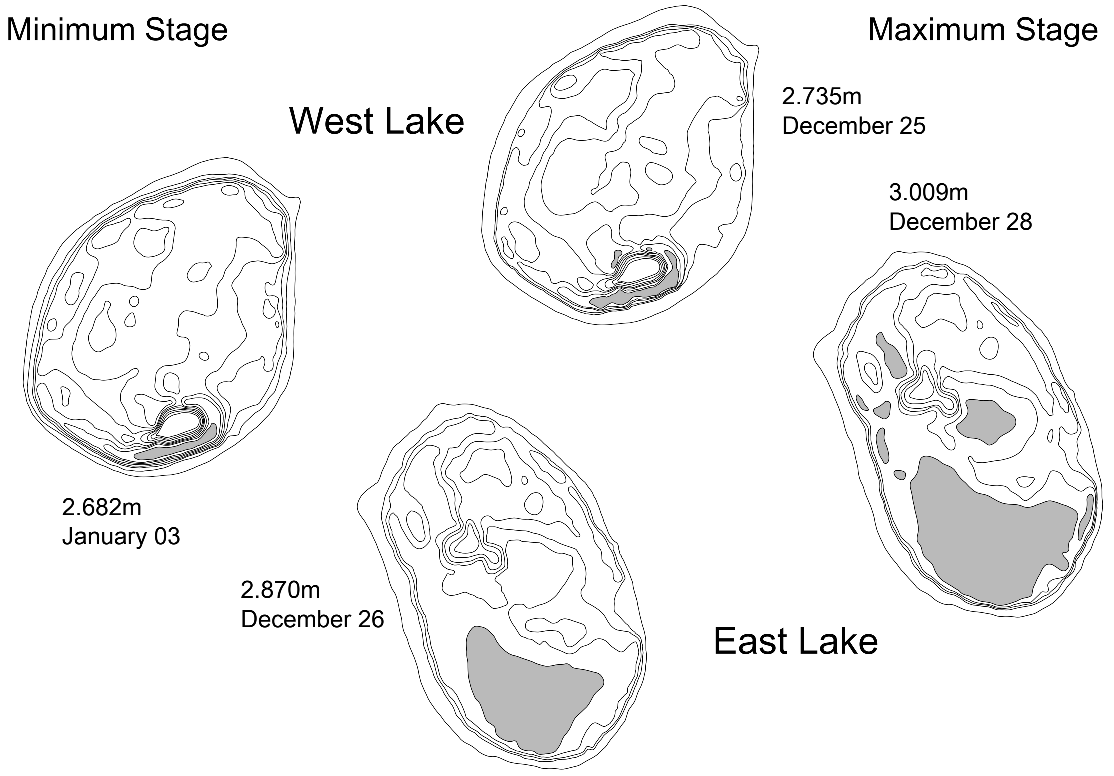


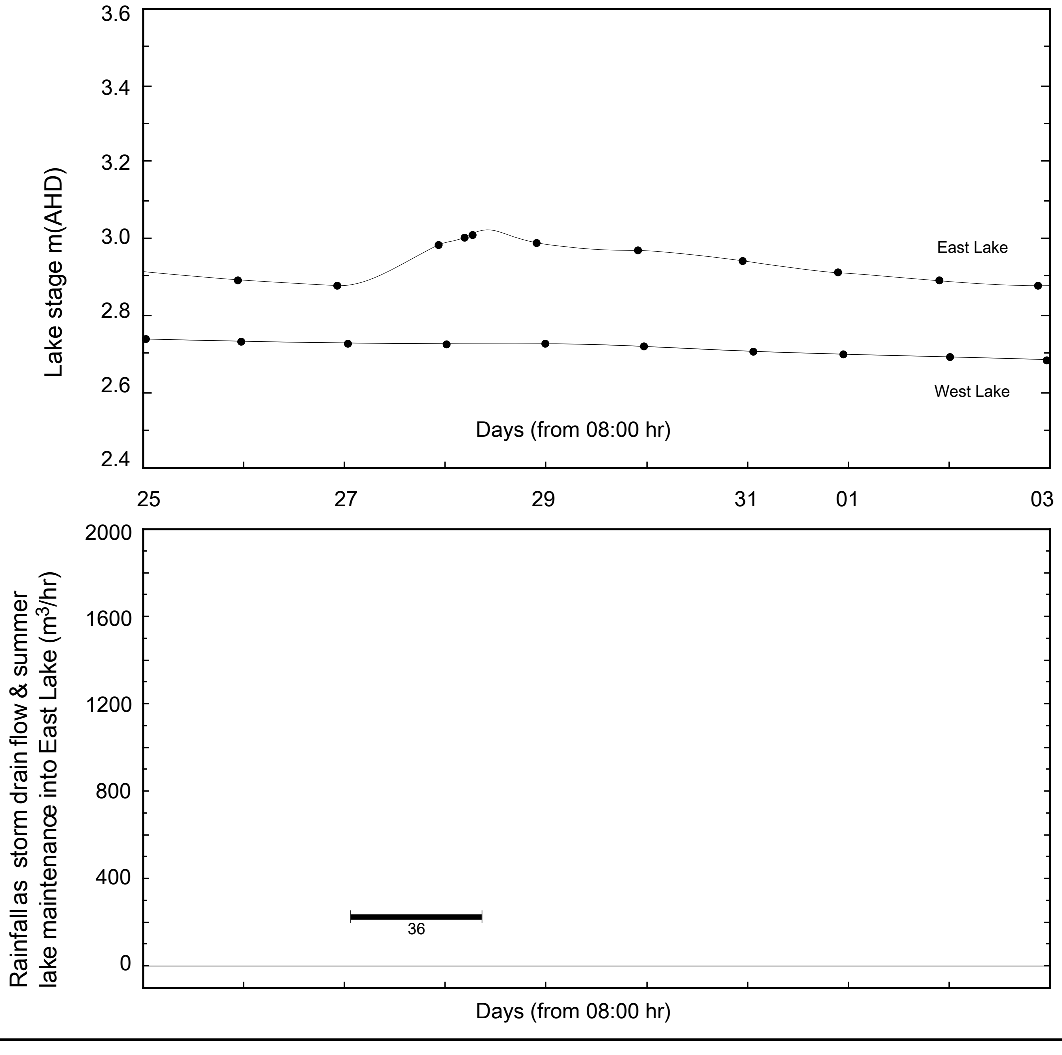
East Lake absolute minimum reached December 20 prior to commencement of lake maintenance pumping



Balance 50

December 25 1997 to January 03 1998





Appendix 6.2

East Lake Balance Sheets, Balance Periods 1-50
(one sheet for each balance period).

Appendix 6.2 (East Lake) and 6.3 (West Lake) Balance Sheets

Component	Units	Details
Day & Time		Date and time of the end of each 24 hour balance 'day'
Stage	m	Lake stage (metres above Australian Height Datum)
Area	m^2	Lake area from lake stage, refer Appendix 3.8
Volume	m^3	Lake volume from lake stage, refer Appendix 3.8
ΔS	m^3	Change in lake volume ('storage') over each 4 day sub-balance
Lake	δ	Deuterium in ‰ measured at the start and end of each 4 day sub-balance
	Cl	Chloride in mg L^{-1} measured at the start and end of each 4 day sub-balance
Rain	mm	Rainfall in mm falling on the lake surface
	m^3	Rainfall volume
	δ	Deuterium (average for each rainfall event which may span several days)
	Cl	Chloride in rain, 12mg L^{-1} being the average for Floreat
Drains	m^3	Storm drain flow (total for lake)
	δ	As per rainfall
	Cl	As per rainfall
Top Up	m^3	Individual volumes for outlets 'A' and 'B'
	δ	Deuterium for each outlet sampled during most top up events
	Cl	Chloride for each outlet sampled during most top up events
Evaporation	mm	Evaporation in mm as measured by the floating evaporation pan
	m^3	Volume of lake water evaporated
	δE_{pan}	δE as measured experimentally for Perry Lakes by pan experiments
	δE^*	δE as estimated from standard equations
	δA	δA as measured or interpolated from vapour sampling
Apparent GW Flux	m^3	Residual in the mass balance
GW In	m^3	Groundwater discharged to lake as computed by integrated balance
Lake-GW	m^3	Groundwater recharged to aquifer as computed by integrated balance

The groundwater ('GW') components are the key components which could not be measured directly. They are the reason for performing an integrated balance in the first place. The 'apparent groundwater flux' is simply the residual in the mass balance alone. It is the apparent surplus or deficit in water required to balance the equation. A negative value indicates an apparent deficit in water and is indicative of water which has flowed out of the lake as recharge to the aquifer. A positive value indicates an apparent surplus and indicates additional water which has entered the lake as groundwater discharge. We use the term 'apparent' because the true groundwater flux (discharge and recharge) cannot be measured directly, only the residual gain or loss.

Groundwater discharge ('GW In') is the groundwater discharged into the lake during flow-through conditions as measured by integrated mass-solute-isotopic balances. Under recharge conditions this figure is zero. Recharge ('Lake-GW') is lake water recharged to the aquifer under both flow-through and recharge flow regimes. Under recharge regimes the mass balance residual (a negative apparent flow) and the recharge as measured by integrated balance will generally be similar. All volumetric quantities are sub-totalled for each four day sub-balance. Each sub-balance row includes ΔS, mean lake water deuterium and chloride and mean δE_{pan} mean δE^* and mean δA. All integrated results were computed using the locally derived δE_{pan} in the isotopic balance.

Balance Period No: 1

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
22/4/96	8:00	3.309	47651	13542	-2.9											2.3		-49.1	-109.4	-85.2			
23/4/96	8:00	3.319	48369	14022			0.1	4.8	-1.4				3525	-5.3		1.4	66	-59.8	-117.2	-85.2	-2984		
24/4/96	8:00	3.358	50736	15956									3525	-5.3		2.4	120	-55.0	-114.6	-85.2	-1471		
25/4/96	8:00	3.363	51017	16210			0.6	31	-1.4		27		2820	-5.3		1.3	66	-77.7	-131.3	-85.2	-2558		
26/4/96	8:00	3.323	48632	14216	-5.7											1.1	57	-76.2	-131.1	-85.2	-1937		
Balance 1A			ΔS	674	-4.30			35			27		9870				309	-67.2	-123.6	-85.2	-8950	0	8974
27/4/96	8:00	3.341	49747	15102									3525	-5.3		2.3	116	-59.4	-119.0	-85.2	-2523		
28/4/96	8:00	3.364	51073	16261									3525	-5.3		2.9	147	-57.4	-117.5	-85.2	-2219		
29/4/96	8:00	3.378	51883	16982									3525	-5.3		4.1	208	-49.2	-111.5	-85.2	-2596		
30/4/96	8:00	3.323	48632	14216	-3.8											3.5	175	-46.8	-109.7	-85.2	-2591		
Balance 1B			ΔS	0	-4.75			0			0		10575				646	-53.2	-114.4	-85.2	-9929	0	9928
1/5/96	8:00	3.266	44723	11557												2.2	103	-73.1	-129.4	-85.2	-2556		
2/5/96	8:00	3.222	41564	9656												2.8	121	-56.3	-117.8	-85.2	-1780		
3/5/96	8:00	3.180	38596	7975												2.4	95	-58.5	-120.0	-85.2	-1586		
4/5/96	8:00	3.196	39649	8601	-6.8								2820	-5.3		2.1	83	-70.2	-129.7	-85.2	-2111		
Balance 1C			ΔS	-5615	-5.30			0			0		2820				403	-64.5	-124.2	-85.2	-8032	0	8061
Totals			ΔS	-4941				35			27		23265				1358				-26911	0	26963

Balance Period No: 2 **East Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
4/5/96	8:00	3.196	39649	8601	-6.8											2.1		-70.2	-129.7	-85.2			
5/5/96	8:00	3.165	37583	7404			3.7	139	-1.4		290					2.1	82	-72.6	-131.4	-85.2	-1544		
6/5/96	8:00	3.122	34381	5854												2.3	83	-52.7	-116.0	-85.2	-1467		
7/5/96	8:00	3.089	31597	4764									400	-5.3		1.8	59	-89.2	-143.7	-85.2	-1431		
8/5/96	8:00	3.127	34783	6027	-4.5		13.4	466	-6.2		2114					5.4	181	-60.1	-121.4	-85.2	-1137		
Balance 2A			ΔS	-2574	-5.65			605			2404		400				404	-68.6	-128.1	-85.2	-5579	0	5584
9/5/96	8:00	3.106	33084	5314			4.5	149	-5.7		357					1.4	49	-79.2	-135.1	-85.2	-1170		
10/5/96	8:00	3.084	31107	4607			4.0	124	-3.5		315					2.8	90	-58.7	-119.1	-85.2	-1057		
11/5/96	8:00	3.054	27923	3720			1.3	36	-3.5		87					2.4	70	-43.6	-107.5	-85.2	-940		
12/5/96	8:00	3.031	25091	3111	0.5											1.9	50	-37.5	-102.6	-85.2	-559		
Balance 2B			ΔS	-2916	-2.00			310			760		0				259	-54.7	-116.1	-85.2	-3726	0	3720
13/5/96	8:00	2.992	18919	2248												2.1	47	-40.2	-105.3	-85.2	-816		
14/5/96	8:00	3.119	34137	5751									4725	-5.3		2.6	68	-39.1	-105.2	-85.2	-1154		
15/5/96	8:00	3.176	38334	7821									3525	-5.3		2.7	99	-44.8	-110.2	-85.2	-1356		
16/5/96	8:00	3.217	41144	9449	-4.1		0.2	8.2	9.7		1		3525	-5.3		1.4	54	-67.6	-128.9	-85.2	-1852		
Balance 2C			ΔS	6338	-1.80			8			1		11775				267	-47.9	-112.4	-85.2	-5179	0	5179
Totals			ΔS	848				923			3165		12175				930				-14485	0	14483

Balance Period No: 3

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
16/5/96	8:00	3.217	41144	9449	-4.1											1.4		-67.6	-128.9	-85.2			
17/5/96	8:00	3.256	44085	11113			2.9	128	9.7		222		3525	-5.3	200	1.2	51	-72.5	-133.0	-85.2	-2160		
18/5/96	8:00	3.275	45302	11963									3525	-5.3	200	2.8	125	-43.2	-109.8	-85.2	-2550		
19/5/96	8:00	3.229	42117	9949												1.7	74	-44.5	-111.0	-85.2	-1940		
20/5/96	8:00	3.186	38986	8208	-4.3											1.9	76	-46.6	-112.9	-85.2	-1665		
Balance 3A			ΔS	-1241	-4.20			128			222		7050				326	-51.7	-116.7	-85.2	-8315	0	8321
21/5/96	8:00	3.161	37313	7254												1.7	65	-51.2	-116.9	-85.2	-889		
22/5/96	8:00	3.214	40912	9326									3525	-5.3	200	1.2	47	-53.2	-118.8	-85.2	-1406		
23/5/96	8:00	3.255	44021	11069									3525	-5.3	200	1.4	58	-52.3	-118.4	-85.2	-1724		
24/5/96	8:00	3.281	45695	12236	-5.6								3525	-5.3	200	1.7	76	-54.5	-120.5	-85.2	-2282		
Balance 3B			ΔS	4028	-4.95			0			0		10575				245	-52.8	-118.7	-85.2	-6302	0	6313
25/5/96	8:00	3.309	47651	13542									3525	-5.3	200	3.0	139	-45.4	-112.9	-85.2	-2080		
26/5/96	8:00	3.258	44214	11202												2.8	129	-45.9	-113.2	-85.2	-2211		
27/5/96	8:00	3.250	43688	10850									1880	-5.3	200	2.3	101	-43.9	-111.6	-85.2	-2131		
28/5/96	8:00	3.264	44596	11468	-3.8	200							2820	-5.3	200	1.3	56	-55.1	-120.8	-85.2	-2146		
Balance 3C			ΔS	-768	-4.70			0			0		8225				425	-47.6	-114.6	-85.2	-8568	0	8564
Totals			ΔS	2019				128			222		25850				996				-23185	0	23198

Balance Period No: 4

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
28/5/96	8:00	3.264	44596	11468	-3.8	200										1.3		-55.1	-120.8	-85.2			
29/5/96	8:00	3.287	46104	12511									3525	-5.3	200	1.5	69	-55.6	-121.7	-85.2	-2413		
30/5/96	8:00	3.318	48300	13974									3525	-5.3	200	2.7	128	-43.0	-111.2	-85.2	-1934		
31/5/96	8:00	3.416	54363	19002			25.8	1403	10.7	12.0	2245	12.0	3500	-5.3	200	4.8	249	-81.5	-144.6	-85.2	-1871		
1/6/96	8:00	3.427	54887	19603	-6.0	168	0.5	27	18.4	12.0	19	12.0	3525	-5.3	200	1.7	92	-59.6	-126.1	-85.2	-2878		
Balance 4A			ΔS	8135	-4.90	184.00		1430			2264		14075				538	-59.9	-125.9	-85.2	-9096	0	9472
2/6/96	8:00	3.378	51883	16982												0.7	37	-63.1	-129.1	-85.2	-2584		
3/6/96	8:00	3.332	49201	14656			1.0	49	7.7	12.0	61	12.0				1.1	57	-70.0	-135.1	-85.2	-2380		
4/6/96	8:00	3.292	46458	12742												1.5	74	-50.1	-117.8	-85.2	-1840		
5/6/96	8:00	3.252	43822	10938	-4.5	172										1.1	51	-47.9	-115.9	-85.2	-1753		
Balance 4B			ΔS	-8665	-5.25	170.00		49			61		0				218	-57.8	-124.5	-85.2	-8557	0	8473
6/6/96	8:00	3.218	41225	9490												1.1	45	-47.9	-115.8	-85.2	-1403		
7/6/96	8:00	3.187	39051	8247												1.3	53	-46.1	-114.3	-85.2	-1190		
8/6/96	8:00	3.153	36768	6958												1.8	66	-43.6	-112.1	-85.2	-1223		
9/6/96	8:00	3.127	34783	6027	-2.7	173	0.5	17	-9.4	12.0	19	12.0				1.3	45	-59.7	-125.8	-85.2	-922		
Balance 4C			ΔS	-4911	-3.60	172.50		17			19		0				209	-49.3	-117.0	-85.2	-4738	0	4777
Totals			ΔS	-5441				1497			2344		14075				966				-22391	0	22722

Balance Period No: 5

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
9/6/96	8:00	3.127	34783	6027	-2.7	173										1.3		-59.7	-125.8	-85.2			
10/6/96	8:00	3.120	34218	5785			7.7	263	-9.4	12.0	628	12.0				0.6	22	-113.3	-171.8	-85.2	-1111		
11/6/96	8:00	3.097	32320	5020			0.5	16	-9.4	12.0						0.8	26	-67.0	-132.0	-85.2	-756		
12/6/96	8:00	3.075	30223	4332			1.5	45	-9.4	12.0	104	12.0				0.8	26	-60.8	-126.8	-85.2	-811		
13/6/96	8:00	3.050	27428	3609	-1.9	159	0.1	2.7	-9.4	12.0						0.7	20	-50.4	-117.8	-85.2	-706		
Balance 5A			ΔS	-2418	-2.30	166.00		328			731		0				94	-72.9	-137.1	-85.2	-3383	0	3221
14/6/96	8:00	3.025	24290	2962												0.7	18	-50.8	-118.3	-85.2	-629		
15/6/96	8:00	3.002	20459	2445												1.0	22	-55.0	-122.2	-85.2	-495		
16/6/96	8:00	3.019	23441	2819			7.2	169	-12.1	12.0	585	12.0				1.9	41	-62.8	-129.1	-85.2	-339		
17/6/96	8:00	3.014	22660	2704	-3.4	129	2	45	-12.1	12.0	146	12.0				1.0	23	-66.8	-132.8	-85.2	-284		
Balance 5B			ΔS	-905	-2.65	144.00		214			732		0				104	-58.8	-125.6	-85.2	-1747	144	1891
18/6/96	8:00	3.074	30125	4301			19.5	587	-12.1	12.0	1653	12.0				3.1	81	-75.8	-142.0	-85.2	-562		
19/6/96	8:00	3.175	38266	7783			32.4	1240	-15.4	12.0	2920	12.0				3.6	122	-126.2	-188.8	-85.2	-556		
20/6/96	8:00	3.245	43337	10632			25.9	1122	-21.0	12.0	2255	12.0				3.0	123	-112.8	-177.7	-85.2	-406		
21/6/96	8:00	3.285	45966	12419	-14.5	32.3	18	827	-21.0	12.0	1518	12.0				3.4	150	-91.2	-158.5	-85.2	-409		
Balance 5C			ΔS	9715	-8.95	80.65		3777			8347		0				476	-101.5	-166.8	-85.2	-1933	381	2337
22/6/96	8:00	3.305	47355	13352			14.7	696	-29.8	12.0	1227	12.0				1.8	82	-110.3	-176.3	-85.2	-908		
23/6/96	8:00	3.290	46315	12650			1.5	69	-29.8	12.0	104	12.0				0.3	13	-142.5	-206.4	-85.2	-862		
24/6/96	8:00	3.292	46458	12742			7.1	330	-29.8	12.0	577	12.0				0.4	19	-128.2	-193.2	-85.2	-795		
25/6/96	8:00	3.277	45432	12053	-16.1	29.4										0.7	32	-81.5	-149.7	-85.2	-657		
Balance 5D			ΔS	-366	-15.30	30.85		1095			1908		0				146	-115.6	-181.4	-85.2	-3223	75	3289
Totals			ΔS	6026				5414			11717		0				821				-10285	600	10738

Balance Period No: 6

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA	GW Flux	m^3	m^3
25/6/96	8:00	3.277	45432	12053	-16.1	29.4										0.7		-81.5	-149.7	-85.2			
26/6/96	8:00	3.257	44150	11158												1.1	47	-89.6	-157.1	-85.2	-848		
27/6/96	8:00	3.282	45762	12281			13.5	618	-9.9	12.0	1040	12.0				1.2	53	-167.3	-229.1	-85.2	-482		
28/6/96	8:00	3.291	46387	12696			7.9	366	-9.9	12.0	668	12.0				2.0	90	-105.7	-171.6	-85.2	-529		
29/6/96	8:00	3.268	44850	11647	-13.2	29.4	0.2	9	-0.6	12.0	3	12.0				1.5	67	-93.2	-159.8	-85.2	-993		
Balance 6A			ΔS	-406	-14.65	29.40		993			1710		0				258	-114.0	-179.4	-85.2	-2852	180	3056
30/6/96	8:00	3.290	46315	12650			11.8	547	-0.6	12.0	966	12.0				2.0	89	-114.1	-178.9	-85.2	-420		
1/7/96	8:00	3.274	45237	11917			1.1	50	-0.6	12.0	32	12.0				1.7	80	-80.6	-148.0	-85.2	-735		
2/7/96	8:00	3.265	44659	11513			2.9	130	-24.4	12.0	197	12.0				1.2	55	-108.9	-174.0	-85.2	-676		
3/7/96	8:00	3.319	48369	14022	-12.9	27.7	22.9	1108	-24.4	12.0	2190	12.0				3.8	178	-120.7	-184.6	-85.2	-611		
Balance 6B			ΔS	2375	-13.05	28.55		1833			3385		0				402	-106.1	-171.4	-85.2	-2442	241	2697
4/7/96	8:00	3.325	48760	14314			8.3	405	-24.4	12.0	613	12.0				1.9	93	-89.5	-155.9	-85.2	-633		
5/7/96	8:00	3.322	48568	14168			3.4	165	-24.4	12.0	286	12.0				0.6	30	-121.8	-185.5	-85.2	-567		
6/7/96	8:00	3.305	47355	13352												1.2	58	-83.1	-150.0	-85.2	-758		
7/7/96	8:00	3.297	46798	12975	-13.6	26.3										2.7	127	-65.5	-133.8	-85.2	-250		
Balance 6C			ΔS	-1047	-13.25	27.00		570			899		0				308	-90.0	-156.3	-85.2	-2207	0	2277
Totals			ΔS	922				3396			5994		0				968				-7501	421	8030

Balance Period No: 7

East Lake

Day & Time		Stage	Area	Volume	Lake			Rain			Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
7/7/96	8:00	3.297	46798	12975	-13.6	26.3										2.7		-65.5	-133.8	-85.2			
8/7/96	8:00	3.347	50104	15401			22.0	1102	-26.9	12.0	1742	12.0				2.3	114	-139.7	-201.6	-85.2	-305		
9/7/96	8:00	3.335	49387	14804												1.8	91	-76.5	-143.7	-85.2	-506		
10/7/96	8:00	3.322	48568	14168												1.4	68	-67.8	-135.8	-85.2	-568		
11/7/96	8:00	3.312	47873	13685	-14.4	23.7										1.7	80	-61.4	-129.8	-85.2	-403		
Balance 7A			ΔS	710	-14.00	25.00		1102			1742		0				353	-86.3	-152.7	-85.2	-1782	0	1868
12/7/96	8:00	3.301	47075	13163							1	12.0				3.2	153	-60.3	-128.7	-85.2	-370		
13/7/96	8:00	3.293	46526	12789			1.2	56	-18.8	12.0	34	12.0				0.4	20	-160.9	-219.9	-85.2	-443		
14/7/96	8:00	3.284	45897	12373							18	12.0				1.2	56	-100.3	-164.7	-85.2	-378		
15/7/96	8:00	3.272	45106	11827	-14.2	22.2										1.1	51	-116.9	-179.5	-85.2	-495		
Balance 7B			ΔS	-1858	-14.30	22.95		56			53		0				281	-109.6	-173.2	-85.2	-1686	0	2048
16/7/96	8:00	3.302	47144	13210			14.3	674	-18.8	12.0	1168	12.0				1.7	80	-165.7	-222.9	-85.2	-379		
17/7/96	8:00	3.330	49075	14558			14.6	716	-18.8	12.0	1471	12.0				3.8	184	-100.0	-163.5	-85.2	-655		
18/7/96	8:00	3.323	48632	14216			2.9	141	5.6	12.0	124	12.0				3.0	149	-78.1	-143.6	-85.2	-458		
19/7/96	8:00	3.324	48696	14265	-12.5	36.2	4.8	234	5.6	12.0	393	12.0				2.0	97	-97.9	-160.9	-85.2	-481		
Balance 7C			ΔS	2438	-13.35	29.20		1765			3156		0				511	-110.4	-172.7	-85.2	-1973	1146	3143
Totals			ΔS	1290				2924			4952		0				1144				-5441	1146	7059

Balance Period No: 8

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
19/7/96	8:00	3.324	48696	14265	-12.5	36.2										2.0		-97.9	-160.9	-85.2			
20/7/96	8:00	3.316	48161	13877			1.0	48	5.6	12.0	102	12.0				0.9	42	-104.9	-166.6	-85.2	-496		
21/7/96	8:00	3.316	48161	13877			4.8	231	-2.6	12.0	355	12.0				1.0	46	-126.3	-184.7	-85.2	-540		
22/7/96	8:00	3.327	48886	14411			7.4	362	-2.6	12.0	601	12.0				1.0	51	-118.6	-158.5	-89.9	-378		
23/7/96	8:00	3.322	48568	14168	-10.0	35.6	3.9	189	-2.6	12.0	262	12.0				2.5	123	-75.3	-135.2	-87.2	-572		
Balance 8A			ΔS	-97	-11.25	35.90		831			1321		0				262	-106.3	-161.2	-86.9	-1987	158	2152
24/7/96	8:00	3.368	51298	16466			18.5	949	-18.2	12.0	1724	12.0				2.9	143	-82.4	-146.5	-84.5	-232		
25/7/96	8:00	3.388	52463	17504			10.4	546	-18.2	12.0	1162	12.0				2.0	104	-74.5	-145.1	-81.8	-566		
26/7/96	8:00	3.378	51883	16982			0.5	26	-18.2	12.0	8	12.0				1.9	100	-69.9	-145.9	-79.1	-456		
27/7/96	8:00	3.440	55481	20320	-6.2	29.5	23.7	1315	-6.8	12.0	2060	12.0				3.7	196	-70.8	-153.3	-76.4	159		
Balance 8B			ΔS	6152	-8.10	32.55		2835			4955		0				543	-74.4	-147.7	-80.5	-1095	161	1185
28/7/96	8:00	3.455	56120	21157			7.5	421	-6.8	12.0	767	12.0				2.3	126	-68.2	-155.5	-73.7	-224		
29/7/96	8:00	3.443	55608	20487			0.3	17	-6.7	12.0	1	12.0				2.3	126	-64.7	-155.5	-71.0	-561		
30/7/96	8:00	3.465	56571	21721			10.5	594	-6.7	12.0	907	12.0				1.7	93	-139.7	-245.0	-76.0	-174		
31/7/96	8:00	3.464	56522	21664	-5.8	30.4	4.0	226	-6.7	12.0	106	12.0				3.0	167	-53.1	-123.3	-80.9	-222		
Balance 8C			ΔS	1344	-6.00	29.95		1258			1781		0				513	-81.4	-169.8	-75.4	-1182	268	1476
1/8/96	8:00	3.455	56120	21157			3.4	191	-6.7	12.0	316	12.0				2.8	157	-61.3	-122.5	-85.9	-857		
2/8/96	8:00	3.454	56077	21101			1.2	67	-6.7	12.0	172	12.0				2.3	127	-71.7	-117.7	-90.8	-169		
3/8/96	8:00	3.446	55736	20654			1.0	56	-33.3	12.0	42	12.0				2.1	117	-64.0	-103.4	-95.8	-428		
4/8/96	8:00	3.454	56077	21101	-4.4	31.7	6.7	376	-33.3	12.0	571	12.0				2.2	122	-68.8	-91.3	-100.7	-379		
Balance 8D			ΔS	-563	-5.10	31.05		690			1102		0				522	-66.4	-108.7	-93.3	-1833	205	2006
5/8/96	8:00	3.455	56120	21157			4.3	241	-33.3	12.0	369	12.0				1.6	88	-63.3	-82.7	-105.7	-467		
6/8/96	8:00	3.463	56474	21608			5.9	333	-33.3	12.0	581	12.0				1.4	78	-56.3	-90.5	-103.1	-384		
7/8/96	8:00	3.470	56800	22004			5.4	307	3.5	12.0	514	12.0				0.8	44	-73.5	-92.8	-100.5	-380		
8/8/96	8:00	3.460	56337	21438	-4.9	30.5										1.7	98	-58.9	-99.3	-97.9	-468		
Balance 8E			ΔS	337	-4.65	31.10		881			1464		0				309	-63.0	-91.3	-101.8	-1699	43	1733
Totals			ΔS	7173				6494			10622		0				2149				-7795	835	8552

Balance Period No: 9

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
8/8/96	8:00	3.460	56337	21438	-4.9	30.5										1.7		-58.9	-99.3	-97.9			
9/8/96	8:00	3.450	55906	20877												1.9	107	-53.2	-101.8	-95.3	-454		
10/8/96	8:00	3.442	55566	20431												2.3	131	-49.2	-103.5	-92.6	-315		
11/8/96	8:00	3.480	57254	22574			18.0	1031	2.6	12.0	1584	12.0				1.5	83	-83.6	-120.9	-90.0	-388		
12/8/96	8:00	3.473	56935	22175	-3.3	29.4	0.5	28	2.6	12.0	9	12.0				1.9	109	-50.8	-109.5	-87.4	-327		
Balance 9A			ΔS	737	-4.10	29.95		1059			1593		0				431	-59.2	-108.9	-91.3	-1484	50	1540
13/8/96	8:00	3.488	57628	23034			9.7	559	-12.8	12.0	793	12.0				2.2	125	-61.5	-120.4	-84.8	-369		
14/8/96	8:00	3.481	57301	22632			1.5	86	-12.8	12.0	161	12.0				1.9	110	-45.0	-110.8	-82.2	-539		
15/8/96	8:00	3.474	56980	22232			1.6	91	1.4	12.0	42	12.0				1.0	60	-58.7	-127.8	-79.2	-473		
16/8/96	8:00	3.478	57161	22460	-2.5	30.1	1.0	57	1.4	12.0	34	12.0				1.3	74	-59.1	-133.5	-76.2	212		
Balance 9B			ΔS	285	-2.90	29.75		793			1029		0				369	-56.1	-123.1	-80.6	-1169	166	1321
17/8/96	8:00	3.462	56428	21551			0.7	39	1.4	12.0	46	12.0				1.7	99	-52.0	-129.3	-73.3	-896		
18/8/96	8:00	3.452	55991	20989												2.8	156	-38.9	-113.2	-70.3	-406		
19/8/96	8:00	3.444	55651	20543												3.2	180	-38.2	-114.7	-67.3	-266		
20/8/96	8:00	3.443	55608	20487	0.5	28.5	3.5	195	-3.2	12.0	191	12.0				2.9	160	-47.8	-129.1	-70.0	-282		
Balance 9C			ΔS	-1973	-1.00	29.30		234			237		0				595	-44.3	-121.6	-70.2	-1850	0	2333
Totals			ΔS	-951				2086			2860		0				1394				-4503	216	5194

Balance Period No: 10

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
20/8/96	8:00	3.443	55608	20487	0.5	28.5										2.9		-47.8	-129.1	-70.0			
21/8/96	8:00	3.457	56206	21270			8.3	467	-3.2	12.0	572	12.0				1.0	58	-65.4	-149.9	-72.8	-197		
22/8/96	8:00	3.451	55948	20933			0.9	50	-3.2	12.0	31	12.0				1.6	88	-52.6	-125.9	-75.5	-331		
23/8/96	8:00	3.446	55736	20654												1.7	97	-55.0	-123.2	-78.2	-182		
24/8/96	8:00	3.462	56428	21551	0.2	30.7	9.0	508	-0.2	12.0	659	12.0				1.7	93	-71.8	-132.1	-80.9	-178		
Balance 10A			ΔS	1064	0.35	29.60		1025			1262		0				336	-61.2	-132.8	-76.9	-887	350	1255
25/8/96	8:00	3.453	56034	21045							51	12.0				2.8	157	-41.9	-103.6	-83.7	-400		
26/8/96	8:00	3.446	55736	20654												2.0	112	-42.9	-101.4	-86.4	-279		
27/8/96	8:00	3.445	55694	20598			2.6	145	-1.0	12.0	201	12.0				1.9	107	-60.1	-113.8	-84.5	-295		
28/8/96	8:00	3.441	55523	20376	-0.1	32.4	1.6	89	-1.0	12.0	105	12.0				2.1	116	-63.8	-120.3	-82.5	-300		
Balance 10B			ΔS	-1175	0.05	31.55		234			356		0				491	-52.2	-109.8	-84.3	-1274	149	1453
29/8/96	8:00	3.433	55178	19933							1	12.0				1.8	101	-51.9	-114.0	-80.6	-343		
30/8/96	8:00	3.428	54935	19658												2.1	115	-50.4	-115.3	-78.6	-160		
31/8/96	8:00	3.442	55566	20431			9.0	500	5.8	12.0	692	12.0				2.2	120	-52.0	-119.7	-76.7	-299		
1/9/96	8:00	3.434	55221	19988	2.3	30.6										3.1	171	-41.8	-110.5	-74.7	-272		
Balance 10C			ΔS	-388	1.10	31.50		500			693		0				508	-49.0	-114.9	-77.7	-1074	0	1375
Totals			ΔS	-499				1758			2312		0				1335				-3234	499	4083

Balance Period No: 11

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
1/9/96	8:00	3.434	55221	19988	2.3	30.6										3.1		-41.8	-110.5	-74.7			
2/9/96	8:00	3.429	54984	19713												2.1	115	-40.8	-111.3	-72.8	-160		
3/9/96	8:00	3.425	54793	19493			2.8	153	1.2	12.0	256	12.0				3.1	170	-43.6	-114.4	-73.4	-460		
4/9/96	8:00	3.421	54605	19274												3.1	169	-38.8	-107.3	-74.0	-50		
5/9/96	8:00	3.414	54264	18893	4.8	33.0										2.5	134	-37.0	-104.4	-74.6	-247		
Balance 11A			ΔS	-1095	3.55	31.80		153			256		0				588	-40.0	-109.4	-73.7	-917	161	1051
6/9/96	8:00	3.422	54652	19329			6.0	328	8.0	12.0	570	12.0				3.5	188	-42.9	-110.3	-75.3	-274		
7/9/96	8:00	3.420	54558	19220			2.1	115	8.0	12.0	149	12.0				3.5	194	-41.6	-107.6	-75.9	-178		
8/9/96	8:00	3.420	54558	19220			3.2	175	8.0	12.0	202	12.0				0.7	40	-53.8	-118.9	-76.5	-337		
9/9/96	8:00	3.429	54984	19713	4.7	33.2	5.5	302	-13.4	12.0	440	12.0				2.4	130	-49.2	-112.6	-77.1	-120		
Balance 11B			ΔS	820	4.75	33.10		919			1360		0				551	-46.9	-112.4	-76.2	-908	159	1088
10/9/96	8:00	3.448	55821	20766			10.1	564	-13.4	12.0	964	12.0				3.2	176	-50.5	-114.2	-76.8	-299		
11/9/96	8:00	3.490	57724	23149			17.9	1033	-13.4	12.0	1364	12.0				2.8	160	-49.1	-112.9	-76.4	146		
12/9/96	8:00	3.482	57347	22689			0.2	11	1.2	12.0	158	12.0				1.7	99	-49.2	-113.2	-76.1	-530		
13/9/96	8:00	3.478	57161	22460	2.5	30.9										1.8	104	-49.6	-113.7	-75.8	-125		
Balance 11C			ΔS	2747	3.60	32.05		1609			2487		0				540	-49.6	-113.5	-76.3	-808	76	890
Totals			ΔS	2472				2681			4103		0				1680				-2633	396	3029

Balance Period No: 12

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
13/9/96	8:00	3.478	57161	22460	2.5	30.9										1.8		-49.6	-113.7	-75.8			
14/9/96	8:00	3.473	56935	22175			2.4	137	1.2	12.0	184	12.0				4.1	234	-51.8	-116.1	-75.5	-372		
15/9/96	8:00	3.475	57025	22289			4.4	251	7.7	12.0	296	12.0				3.6	207	-67.2	-132.3	-75.1	-225		
16/9/96	8:00	3.480	57254	22574			3.5	200	7.7	12.0	314	12.0				2.2	125	-64.0	-129.3	-74.8	-105		
17/9/96	8:00	3.472	56890	22118	4.1	33.9	1.3	74	7.7	12.0	64	12.0				2.9	166	-58.4	-120.8	-75.8	-428		
Balance 12A			ΔS	-342	3.30	32.40		662			858		0				732	-60.3	-124.6	-75.3	-1130	342	1483
18/9/96	8:00	3.480	57254	22574			4.9	281	5.2	12.0	382	12.0				2.5	145	-69	-127.5	-76.8	-61.1		
19/9/96	8:00	3.475	57025	22289			1.2	68	5.2	12.0	67	12.0				4.4	250	-42	-102.2	-77.9	-170.8		
20/9/96	8:00	3.470	56800	22004			0.1	5.7	5.2	12.0	1	12.0				3.3	186	-42	-100.0	-78.9	-105.1		
21/9/96	8:00	3.465	56571	21721	6.1	36.1										2.6	150	-41	-98.0	-79.9	-133.4		
Balance 12B			ΔS	-397	5.10	35.00		355			450		0				731	-48.5	-106.9	-78.4	-470	190	653
22/9/96	8:00	3.515	59030	24609			22.5	1328	-13.9	12.0	2051	12.0				5.6	321	-58.5	-108.5	-80.9	-170		
23/9/96	8:00	3.509	58761	24255			0.1	5.9	-13.9	12.0	20	12.0				3.5	204	-40.5	-97.2	-80.8	-176		
24/9/96	8:00	3.502	58334	23846	5.7	30.8	0.1	5.8	-13.9	12.0						3.0	176	-44.3	-98.7	-80.7	-239		
25/9/96	8:00	3.495	57969	23438	6.4	30.9										2.6	153	-39.3	-95.3	-80.6	-255		
Balance 12C			ΔS	1717	6.25	33.50		1340			2071		0				854	-45.7	-99.9	-80.7	-840	0	1553
Totals			ΔS	978				2356			3378		0				2317				-2440	532	3689

Balance Period No: 13 **East Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
25/9/96	8:00	3.495	57969	23438	6.4	30.9										2.6		-39.3	-95.3	-80.6			
26/9/96	8:00	3.490	57724	23149	7.1	31.0										3.1	179	-37.7	-93.8	-80.5	-110		
27/9/96	8:00	3.532	59725	25618			17.9	1069	-13.2	12.0	1643	12.0				1.5	91	-71.1	-115.7	-80.3	-152		
28/9/96	8:00	3.522	59318	25023							2	12.0				4.0	238	-54.7	-105.6	-80.2	-358		
29/9/96	8:00	3.518	59155	24786	4.7	37.3	1.5	89	1.5	12.0	57	12.0				3.8	226	-44.2	-99.2	-80.1	-156		
Balance 13A			ΔS	1348	5.55	34.10		1158			1702		0				735	-51.9	-103.6	-80.3	-777	894	1687
30/9/96	8:00	3.512	58901	24432												4.0	236	-40	-96.8	-80.0	-117.7		
1/10/96	8:00	3.505	58511	24021			0.1	5.9	1.5	12.0						2.2	130	-45	-99.2	-79.9	-286.9		
2/10/96	8:00	3.501	58279	23787												1.9	110	-49	-103.7	-78.1	-123.9		
3/10/96	8:00	3.494	57918	23381	5.1	38.1										3.3	191	-43	-101.4	-76.2	-215.4		
Balance 13B			ΔS	-1405	4.90	37.70		6			0		0				667	-44.3	-100.3	-78.5	-744	0	802
4/10/96	8:00	3.489	57676	23092												3.4	194	-44.1	-103.3	-74.4	-95		
5/10/96	8:00	3.482	57347	22689												3.9	222	-42.1	-102.8	-72.5	-181		
6/10/96	8:00	3.477	57115	22403												3.3	188	-40.4	-102.4	-70.7	-98		
7/10/96	8:00	3.472	56890	22118	7.3	41.9										3.7	210	-38.3	-101.2	-68.8	-75		
Balance 13C			ΔS	-1263	6.20	40.00		0			0		0				814	-41.2	-102.5	-71.6	-449	254	687
Totals			ΔS	-1320				1164			1702		0				2216				-1970	1148	3176

Balance Period No: 14

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA	GW Flux	m^3	m^3
7/10/96	8:00	3.472	56890	22118	7.3	41.9													3.7		-38.3	-101.2	-68.8			
8/10/96	8:00	3.465	56571	21721							3	12.0							4.5	256	-39.5	-103.1	-68.3	-144		
9/10/96	8:00	3.460	56337	21438															3.7	208	-46.3	-112.5	-67.7	-75		
10/10/96	8:00	3.462	56428	21551			4.2	237	0.4	12.0	189	12.0							3.0	166	-40.6	-105.3	-67.2	-147		
11/10/96	8:00	3.461	56382	21495	9.0	46.2	3.4	192	0.4	12.0	225	12.0							3.9	222	-37.2	-101.1	-66.6	-251		
Balance 14A			ΔS	-623	8.15	44.05		429			417		0			0				853	-40.9	-105.5	-67.4	-616	402	1009
12/10/96	8:00	3.454	56077	21101							2	12.0							3.3	184	-34.8	-98.3	-66.1	-211		
13/10/96	8:00	3.450	55906	20877															3.7	207	-34.8	-98.8	-65.5	-17		
14/10/96	8:00	3.446	55736	20654			0.1	5.6	0.4	12.0									3.4	188	-38.5	-105.4	-65.0	-41		
15/10/96	8:00	3.440	55481	20320	12.2	50.5							58	-2.5	204	2	-13.5	174	2.7	150	-38.6	-103.0	-67.3	-244		
Balance 14B			ΔS	-1175	10.60	48.35		6			2		58			2				729	-36.7	-101.4	-66.0	-513	217	693
16/10/96	8:00	3.433	55178	19933															4.0	222	-32.3	-92.5	-69.7	-165		
17/10/96	8:00	3.427	54887	19603															3.9	217	-30.7	-88.9	-72.0	-113		
18/10/96	8:00	3.419	54510	19165															3.4	188	-34.4	-89.2	-74.4	-250		
19/10/96	8:00	3.414	54264	18893	14.5	54.4													3.4	187	-32.8	-85.2	-76.7	-85		
Balance 14C			ΔS	-1427	13.35	52.45		0			0		0			0				815	-32.5	-89.0	-73.2	-612	168	768
Totals			ΔS	-3225				434			419		58			2				2396				-1742	787	2470

Balance Period No: 15

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
19/10/96	8:00	3.414	54264	18893	14.5	54.4													3.4		-32.8	-85.2	-76.7			
20/10/96	8:00	3.453	56034	21045							1	12.0	2075	-2.5	204	720	-12.8	164	3.9	217	-31.2	-80.5	-79.1	-427		
21/10/96	8:00	3.509	58761	24255			14.2	834	-22.1	12.0	847	12.0	1389	-2.5	204	482	-12.8	164	5.5	315	-52.3	-94.4	-81.4	-27		
22/10/96	8:00	3.515	59030	24609			4.5	266	-22.1	12.0	625	12.0							1.9	111	-70.9	-106.5	-79.0	-425		
23/10/96	8:00	3.527	59522	25320	8.5	75.2	10.2	607	-7.2	12.0	792	12.0							4.2	248	-53.9	-102.0	-76.5	-441		
Balance 15A			ΔS	6427	11.50	64.80		1707			2265		3464			1202				891	-52.0	-95.9	-79.0	-1320	55	1373
24/10/96	8:00	3.527	59522	25320			6.0	357	-7.2	12.0	405	12.0							3.4	205	-47.7	-101.0	-74.1	-557		
25/10/96	8:00	3.517	59115	24727															4.1	243	-39.7	-96.4	-71.6	-350		
26/10/96	8:00	3.506	58581	24079															4.2	246	-39.9	-98.1	-69.2	-402		
27/10/96	8:00	3.497	58071	23555	9.0	75.7													4.8	277	-41.7	-101.8	-66.7	-247		
Balance 15B			ΔS	-1765	8.75	75.45		357			405		0			0				972	-42.2	-99.3	-70.4	-1555	0	1620
28/10/96	8:00	3.488	57628	23034															4.8	275	-42.0	-104.4	-64.3	-246		
29/10/96	8:00	3.478	57161	22460							3	12.0	48	-2.5	204				5.3	306	-40.5	-100.1	-67.0	-319		
30/10/96	8:00	3.472	56890	22118							11	12.0							5.2	299	-39.1	-96.1	-69.6	-54		
31/10/96	8:00	3.458	56249	21326	11.5	79.4	0.3	17	22.1	12.0	46	12.0							3.7	209	-47.2	-100.0	-72.3	-646		
Balance 15C			ΔS	-2229	10.25	77.55		17			60		48			0				1089	-42.2	-100.2	-68.3	-1265	0	1276
Totals			ΔS	2433				2081			2730		3512			1202				2952				-4141	55	4269

Lawn irrigation and lake top up commence sub balance 15A

Balance Period No: 16

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
31/10/96	8:00	3.458	56249	21326	11.5	79.4													3.7		-47.2	-100.0	-72.3			
1/11/96	8:00	3.450	55906	20877															4.3	239	-36.4	-88.7	-75.0	-210		
2/11/96	8:00	3.439	55438	20265															4.6	256	-34.2	-84.5	-77.7	-356		
3/11/96	8:00	3.431	55085	19823															5.0	276	-32.6	-80.6	-80.3	-166		
4/11/96	8:00	3.418	54461	19111	16.0	86.5													6.2	341	-29.1	-77.4	-83.0	-371		
Balance 16A			ΔS	-2215	13.75	82.95		0			0		0			0				1113	-33.1	-82.8	-79.0	-1102	284	1341
5/11/96	8:00	3.404	53707	18353															7.2	390	-28.0	-79.1	-79.8	-368		
6/11/96	8:00	3.412	54163	18785			7.7	417	9.5	12.0	582	12.0							3.6	195	-35.7	-82.5	-76.5	-372		
7/11/96	8:00	3.431	55085	19823			6.0	331	9.5	12.0	423	12.0							0.4	22	-53.1	-96.0	-73.3	307		
8/11/96	8:00	3.422	54652	19329	16.6	85.9													3.6	198	-39.6	-93.4	-70.0	-296		
Balance 16B			ΔS	218	16.30	86.20		748			1005		0			0				805	-39.1	-87.8	-74.9	-729	307	1049
9/11/96	8:00	3.412	54163	18785															4.6	250	-33.9	-91.9	-66.8	-294		
10/11/96	8:00	3.449	55863	20821									2031	-2.5	204	681	-13.5	174	5.0	275	-40.9	-101.9	-63.5	-401		
11/11/96	8:00	3.478	57161	22460									1766	-2.5	204	651	-13.5	174	6.2	352	-36.6	-98.3	-60.3	-426		
12/11/96	8:00	3.460	56337	21438	13.1	119													6.1	344	-38.0	-98.6	-62.5	-678		
Balance 16C			ΔS	2109	14.85	102.45		0			0		3797			1332				1222	-37.4	-97.7	-63.3	-1798	478	2295
Totals			ΔS	112				748			1005		3797			1332				3139				-3630	1069	4685

Balance Period No: 17

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
12/11/96	8:00	3.460	56337	21438	13.1	119													6.1		-38.0	-98.6	-62.5			
13/11/96	8:00	3.447	55778	20710			0.3	17	-24.9	12.0	18	12.0							5.0	280	-40.2	-99.3	-64.8	-482		
14/11/96	8:00	3.430	55036	19768			0.2	11	-24.9	12.0	8	12.0							4.0	223	-38.2	-94.7	-67.0	-738		
15/11/96	8:00	3.474	56980	22232			19.5	1111	-24.9	12.0	1792	12.0							4.4	248	-63.4	-117.4	-69.3	-192		
16/11/96	8:00	3.503	58389	23904	4.0	92.0	18.0	1051	-24.9	12.0	1651	12.0	3	-2.5	204	9	-13.5	174	5.5	317	-69.1	-119.0	-71.5	-725		
Balance 17A			ΔS	2466	8.55	105.50		2190			3469		3			9				1068	-52.7	-107.6	-68.2	-2137	0	2785
17/11/96	8:00	3.492	57819	23265			0.1	5.8	-24.9	12.0	45	12.0							4.1	238	-55.1	-104.3	-73.8	-452		
18/11/96	8:00	3.481	57301	22632									15	-2.5	204	15	-2.5	204	4.0	231	-50.4	-97.7	-76.0	-432		
19/11/96	8:00	3.471	56845	22060															4.6	262	-52.0	-96.4	-76.5	-310		
20/11/96	8:00	3.459	56293	21382	11.1	101													4.4	250	-48.9	-92.4	-77.0	-428		
Balance 17B			ΔS	-2522	7.55	96.50		6			45		15			15				982	-51.6	-97.7	-75.8	-1621	644	2149
21/11/96	8:00	3.447	55778	20710							5	12.0							4.7	262	-47.8	-90.8	-77.5	-415		
22/11/96	8:00	3.430	55036	19768							13	12.0							4.9	273	-47.9	-89.7	-77.9	-683		
23/11/96	8:00	3.429	54984	19713							15	12.0	348	-2.5	204	148	-2.5	204	5.1	280	-47.0	-88.1	-78.4	-286		
24/11/96	8:00	3.413	54214	18839	12.8	109	1.0	54	2.7	12.0	45	12.0							5.1	278	-40.8	-85.4	-78.9	-696		
Balance 17C			ΔS	-2543	11.95	105.00		54			78		348			148				1092	-45.9	-88.5	-78.2	-2079	78	2176
Totals			ΔS	-2599				2250			3592		366			172				3142				-5837	722	7110

Balance Period No: 18

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
24/11/96	8:00	3.413	54214	18839	12.8	109.0													5.1		-40.8	-85.4	-78.9			
25/11/96	8:00	3.403	53644	18300									20	-2.5	204	5	-13.5	174	5.7	205	-36.1	-82.7	-79.4	-359		
26/11/96	8:00	3.391	52672	17661									50	-2.5	204				5.1	180	-37.2	-80.3	-80.4	-509		
27/11/96	8:00	3.380	51996	17086															5.0	174	-34.3	-77.8	-81.5	-401		
28/11/96	8:00	3.367	51241	16415	17.2	119.0							100	-2.5	204				4.4	151	-34.4	-74.6	-82.5	-620		
Balance 18A			ΔS	-2424	15.00	114.00		0			0		170			5				711	-35.5	-78.8	-80.9	-1888	537	2366
29/11/96	8:00	3.352	50395	15653															5.1	170	-33.2	-71.3	-83.5	-592		
30/11/96	8:00	3.369	51356	16517			0.5	26	-9.4	12.0	51	12.0	1508	-2.5	204	137	-9.3	242	5.2	176	-36.0	-69.5	-84.5	-682		
1/12/96	8:00	3.397	53204	17979			3.0	160	-9.4	12.0	175	12.0	1420	-2.5	204	461	-9.3	242	4.0	138	-50.0	-74.4	-85.6	-616		
2/12/96	8:00	3.418	54461	19111	11.1	147.0	1.0	54	-9.4	12.0	31	12.0	1320	-2.5	204	678	-9.3	242	3.5	127	-54.5	-80.0	-86.6	-825		
Balance 18B			ΔS	2696	14.15	133.00		240			257		4248			1276				610	-43.4	-73.8	-85.1	-2715	330	3067
3/12/96	8:00	3.408	53945	18569			0.5	27	4.5	12.0	8	12.0				50	-9.3	242	4.3	158	-41.0	-79.9	-85.0	-468		
4/12/96	8:00	3.388	52463	17504															5.2	184	-36.4	-78.5	-83.5	-881		
5/12/96	8:00	3.370	51415	16569															5.5	191	-34.4	-76.6	-81.9	-744		
6/12/96	8:00	3.354	50510	15753	18.4	151.0													5.5	186	-29.9	-75.4	-80.3	-630		
Balance 18C			ΔS	-3358	14.75	149.00		27			8		0			50				719	-35.4	-77.6	-82.7	-2723	0	2777
7/12/96	8:00	3.345	49985	15301									468	-4.5	186	160	-9.1	237	5.5	180	-31.9	-77.6	-78.7	-900		
8/12/96	8:00	3.375	51709	16827									2480	-4.5	186	848	-9.1	237	5.9	199	-34.3	-80.1	-77.2	-1603		
9/12/96	8:00	3.403	53644	18300									2404	-4.5	186	822	-9.1	237	5.2	182	-39.6	-83.9	-75.6	-1571		
10/12/96	8:00	3.382	52109	17190	15.0	172.0													5.3	187	-40.7	-83.5	-77.3	-923		
Balance 18D			ΔS	1437	16.70	161.50		0			0		5352			1830				748	-36.6	-81.3	-77.2	-4997	0	5067
Totals			ΔS	-1649				267			264		9770			3161				2788				-12324	867	13277

Balance Period No: 19

East Lake

Day & Time	Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
	m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
10/12/96 8:00	3.382	52109	17190	15.0	172.0													5.3		-40.7	-83.5	-77.3			
11/12/96 8:00	3.359	50792	16007															5.2	270	-39.7	-80.6	-79.1	-913		
12/12/96 8:00	3.352	50395	15653			5.5	277	-16.3	12.0	348	12.0							4.9	250	-38.6	-77.7	-80.8	-729		
13/12/96 8:00	3.335	49387	14804			1.0	49	-1.8	12.0	42	12.0							4.8	239	-40.1	-74.0	-82.6	-702		
14/12/96 8:00	3.325	48760	14314	17.4	182.0							510	-7.6	176	141	-14.7	147	5.1	250	-36.2	-72.0	-84.3	-891		
Balance 19A		ΔS	-2876	16.20	177.00		327			390		510			141				1008	-38.6	-76.1	-81.7	-3235	0	3036
15/12/96 8:00	3.389	52529	17556									2950	-7.6	176	1020	-14.7	147	5.5	281	-39.9	-74.6	-86.1	-447		
16/12/96 8:00	3.435	55265	20043									2600	-7.6	176	976	-14.7	147	8.1	434	-39.1	-78.5	-87.8	-655		
17/12/96 8:00	3.410	54055	18677															7.4	407	-44.2	-81.7	-87.8	-959		
18/12/96 8:00	3.382	52109	17190	11.7	194.0													8.1	432	-39.8	-80.7	-87.8	-1055		
Balance 19B		ΔS	2876	14.55	188.00		0			0		5550			1996				1554	-40.8	-78.9	-87.4	-3116	0	3034
19/12/96 8:00	3.356	50623	15855															8.0	410	-35.8	-80.0	-87.8	-925		
20/12/96 8:00	3.334	49326	14755															6.8	342	-39.9	-76.3	-87.7	-758		
21/12/96 8:00	3.325	48760	14314									527	-2.5	204	181	-13.5	174	6.5	317	-43.0	-72.2	-87.7	-832		
22/12/96 8:00	3.305	47355	13352	15.9	210.0													9.0	431	-35.0	-73.8	-87.7	-531		
Balance 19C		ΔS	-3838	13.80	202.00		0			0		527			181				1500	-38.4	-75.6	-87.7	-3046	0	3136
Totals		ΔS	-3838				327			390		6587			2318				4062				-9397	0	9206

Balance Period No: 20

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE^*	δA		m^3	m^3
22/12/96	8:00	3.305	47355	13352	15.9	210													9.0		-35.0	-73.8	-87.7			
23/12/96	8:00	3.342	49807	15152									2017	-2.5	204	741	-13.5	174	6.1	296	-36.0	-71.1	-87.7	-662		
24/12/96	8:00	3.316	48161	13877															8.3	409	-34.2	-71.2	-86.6	-866		
25/12/96	8:00	3.293	46526	12789															7.0	331	-30.9	-72.2	-85.6	-757		
26/12/96	8:00	3.274	45237	11917	18.9	223													5.8	268	-30.3	-71.4	-84.5	-604		
Balance 20A			ΔS	-1435	17.40	216.50		0			0		2017			741				1304	-32.8	-71.5	-86.1	-2889	0	2972
27/12/96	8:00	3.257	44150	11158															5.8	261	-31.5	-71.7	-83.4	-498		
28/12/96	8:00	3.240	42963	10417															7.9	345	-32.6	-72.2	-82.3	-396		
29/12/96	8:00	3.268	44850	11647									1678	-4.5	186	525	-12.6	151	7.4	325	-33.4	-74.5	-81.3	-648		
30/12/96	8:00	3.275	45302	11963	18.5	229							1091	-4.5	186	214	-12.6	151	5.8	263	-33.7	-74.3	-80.2	-726		
Balance 20B			ΔS	46	18.70	226.00		0			0		2769			739				1195	-32.8	-73.2	-81.8	-2267	0	2308
31/12/96	8:00	3.250	43688	10850															6.5	288	-30.9	-72.8	-81.7	-825		
1/1/97	8:00	3.229	42117	9949															7.4	318	-29.4	-71.3	-83.2	-583		
2/1/97	8:00	3.252	43822	10938									1674	-1.7	204	537	-13.8	152	7.4	318	-38.7	-74.1	-84.7	-904		
3/1/97	8:00	3.230	42194	9991	16.5	252													7.1	305	-39.5	-70.7	-86.1	-642		
Balance 20C			ΔS	-1972	17.50	240.50		0			0		1674			537				1229	-34.6	-72.2	-83.9	-2954	0	2876
Totals			ΔS	-3361				0			0		6460			2017				3727				-8111	0	8156

Balance Period No: 21

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
3/1/97	8:00	3.230	42194	9991	16.5	252													7.1		-39.5	-70.7	-86.1			
4/1/97	8:00	3.204	40187	8921									14	-1.7	204				8.3	344	-36.9	-66.7	-87.6	-740		
5/1/97	8:00	3.243	43192	10546									2437	-1.8	206	442	-16.4	148	7.5	313	-41.9	-75.3	-89.1	-941		
6/1/97	8:00	3.284	45897	12373									2555	-1.8	206	520	-16.4	148	6.0	269	-46.5	-82.1	-90.6	-979		
7/1/97	8:00	3.255	44021	11069	10.2	237													6.3	281	-39.7	-82.1	-89.9	-1023		
Balance 21A			ΔS	1078	13.35	244.50		0			0		5006			962				1208	-41.2	-76.5	-89.3	-3682	0	3920
8/1/97	8:00	3.228	42039	9907															7.0	301	-38.6	-78.9	-89.1	-861		
9/1/97	8:00	3.201	39984	8800															6.6	269	-39.5	-74.2	-88.4	-838		
10/1/97	8:00	3.178	38466	7898															5.6	221	-42.4	-66.6	-87.7	-681		
11/1/97	8:00	3.153	36768	6958	18.5	268													6.7	251	-36.4	-64.3	-87.0	-689		
Balance 21B			ΔS	-4111	14.35	252.50		0			0		0			0				1042	-39.2	-71.0	-88.1	-3069	0	3041
12/1/97	8:00	3.214	40912	9326									2794	-0.1	205	918	-15.1	152	8.1	316	-51.5	-78.1	-86.2	-1028		
13/1/97	8:00	3.258	44214	11202									2534	-0.1	205	824	-15.1	152	7.1	302	-51.6	-86.0	-85.5	-1180		
14/1/97	8:00	3.229	42117	9949															6.2	266	-45.5	-84.0	-87.1	-987		
15/1/97	8:00	3.198	39783	8681	9.9	240													5.4	222	-46.9	-81.5	-88.7	-1046		
Balance 21C			ΔS	1723	14.20	254.00		0			0		5328			1742				1106	-48.9	-82.4	-86.9	-4241	0	4324
Totals			ΔS	-1310				0			0		10334			2704				3355				-10993	0	11285

Balance Period No: 22

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
15/1/97	8:00	3.198	39783	8681	9.9	240													5.4		-46.9	-81.5	-88.7			
16/1/97	8:00	3.168	37787	7517															5.8	227	-44.3	-79.2	-90.3	-937		
17/1/97	8:00	3.140	35818	6486															5.5	203	-40.9	-77.7	-91.9	-828		
18/1/97	8:00	3.114	33734	5582									39	-2.2	211	22	-16.2	152	6.8	236	-44.2	-72.3	-93.5	-729		
19/1/97	8:00	3.159	37177	7180	12.8	243							2018	-2.2	211	724	-16.2	152	8.0	285	-48.5	-64.5	-95.1	-859		
Balance 22A			ΔS	-1501	11.35	241.50		0			0		2057			746				950	-44.5	-73.4	-92.7	-3354	0	3453
20/1/97	8:00	3.193	39451	8483			0.3	12	15.5	12.0			1981	-2.5	208	718	-16.4	150	9.4	359	-46.0	-74.0	-96.7	-1049		
21/1/97	8:00	3.164	37516	7366															4.7	181	-43.6	-74.7	-96.0	-936		
22/1/97	8:00	3.134	35344	6272															5.6	205	-37.9	-77.7	-95.3	-889		
23/1/97	8:00	3.108	33246	5381	12.0	253													7.4	254	-41.5	-72.8	-94.6	-637		
Balance 22B			ΔS	-1799	12.40	248.00		12			0		1981			718				999	-42.3	-74.8	-95.7	-3511	0	3558
24/1/97	8:00	3.080	30711	4484															10.4	334	-38.1	-73.0	-93.9	-563		
25/1/97	8:00	3.094	32057	4923									876	-3.3	208	296	-13.9	174	7.4	232	-43.7	-76.7	-93.2	-501		
26/1/97	8:00	3.134	35344	6272									1893	-3.3	208	798	-13.9	174	4.0	134	-52.0	-80.0	-92.5	-1208		
27/1/97	8:00	3.172	38059	7669	5.7	225							1842	-1.0	212	750	-13.5	172	5.2	191	-48.9	-86.5	-91.8	-1004		
Balance 22C			ΔS	2288	8.85	239.00		0			0		4611			1844				891	-45.7	-79.1	-92.9	-3276	0	3468
Totals			ΔS	-1012				12			0		8649			3308				2840				-10140	0	10479

Balance Period No: 23

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
27/1/97	8:00	3.172	38059	7669	5.7	225													5.2		-48.9	-86.5	-91.8			
28/1/97	8:00	3.141	35893	6522									3	-1.0	212				6.0	224	-44.2	-84.9	-91.0	-926		
29/1/97	8:00	3.111	33489	5481															7.1	246	-41.2	-83.0	-90.2	-795		
30/1/97	8:00	3.083	31008	4576															5.5	178	-48.5	-77.9	-89.4	-727		
31/1/97	8:00	3.053	27801	3692	12.3	257													6.8	199	-40.6	-77.3	-88.7	-685		
Balance 23A			ΔS	-3977	9.00	241.00		0			0		3			0				847	-43.6	-80.8	-89.8	-3133	0	3166
1/2/97	8:00	3.038	25951	3289															5.1	137	-37.0	-75.5	-87.9	-266		
2/2/97	8:00	3.081	30810	4515									1538	-0.4	211	770	-8.8	242	6.9	195	-48.5	-80.6	-87.1	-887		
3/2/97	8:00	3.143	36045	6594									2119	-0.4	211	1212	-8.8	242	3.4	115	-72.4	-89.1	-86.3	-1137		
4/2/97	8:00	3.107	33165	5347	4.3	239													3.8	130	-74.5	-97.6	-86.1	-1117		
Balance 23B			ΔS	1655	8.30	248.00		0			0		3657			1982				578	-58.1	-85.7	-86.9	-3406	0	3513
5/2/97	8:00	3.072	29929	4241															7.1	224	-50.6	-90.1	-86.0	-882		
6/2/97	8:00	3.042	26423	3394															5.8	165	-46.2	-86.2	-85.8	-682		
7/2/97	8:00	3.021	23729	2866									86	-1.7	210				5.8	146	-43.7	-82.1	-85.7	-468		
8/2/97	8:00	2.994	19195	2287	13.3	281													6.2	132	-41.1	-77.4	-85.5	-447		
Balance 23C			ΔS	-3060	8.80	260.00		0			0		86			0				667	-45.4	-83.9	-85.8	-2479	0	2491
Totals			ΔS	-5382				0			0		3746			1982				2092				-9018	0	9170

Balance Period No: 24

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA	GW Flux	m^3	m^3
8/2/97	8:00	2.994	19195	2287	13.3	281													6.2		-41.1	-77.4	-85.5			
9/2/97	8:00	3.090	31692	4796									2074	-0.7	211	1426	-8.8	248	5.3	135	-37.2	-82.0	-85.4	-856		
10/2/97	8:00	3.151	36630	6884									2318	-0.7	211	1460	-8.8	248	4.8	164	-46.1	-84.7	-85.2	-1526		
11/2/97	8:00	3.120	34218	5785									72	-0.7	211	309	-8.8	248	6.7	236	-44.3	-87.7	-85.1	-1244		
12/2/97	8:00	3.083	31008	4576	6.6	256													5.7	187	-46.8	-90.6	-85.0	-1022		
Balance 24A			ΔS	2289	9.95	268.50		0			0		4464			3195				723	-43.6	-86.2	-85.2	-4647	0	4579
13/2/97	8:00	3.049	27302	3582															5.2	152	-58.4	-96.7	-84.9	-842		
14/2/97	8:00	3.022	23869	2890															6.3	160	-61.1	-101.0	-84.7	-532		
15/2/97	8:00	3.014	22660	2704									330	-0.6	213	97	-13.0	186	5.2	121	-59.8	-103.5	-84.6	-492		
16/2/97	8:00	3.158	37109	7143	-2.7	208							3757	-0.6	213	2244	-13.0	186	4.5	134	-71.6	-111.3	-84.5	-1428		
Balance 24B			ΔS	2567	1.95	232.00		0			0		4087			2341				568	-62.7	-103.2	-84.7	-3293	0	3635
17/2/97	8:00	3.228	42039	9907									1878	-0.6	213	1302	-13.0	186	6.2	244	-75.6	-111.4	-84.4	-172		
18/2/97	8:00	3.182	38726	8053															4.6	185	-61.7	-102.4	-85.6	-1669		
19/2/97	8:00	3.140	35818	6486															6.5	241	-64.8	-99.4	-86.9	-1326		
20/2/97	8:00	3.100	32578	5117	3.8	226	0.3	9.8	15.2	12.0									2.9	99	-63.1	-94.2	-88.1	-1279		
Balance 24C			ΔS	-2026	0.55	217.00		10			0		1878			1302				769	-66.3	-101.9	-86.3	-4446	0	4454
Totals			ΔS	2830				9.8			0		10429			6838				2060				-12387	0	12668

Balance Period No: 25 **East Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
20/2/97	8:00	3.100	32578	5117	3.8	226													2.9		-63.1	-94.2	-88.1			
21/2/97	8:00	3.069	29623	4152			0.2	5.9	15.2	12.0	12	12.0							4.7	146	-58.8	-88.6	-89.4	-838		
22/2/97	8:00	3.051	27555	3637									561	-0.6	213	193	-14.2	168	3.9	110	-63.3	-93.1	-90.6	-1159		
23/2/97	8:00	3.110	33408	5447							1	12.0	2052	-0.6	213	706	-14.2	168	2.7	83	-58.9	-92.9	-91.9	-867		
24/2/97	8:00	3.128	34863	6062	-0.3	221	1.0	35	-25.2	12.0	28	12.0	1294	-0.6	213	445	-14.2	168	2.5	84	-102.7	-97.6	-93.1	-1102		
Balance 25A			ΔS	945	1.75	223.50		40.8			41		3907			1344				423	-70.9	-93.0	-91.2	-3965	0	3957
25/2/97	8:00	3.092	31878	4859							4	12.0							2.3	77	-89.4	-92.6	-92.6	-1131		
26/2/97	8:00	3.060	28623	3890												5	-14.2	168	1.3	38	-64.7	-89.0	-92.2	-936		
27/2/97	8:00	3.025	24290	2962															4.7	124	-54.6	-86.1	-91.7	-804		
28/2/97	8:00	2.983	17777	2083	6.9	245													5.2	110	-50.3	-82.9	-91.2	-769		
Balance 25B			ΔS	-3979	3.30	233.00		0			4		0			5				348	-64.8	-87.6	-91.9	-3641	0	3613
1/3/97	8:00	3.040	26186	3341									960	-0.1	213	330	-15.4	151	6.9	151	-42.0	-89.6	-90.7	119		
2/3/97	8:00	3.129	34943	6097									3512	-0.1	213	1301	-15.4	151	2.5	77	-63.1	-95.6	-90.3	-1980		
3/3/97	8:00	3.191	39319	8404	-0.9								3632	-0.8	216	1202	-15.8	149	6.0	225	-59.4	-100.1	-89.8	-2302		
4/3/97	8:00	3.255	44021	11069	-1.0	206							4305	-1.4	215	1425	-15.6	150	6.4	265	-50.8	-100.1	-87.4	-2800		
Balance 25C			ΔS	8986	2.98	225.50		0			0		12409			4258				718	-53.8	-96.4	-89.5	-6963	0	6896
Totals			ΔS	5952				40.8			46		16316			5607				1489				-14569	0	14466

Balance Period No: 26

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	$δE_{pan}$	δE*	δA		m^3	m^3
4/3/97	8:00	3.255	44021	11069	-1.0	206													6.4		-50.8	-100.1	-87.4			
5/3/97	8:00	3.201	39984	8800	-1.0														4.7	197	-51.0	-102.0	-84.9	-2072		
6/3/97	8:00	3.155	36905	7032															5.1	196	-50.4	-101.9	-82.5	-1572		
7/3/97	8:00	3.110	33408	5447			0.2	6.7	34.4	12.0									6.3	220	-49.3	-101.9	-80.1	-1372		
8/3/97	8:00	3.068	29517	4122	5.7	230													3.8	118	-42.9	-98.9	-77.7	-1207		
Balance 26A			ΔS	-6947	2.38	218.00		6.7			0		0			0				732	-48.4	-101.2	-81.3	-6222	0	6180
9/3/97	8:00	3.038	25951	3289															5.8	162	-41.5	-99.6	-75.2	-671		
10/3/97	8:00	3.070	29727	4182									1403	-2.5	204	520	-13.5	174	4.4	122	-52.3	-113.5	-72.8	-908		
11/3/97	8:00	3.037	25834	3263									57	-2.5	204	37	-13.5	174	5.6	156	-48.9	-108.6	-74.1	-857		
12/3/97	8:00	3.001	20280	2425	8.8	251													4.7	108	-35.9	-95.3	-75.3	-730		
Balance 26B			ΔS	-1697	7.25	240.50		0			0		1460			557				549	-44.7	-104.3	-74.4	-3165	0	3125
13/3/97	8:00	2.960	15365	1703															4.7	84	-30.6	-89.6	-76.6	-638		
14/3/97	8:00	2.927	12908	1240															3.3	47	-29.7	-86.8	-77.9	-416		
15/3/97	8:00	2.896	10945	869															6.7	80	-23.7	-81.3	-79.2	-291		
16/3/97	8:00	2.867	8651	582	17.0	282													5.8	57	-23.3	-76.0	-80.4	-230		
Balance 26C			ΔS	-1843	12.90	266.50		0			0		0			0				267	-26.8	-83.4	-78.5	-1576	0	1606
Totals			ΔS	-10487				6.7			0		1460			557				1548				-10963	0	10911

Balance Period No: 27

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
16/3/97	8:00	2.867	8651	582	17.0	282													5.8		-23.3	-76.0	-80.4			
17/3/97	8:00	3.072	29929	4241			5.8	174	-3.4	12.0	375	12.0	2806	-14.6	152	1895	-13.8	186	4.0	77	-73.8	-122.0	-81.7	-1513		
18/3/97	8:00	3.028	24697	3036							195	12.0	21	-14.6	152				3.9	105	-64.0	-114.9	-81.8	-1315		
19/3/97	8:00	2.990	18657	2211															4.8	104	-56.3	-109.3	-81.8	-721		
20/3/97	8:00	2.955	14894	1627	0.9	203													3.9	65	-56.5	-108.7	-81.9	-519		
Balance 27A			ΔS	1045	8.95	242.50		174			570		2827			1895				351	-62.6	-113.7	-81.8	-4069	0	3547
21/3/97	8:00	2.915	12173	1089															3.3	45	-59.5	-111.5	-81.9	-493		
22/3/97	8:00	3.088	31498	4733									4006	-0.9	214	981	-16.9	151	6.0	132	-65.2	-116.1	-82.0	-1211		
23/3/97	8:00	3.133	35264	6237									3144	-0.7	214	954	-17.5	148	3.5	118	-59.5	-113.3	-82.0	-2476		
24/3/97	8:00	3.191	39319	8404	-3.0	205							2139	-0.7	214	195	-17.5	148	4.5	167	-63.1	-116.5	-82.1	0		
Balance 27B			ΔS	6777	-1.05	204.00		0			0		9289			2130				463	-61.8	-114.4	-82.0	-4179	0	4284
25/3/97	8:00	3.140	35818	6486									9	-0.7	214				2.8	106	-64.7	-118.5	-81.2	-1821		
26/3/97	8:00	3.089	31597	4764															5.0	169	-58.4	-114.8	-80.3	-1553		
27/3/97	8:00	3.043	26544	3421	0.3	212													3.4	100	-49.9	-109.2	-79.4	-1243		
28/3/97	8:00	3.045	26794	3474	0.1	220							1000	-2.5	217	270	-13.5	149	3.9	103	-44.3	-105.6	-78.4	-1114		
Balance 27C			ΔS	-4930	-1.45	212.50		0			0		1009			270				478	-54.3	-112.0	-79.8	-5731	0	5732
Totals			ΔS	2892				174			570		13125			4295				1292				-13980	0	13563

Balance Period No: 28

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
28/3/97	8:00	3.045	26794	3474	0.1	220													3.9		-44.3	-105.6	-78.4			
29/3/97	8:00	3.092	31878	4859			20.3	647	-12.0	12.0	1747	12.0	480	-2.5	217	135	-13.5	149	2.6	75	-65.5	-126.1	-77.5	-1548		
30/3/97	8:00	3.329	49013	14509			43.5	2132	-12.0	12.0	4157	12.0	3340	-0.8	217	2222	-16.8	149	2.6	106	-121.6	-182.9	-76.6	-2096		
31/3/97	8:00	3.292	46458	12742							8								2.5	119	-78.6	-143.6	-75.7	-1655		
1/4/97	8:00	3.256	44085	11113	-3.4	130													3.9	175	-79.7	-133.4	-80.9	-1454		
Balance 28A			ΔS	7639	-1.65	175.00		2779			5912		3820			2357				475	-86.4	-146.5	-77.7	-6754	0	5634
2/4/97	8:00	3.225	41803	9781									146	-11.2	163				3.0	130	-56.2	-109.5	-86.2	-1348		
3/4/97	8:00	3.223	41644	9697									1219	-11.2	163				3.9	161	-55.4	-103.5	-91.4	-1142		
4/4/97	8:00	3.220	41400	9573			0.7	29	-26.1	12.0	42	12.0	1134	-2.5	204	310	-13.5	149	3.1	129	-65.9	-98.3	-96.6	-1510		
5/4/97	8:00	3.215	40988	9367	-3.7	145	0.1	4.1	-26.1	12.0	9	12.0	909	-2.5	204	356	-13.5	149	2.8	116	-77.0	-87.5	-101.8	-1368		
Balance 28B			ΔS	-1746	-3.55	137.50		33			51		3408			666				535	-63.6	-99.7	-94.0	-5368	0	5588
6/4/97	8:00	3.197	39716	8641			5.5	218	-39.5	12.0	524	12.0							1.8	75	-84.0	-75.6	-107.1	-1394		
7/4/97	8:00	3.170	37923	7593			0.2	7.6	-40.2	12.0	10	12.0							4.2	162	-86.5	-64.4	-112.3	-904		
8/4/97	8:00	3.168	37787	7517			6.7	253	-40.2	12.0	738	12.0							1.3	48	-95.5	-75.1	-107.7	-1019		
9/4/97	8:00	3.143	36045	6594	-6.4	133													4.7	173	-71.3	-94.3	-103.1	-750		
Balance 28C			ΔS	-2773	-5.05	139.00		479			1272		0			0				458	-84.3	-77.4	-107.5	-4066	0	3914
Totals			ΔS	3120				3291			7234		7228			3023				1469				-16188	0	15136

Balance Period No: 29

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
9/4/97	8:00	3.143	36045	6594	-6.4	133													4.7		-71.3	-94.3	-103.1			
10/4/97	8:00	3.197	39716	8641									2950	-1.6	216	723	-13.0	157	2.8	107	-77.4	-100.5	-98.5	-1519		
11/4/97	8:00	3.176	38334	7821			4.3	165	-71.0	12.0	273	12.0							1.7	66	-93.5	-112.1	-93.8	-1191		
12/4/97	8:00	3.208	40465	9082			0.5	20	-71.0	12.0	6	12.0	2175	-2.5	204	594	-13.5	169	1.9	74	-61.9	-110.7	-89.2	-1461		
13/4/97	8:00	3.173	38128	7707	-3.6	177	0.2	7.6	-71.0	12.0									3.2	127	-54.1	-112.1	-84.6	-1256		
Balance 29A			ΔS	1113	-5.00	155.00		193			279		5125			1317				373	-71.7	-108.8	-91.5	-5427	0	5360
14/4/97	8:00	3.143	36045	6594															4.2	155	-57.8	-121.1	-80.0	-958		
15/4/97	8:00	3.130	35025	6132									351	-2.5	204	240	-13.5	169	2.8	100	-59.3	-120.6	-81.4	-953		
16/4/97	8:00	3.102	32749	5183															3.3	113	-56.2	-116.2	-82.9	-836		
17/4/97	8:00	3.151	36630	6884	-2.9	206							2325	-1.6	215	637	-14.8	156	1.8	62	-59.3	-116.4	-84.3	-1199		
Balance 29B			ΔS	-823	-3.25	191.50		0			0		2676			877				429	-58.2	-118.6	-82.1	-3947	0	3780
18/4/97	8:00	3.135	35425	6308									623	-1.6	215	166	-14.8	156	3.0	109	-59.6	-114.1	-85.7	-1256		
19/4/97	8:00	3.177	38400	7860							1	12.0	2482	-4.9	215	667	-13.4	164	2.1	77	-61.2	-112.3	-87.1	-1521		
20/4/97	8:00	3.155	36905	7032							4	12.0	492	-4.9	215	139	-13.4	164	2.6	98	-58.2	-108.0	-88.6	-1364		
21/4/97	8:00	3.147	36349	6738	-1.4	196	9.6	349	-8.0	12.0	663	12.0							3.4	123	-64.4	-106.9	-90.0	-1184		
Balance 29C			ΔS	-146	-2.15	201.00		349			668		8598			2486				407	-60.8	-110.3	-87.9	-5325	0	5273
Totals			ΔS	144				542			946		16399			4680				1209				-14699	0	14413

Balance Period No: 30

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
21/4/97	8:00	3.147	36349	6738	-1.4	196													3.4		-64.4	-106.9	-90.0			
22/4/97	8:00	3.120	34218	5785															1.7	59	-47.5	-102.8	-88.5	-894		
23/4/97	8:00	3.103	32834	5215															2.3	77	-48.6	-105.0	-87.0	-493		
24/4/97	8:00	3.070	29727	4182															1.9	59	-50.2	-107.8	-85.5	-974		
25/4/97	8:00	3.095	32145	4955	0.2	221							1817	-2.5	220				2.9	90	-49.0	-109.3	-84.1	-954		
Balance 30A			ΔS	-1783	-0.60	208.50		0			0		1817			0				285	-48.8	-106.2	-86.3	-3315	0	3210
26/4/97	8:00	3.068	29517	4122															2.3	71	-53.7	-115.4	-82.6	-762		
27/4/97	8:00	3.045	26794	3474			0.2	5.4	7.9	12.0									2.3	64	-59.0	-123.5	-81.1	-589		
28/4/97	8:00	3.024	24150	2938															1.7	43	-40.4	-108.5	-79.6	-493		
29/4/97	8:00	3.105	33001	5281	2.1	220							2195	-2.2	224	616	-12.3	168	4.0	113	-41.4	-109.3	-80.1	-355		
Balance 30B			ΔS	326	1.15	220.50		5			0		2195			616				291	-48.6	-114.2	-80.8	-2199	0	2261
30/4/97	8:00	3.083	31008	4576			2.5	78	7.9	12.0	121	12.0	215	-2.2	224	53	-12.3	168	2.0	64	-58.7	-125.8	-80.5	-1108		
1/5/97	8:00	3.073	30028	4271			6.0	180	4.0	12.0	383	12.0							1.2	37	-74.3	-139.8	-81.0	-830		
2/5/97	8:00	3.049	27302	3582															1.9	54	-38.6	-105.5	-81.4	-635		
3/5/97	8:00	3.046	26918	3501	1.9	190	6.1	164	-5.8	12.0	360	12.0							2.6	69	-45.8	-111.6	-81.9	-536		
Balance 30C			ΔS	-1780	2.00	205.00		422			864		215			53				225	-54.3	-120.7	-81.2	-3110	0	3002
Totals			ΔS	-3237				427			864		4227			669				800				-8624	0	8473

Balance Period No: 31

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
3/5/97	8:00	3.046	26918	3501	1.9	190													2.6		-45.8	-111.6	-81.9			
4/5/97	8:00	3.025	24290	2962							97	12.0							1.7	43	-36.3	-102.5	-82.3	-594		
5/5/97	8:00	3.006	21204	2528															2.9	66	-32.3	-98.4	-82.8	-368		
6/5/97	8:00	2.980	17434	2031															1.7	32	-30.7	-89.5	-88.3	-465		
7/5/97	8:00	2.968	16172	1829	6.9	201													2.9	49	-24.7	-82.6	-93.8	-153		
Balance 31A			ΔS	-1672	4.40	195.50		0			97		0			0				190	-31.0	-93.3	-86.8	-1579	0	1527
8/5/97	8:00	3.080	30711	4484									2956	-1.4	220	798	-12.0	166	4.6	108	-34.5	-89.8	-99.3	-991		
9/5/97	8:00	3.048	27174	3555															3.4	100	-33.7	-82.3	-104.9	-829		
10/5/97	8:00	3.019	23441	2819															2.1	53	-33.9	-70.6	-110.4	-683		
11/5/97	8:00	2.996	19487	2325	4.0	220													2.1	45	-35.4	-50.0	-115.9	-449		
Balance 31B			ΔS	496	5.45	210.50		0			0		2956			798				305	-34.4	-73.2	-107.6	-2953	0	2975
12/5/97	8:00	2.975	16910	1945			1.1	19	-50.5	12.0	24	12.0							0.8	14	-42.0	3.7	-121.4	-408		
13/5/97	8:00	2.972	16596	1894			2.6	43	-50.5	12.0	126	12.0							0.7	12	-60.8	128.4	-120.7	-208		
14/5/97	8:00	3.084	31107	4607									2946	-1.4	220	789	-12.0	166	2.5	60	-60.2	-45.5	-120.0	-962		
15/5/97	8:00	3.050	27428	3609	-1.7	219													2.2	64	-55.0	-45.2	-119.3	-934		
Balance 31C			ΔS	1284	1.15	219.50		62			150		2946			789				150	-54.5	10.4	-120.4	-2513	0	2438
Totals			ΔS	108				62			248		5902			1587				645				-7045	0	6940

Balance Period No: 32

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA	GW Flux	m^3	m^3
15/5/97	8:00	3.050	27428	3609	-1.7	219													2.2		-55.0	-45.2	-119.3			
16/5/97	8:00	3.108	33246	5381									2469	-1.2	222	637	-13.1	162	1.7	51	-61.4	-39.9	-118.7	-1283		
17/5/97	8:00	3.095	32145	4955									537	-1.2	222	157	-13.1	162	1.9	61	-58.5	-49.7	-118.0	-1059		
18/5/97	8:00	3.072	29929	4241			2.9	87	-35.5	12.0	103	12.0							1.1	35	-83.2	-21.0	-117.3	-868		
19/5/97	8:00	3.059	28507	3861	-3.9	213	4.5	128	-35.5	12.0	316	12.0							1.7	50	-61.4	-55.6	-116.6	-774		
Balance 32A			ΔS	252	-2.80	216.00		215			418		3006			794				197	-66.2	-41.5	-117.6	-3984	0	3846
20/5/97	8:00	3.038	25951	3289															0.9	26	-65.8	-54.3	-112.7	-546		
21/5/97	8:00	3.118	34057	5717									3053	-0.5	218	797	-11.6	168	2.3	69	-45.1	-78.5	-108.8	-1353		
22/5/97	8:00	3.088	31498	4733															2.9	96	-51.0	-76.4	-104.9	-888		
23/5/97	8:00	3.065	29194	4034	-0.7	217													3.1	95	-46.7	-83.0	-100.9	-604		
Balance 32B			ΔS	173	-2.30	215.00		0			0		3053			797				285	-52.1	-73.1	-106.8	-3392	0	3419
24/5/97	8:00	3.081	30810	4515			14.5	447	-3.0	12.0	1238	12.0							1.3	39	-56.1	-88.3	-97.0	-1165		
25/5/97	8:00	3.073	30028	4271			5.5	165	-3.0	12.0	332	12.0							1.5	46	-67.8	-100.2	-93.1	-696		
26/5/97	8:00	3.052	27679	3665			0.2	5.5	-7.5	12.0									1.6	45	-45.2	-104.2	-89.2	-567		
27/5/97	8:00	3.033	25349	3161	-0.8	165	0.5	13	-7.5	12.0	15	12.0							1.8	47	-53.4	-104.6	-90.6	-485		
Balance 32C			ΔS	-873	-0.75	191.00		630			1586		0			0				176	-55.6	-99.3	-92.5	-2912	0	2607
Totals			ΔS	-448				845			2004		6059			1591				659				-10288	0	9872

Balance Period No: 33

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
27/5/97	8:00	3.033	25349	3161	-0.8	165													1.8		-53.4	-104.6	-90.6			
28/5/97	8:00	3.128	34863	6062			14.0	488	-7.5	12.0	1269	12.0	2315	-0.6	221				1.4	42	-55.4	-100.8	-92.0	-1129		
29/5/97	8:00	3.169	37855	7555									2832	-1.8	224				3.0	110	-41.2	-95.1	-93.4	-1229		
30/5/97	8:00	3.157	37041	7105									667	-1.8	224				2.2	82	-36.5	-92.5	-94.9	-1035		
31/5/97	8:00	3.220	41400	9573	0.5	133	28.4	1176	-3.0	12.0	2617	12.0							3.5	137	-50.3	-86.4	-96.3	-1187		
Balance 33A			ΔS	6412	-0.15	149.00		1664			3886		5814			0				372	-45.9	-93.7	-94.2	-4580	0	4412
1/6/97	8:00	3.240	42963	10417			15.7	675	-21.0	12.0	953	12.0							0.7	30	-69.3	-87.3	-97.7	-754		
2/6/97	8:00	3.305	47355	13352			28.9	1369	-21.0	12.0	2241	12.0							1.7	79	-125.5	-85.0	-99.1	-596		
3/6/97	8:00	3.294	46594	12835			2.8	130	-21.0	12.0	1070	12.0							3.1	146	-74.2	-103.0	-97.9	-1571		
4/6/97	8:00	3.292	46458	12742	-7.9	73.7	9.1	423	-1.3	12.0	622	12.0							0.2	8	-69.3	-110.7	-96.7	-1129		
Balance 33B			ΔS	3169	-3.70	103.35		2596			4885		0			0				263	-84.6	-96.5	-97.8	-4049	0	4069
5/6/97	8:00	3.282	45762	12281			4.3	197	-1.3	12.0	343	12.0							1.9	89	-70.5	-112.6	-95.5	-912		
6/6/97	8:00	3.271	45041	11782			2.7	122	-0.5	12.0	193	12.0							0.0	1	-105.9	-126.7	-94.3	-813		
7/6/97	8:00	3.257	44150	11158			1.1	49	-0.5	12.0	39	12.0							0.2	8	-109.3	-132.0	-93.1	-704		
8/6/97	8:00	3.265	44659	11513	-5.8	69.7	10.2	456	-41.4	12.0	753	12.0							2.0	88	-65.6	-116.4	-91.9	-766		
Balance 33C			ΔS	-1229	-6.85	71.70		822			1328		0			0				185	-87.8	-121.9	-93.7	-3194	355	3502
9/6/97	8:00	3.292	46458	12742			12.3	571	-41.4	12.0	1320	12.0							0.9	41	-73.7	-125.5	-90.7	-622		
10/6/97	8:00	3.277	45432	12053															2.6	120	-62.4	-120.6	-90.6	-569		
11/6/97	8:00	3.278	45498	12099			6.8	309	-4.0	12.0	520	12.0							0.5	21	-93.3	-141.4	-90.6	-763		
12/6/97	8:00	3.280	45629	12190	-10.9	56.2	6.0	274	-4.0	12.0	445	12.0							0.3	14	-82.5	-136.2	-90.5	-614		
Balance 33D			ΔS	677	-8.35	62.95		1155			2285		0			0				195	-78.0	-130.9	-90.6	-2568	22	2607
13/6/97	8:00	3.268	44850	11647			0.6	27	-4.0	12.0	5	12.0							1.4	65	-92.4	-141.6	-90.5	-510		
14/6/97	8:00	3.286	46035	12465									1432	-2.1	222	232	-1.9	221	1.8	81	-54.9	-116.9	-90.4	-765		
15/6/97	8:00	3.309	47651	13542									1753	-2.1	222	327	-1.9	221	2.4	112	-47.3	-111.5	-90.4	-891		
16/6/97	8:00	3.290	46315	12650	-6.6	108													1.9	88	-54.2	-114.8	-90.3	-804		
Balance 33E			ΔS	460	-8.75	82.10		27			5		3185			559				346	-62.2	-121.2	-90.4	-2970	554	3513
Totals			ΔS	9489				6264			12390		8999			559				1362				-17361	931	18103

Balance Period No: 34

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
16/6/97	8:00	3.290	46315	12650	-6.6	108													1.9		-54.2	-114.8	-90.3			
17/6/97	8:00	3.273	45172	11872															1.8	81	-61.1	-120.1	-89.5	-697		
18/6/97	8:00	3.258	44214	11202															2.9	131	-49.2	-113.4	-88.7	-539		
19/6/97	8:00	3.246	43409	10676			1.4	61	4.2	12.0	41	12.0							1.3	57	-60.9	-122.7	-87.9	-571		
20/6/97	8:00	3.235	42577	10203	-5.1	106	2.0	85	4.2	12.0	68	12.0							1.9	82	-60.1	-123.5	-87.1	-544		
Balance 34A			ΔS	-2447	-5.85	107.00		146			109		0			0				351	-57.8	-119.9	-88.3	-2351	0	2465
21/6/97	8:00	3.225	41803	9781			2.0	84	4.2	12.0	92	12.0							1.0	41	-74.6	-136.7	-86.3	-557		
22/6/97	8:00	3.211	40683	9204			0.2	8	-0.1	12.0									1.0	43	-61.5	-121.1	-88.2	-542		
23/6/97	8:00	3.205	40254	8961			2.3	93	-0.1	12.0	101	12.0							1.4	56	-71.4	-120.7	-90.1	-380		
24/6/97	8:00	3.192	39385	8443	-3.0	104													0.8	33	-50.8	-114.9	-87.2	-485		
Balance 34B			ΔS	-1760	-4.05	105.00		184			193		0			0				173	-64.6	-123.3	-88.0	-1965	0	1968
25/6/97	8:00	3.182	38726	8053			0.2	8	13.8	12.0	1	12.0							1.3	53	-57.3	-126.5	-84.3	-346		
26/6/97	8:00	3.171	37991	7631															1.1	44	-52.4	-128.1	-81.4	-378		
27/6/97	8:00	3.162	37381	7292															1.1	43	-52.2	-119.4	-85.3	-296		
28/6/97	8:00	3.155	36905	7032	-1.8	112							66	-2.5	204	29	-11.6	174	1.7	62	-59.0	-114.0	-89.2	-293		
Balance 34C			ΔS	-1411	-2.40	108.00		8			1		66			29				202	-55.2	-122.0	-85.0	-1313	230	1542
Totals			ΔS	-5618				338			303		66			29				725				-5629	230	5975

Balance Period No: 35

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
28/6/97	8:00	3.155	36905	7032	-1.8	112										1.7		-59.0	-114.0	-89.2			
29/6/97	8:00	3.145	36197	6666												0.7	27	-52.1	-101.1	-93.0	-339		
30/6/97	8:00	3.136	35507	6343												1.8	64	-39.4	-93.3	-96.9	-259		
1/7/97	8:00	3.127	34783	6027												2.1	73	-34.9	-94.2	-96.3	-243		
2/7/97	8:00	3.116	33896	5649	-1.2	122										2.5	86	-32.2	-94.6	-95.7	-292		
Balance 35A			ΔS	-1383	-1.50	117.00		0			0		0				250	-39.7	-95.8	-95.5	-1133	260	1396
3/7/97	8:00	3.128	34863	6062			8.1	282	-44.2	12.0	612	12.0				2.6	89	-40	-96.3	-95.1	-393		
4/7/97	8:00	3.123	34463	5888							6	12.0				2.1	72	-75	-102.9	-94.6	-108		
5/7/97	8:00	3.116	33896	5649			0.3	10	-15.2	12.0	13	12.0				1.6	53	-88	-110.2	-94.0	-209		
6/7/97	8:00	3.160	37244	7217	-3.9	79.9	17.4	648	-15.2	12.0	1403	12.0				1.5	55	-94	-116.9	-93.4	-428		
Balance 35B			ΔS	1568	-2.55	100.95		941			2033		0				269	-74.2	-106.6	-94.3	-1137	0	1238
7/7/97	8:00	3.186	38986	8208			9.8	382	-15.2	12.0	950	12.0				2.4	92	-60.6	-109.6	-92.8	-249		
8/7/97	8:00	3.181	38661	8014			2.2	85	2.9	12.0	52	12.0				0.5	21	-46.8	-109.8	-89.3	-310		
9/7/97	8:00	3.215	40988	9367			13.4	549	-14.7	12.0	1194	12.0				1.2	48	-52.1	-103.2	-95.8	-342		
10/7/97	8:00	3.207	40394	9041	-5.7	59.4										2.2	89	-50.6	-94.7	-102.3	-237		
Balance 35C			ΔS	1824	-4.80	69.65		1016			2196		0				250	-52.5	-104.4	-95.1	-1139	5	1139
Totals			ΔS	2009				1957			4230		0				768				-3410	265	3773

Balance Period No: 36

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
10/7/97	8:00	3.207	40394	9041	-5.7	59.4										2.2		-50.6	-94.7	-102.3			
11/7/97	8:00	3.199	39850	8721												1.0	42	-46.7	-98.0	-99.4	-278		
12/7/97	8:00	3.190	39251	8365												2.5	99	-47.3	-100.8	-96.5	-257		
13/7/97	8:00	3.199	39850	8721			6.9	275	-0.4	12.0	450	12.0				0.5	21	-78.8	-113.2	-93.6	-348		
14/7/97	8:00	3.240	42963	10417	-4.1	50.6	14.0	601	-0.4	12.0	1356	12.0				0.6	23	-87.9	-126.4	-90.7	-238		
Balance 36A			ΔS	1376	-4.90	55.00		876			1806		0				186	-65.2	-109.6	-95.1	-1121	102	1229
15/7/97	8:00	3.231	42271	10033												2.0	84	-43.5	-113.9	-83.0	-300		
16/7/97	8:00	3.224	41724	9739												2.5	105	-43.0	-122.4	-75.2	-189		
17/7/97	8:00	3.216	41066	9408												1.7	69	-39.5	-124.0	-68.4	-262		
18/7/97	8:00	3.209	40536	9122	-2.2	53.0										1.9	77	-39.4	-121.6	-71.0	-209		
Balance 36B			ΔS	-1295	-3.15	51.80		0			0		0				335	-41.4	-120.5	-74.4	-960	29	983
19/7/97	8:00	3.200	39917	8760												1.5	59	-41.6	-123.0	-73.6	-303		
20/7/97	8:00	3.196	39649	8601												1.0	41	-41.9	-120.1	-76.1	-118		
21/7/97	8:00	3.188	39117	8286												1.8	70	-39.4	-113.6	-78.7	-245		
22/7/97	8:00	3.183	38791	8091	-1.2	55.6										2.1	81	-35.7	-110.6	-76.6	-114		
Balance 36C			ΔS	-1031	-1.70	54.30		0			0		0				251	-39.7	-116.8	-76.2	-780	45	825
Totals			ΔS	-950				876			1806		0				772				-2861	176	3037

Balance Period No: 37

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
22/7/97	8:00	3.183	38791	8091	-1.2	55.6										2.1		-35.7	-110.6	-76.6			
23/7/97	8:00	3.177	38400	7860												2.8	109	-35.3	-107.9	-78.5	-122		
24/7/97	8:00	3.189	39183	8325			8.4	329	-13.6	12.0	475	12.0				2.6	100	-49.4	-122.2	-80.4	-239		
25/7/97	8:00	3.210	40608	9163			9.5	386	-13.6	12.0	689	12.0				2.2	88	-73.5	-142.8	-82.3	-149		
26/7/97	8:00	3.207	40394	9041	-3.8	49.4	1.7	69	-11.8	12.0	52	12.0				1.4	56	-78.5	-141.1	-84.2	-187		
Balance 37A			ΔS	950	-2.50	52.50		784			1216		0				353	-59.2	-128.5	-81.4	-697	53	770
27/7/97	8:00	3.216	41066	9408			6.4	263	-11.8	12.0	506	12.0				1.1	45	-77.7	-133.6	-86.1	-357		
28/7/97	8:00	3.211	40683	9204							2	12.0				2.2	90	-56.6	-114.0	-88.0	-117		
29/7/97	8:00	3.207	40394	9041			0.8	32	-3.8	12.0	54	12.0				2.2	88	-61.7	-119.5	-86.7	-162		
30/7/97	8:00	3.200	39917	8760	-2.2	50.4										1.8	71	-55.4	-117.4	-85.4	-210		
Balance 37B			ΔS	-281	-3.00	49.90		295			562		0				293	-62.9	-121.1	-86.5	-845	133	973
31/7/97	8:00	3.195	39583	8562	-3.2	52.0										1.6	62	-54.7	-119.7	-84.0	-136		
1/8/97	8:00	3.190	39251	8365												2.3	90	-53.2	-120.2	-82.7	-107		
2/8/97	8:00	3.183	38791	8091												2.9	114	-48.0	-117.1	-81.4	-160		
3/8/97	8:00	3.179	38531	7937	-0.8	55.3										0.7	28	-56.8	-113.5	-86.6	-126		
Balance 37C			ΔS	-823	-1.50	52.85		0			0		0				295	-53.2	-117.6	-83.7	-528	129	659
Totals			ΔS	-154				1079			1778		0				941				-2070	315	2402

Balance Period No: 38

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
3/8/97	8:00	3.179	38531	7937	-0.8	55.3													0.7		-56.8	-113.5	-86.6			
4/8/97	8:00	3.233	42424	10118			22.0	933	-14.0	12.0	1035	12.0							1.3	51	-87.5	-111.0	-91.8	264		
5/8/97	8:00	3.248	43550	10763			7.5	327	-10.5	12.0	1116	12.0							2.8	121	-65.7	-105.8	-92.4	-676		
6/8/97	8:00	3.249	43619	10806			2.6	113	-2.8	12.0	244	12.0							1.9	82	-59.8	-104.7	-93.0	-233		
7/8/97	8:00	3.248	43550	10763	-4.1	46.2	1.6	70	-2.8	12.0	143	12.0							2.0	88	-74.7	-108.7	-93.6	-167		
Balance 38A			ΔS	2826	-2.45	50.75		1443			2538									342	-71.9	-107.5	-92.7	-812	265	1095
8/8/97	8:00	3.245	43337	10632			2.0	87	-2.8	12.0	128	12.0	39	-2.5	204	38	-13.5	174	1.4	60	-76.3	-107.5	-94.3	-363		
9/8/97	8:00	3.250	43688	10850			5.5	240	-19.9	12.0	514	12.0							2.4	103	-67.3	-104.4	-94.9	-433		
10/8/97	8:00	3.316	48161	13877			24.8	1194	-19.9	12.0	2338	12.0							1.5	68	-63.0	-102.7	-95.5	-438		
11/8/97	8:00	3.310	47725	13590	-4.5	45.5					34	12.0							1.9	90	-48.0	-100.0	-96.1	-231		
Balance 38B			ΔS	2827	-4.30	45.85		1521			3014		39			38				320	-63.7	-103.7	-95.2	-1465	556	1897
12/8/97	8:00	3.303	47214	13257							0								1.5	69	-54.9	-107.3	-91.5	-264		
13/8/97	8:00	3.298	46866	13022							0								2.3	108	-52.8	-107.5	-90.7	-127		
14/8/97	8:00	3.293	46526	12789							0								3.1	146	-69.9	-116.3	-89.8	-87		
15/8/97	8:00	3.343	49866	15201	-4.6	46.7	17.5	873	-5.9	12.0	1764	12.0							3.3	159	-90.6	-128.5	-89.0	-66		
Balance 38C			ΔS	1611	-4.55	46.10		873			1764									482	-67.1	-114.9	-90.3	-544	442	992
16/8/97	8:00	3.347	50104	15401			5.0	251	-18.0	12.0	422	12.0							2.1	104	-59.7	-113.5	-88.2	-368		
17/8/97	8:00	3.340	49688	15052							26	12.0							2.2	109	-46.8	-106.9	-87.3	-265		
18/8/97	8:00	3.335	49387	14804							0								2.7	134	-47.0	-107.3	-86.5	-114		
19/8/97	8:00	3.330	49075	14558	-2.6	50.9					0								2.5	123	-48.3	-115.9	-79.1	-123		
Balance 38D			ΔS	-643	-3.60	48.80		251			447									471	-50.5	-110.9	-85.3	-870	319	1170
Totals			ΔS	6621				4088			7763		39			38				1616				-3691	1582	5154

Balance Period No: 39

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
19/8/97	8:00	3.330	49075	14558	-2.6	50.9													2.5		-48.3	-115.9	-79.1			
20/8/97	8:00	3.325	48760	14314															1.8	87	-47.0	-110.5	-82.7	-157		
21/8/97	8:00	3.320	48436	14071															3.0	147	-49.5	-107.6	-86.3	-96		
22/8/97	8:00	3.316	48161	13877															2.1	101	-55.9	-104.7	-89.8	-93		
23/8/97	8:00	3.311	47799	13638	-1.2	61.9													2.1	100	-53.9	-97.7	-93.4	-139		
Balance 39A			ΔS	-920	-1.90	56.40		0			0		0			0				435	-51.6	-105.1	-88.0	-485	673	1152
24/8/97	8:00	3.306	47427	13399															2.4	114	-41.4	-101.0	-86.8	-125		
25/8/97	8:00	3.301	47075	13163															2.4	113	-42.9	-107.8	-80.2	-123		
26/8/97	8:00	3.295	46662	12882															4.3	200	-38.5	-102.1	-81.9	-81		
27/8/97	8:00	3.294	46594	12835	1.8	68.5	0.5	23	-24.5	12.0									2.8	130	-54.3	-110.1	-83.6	60		
Balance 39B			ΔS	-803	0.30	65.20		23			0		0			0				558	-44.3	-105.3	-83.1	-268	276	525
28/8/97	8:00	3.314	48019	13781			9.0	432	-24.5	12.0	771	12.0							1.5	71	-56.1	-108.0	-85.2	-186		
29/8/97	8:00	3.326	48823	14362			6.2	303	-24.5	12.0	454	12.0							1.8	89	-48.7	-101.9	-86.9	-87		
30/8/97	8:00	3.321	48503	14119															2.3	112	-54.8	-101.9	-88.6	-131		
31/8/97	8:00	3.318	48300	13974	0.2	69.1													2.4	116	-46.8	-94.9	-92.8	-29		
Balance 39C			ΔS	1139	1.00	68.80		735			1226									388	-51.6	-101.7	-88.4	-434	506	925
Totals			ΔS	-584				758			1226		0			0				1380				-1187	1455	2602

Balance Period No: 40

East Lake

Day & Time		Stage	Area	Volume	Lake			Rain			Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
31/8/97	8:00	3.318	48300	13974	0.2	69.1													2.4		-46.8	-94.9	-92.8			
1/9/97	8:00	3.312	47873	13685															3.2	155	-44.8	-90.9	-97.0	-134		
2/9/97	8:00	3.343	49866	15201			13.0	648	-28.4	12.0	901	12.0							1.3	65	-55.9	-91.5	-95.7	32		
3/9/97	8:00	3.355	50567	15804			7.6	384	-2.4	12.0	396	12.0							2.0	99	-61.9	-94.0	-94.4	-78		
4/9/97	8:00	3.350	50280	15552	-0.5	67.4	0.1	5.0	-2.4	12.0	2	12.0							2.0	100	-53.2	-96.3	-93.1	-159		
Balance 40A			ΔS	1578	-0.15	68.25		1038			1299		0			0				420	-53.9	-93.2	-95.0	-338	421	741
5/9/97	8:00	3.345	49985	15301															2.3	115	-54.3	-97.1	-91.7	-136		
6/9/97	8:00	3.463	56474	21608			39.3	2219	-54.8	12.0	5067	12.0							2.1	112	-166.6	-188.5	-90.4	-867		
7/9/97	8:00	3.456	56163	21213			1.0	56	-22.6	12.0	10	12.0							3.0	168	-101.7	-148.4	-89.1	-293		
8/9/97	8:00	3.526	59481	25261	-20.3	43.5	26.3	1564	-22.6	12.0	3144	12.0							3.0	171	-131.5	-170.1	-87.8	-490		
Balance 40B			ΔS	9709	-10.40	55.45		3840			8221		0			0				566	-113.5	-151.0	-89.8	-1786	48	1915
9/9/97	8:00	3.551	60631	26761			14.4	873	-22.6	12.0	911	12.0							3.3	197	-127.7	-168.4	-87.0	-87		
10/9/97	8:00	3.575	62269	28233			12.9	803	-26.2	12.0	1441	12.0							2.6	157	-96.2	-146.7	-86.2	-615		
11/9/97	8:00	3.570	61779	27923			0.6	37	-26.2	12.0	23	12.0							2.3	141	-92.6	-144.5	-85.4	-229		
12/9/97	8:00	3.567	61539	27738	-18.0	47.2	1.2	74	-23.9	12.0	71	12.0							2.7	164	-132.9	-175.5	-84.6	-165		
Balance 40C			ΔS	2477	-19.15	45.35		1787			2445		0			0				659	-112.3	-158.8	-85.8	-1097	1020	2101
Totals			ΔS	13764				6665			11965		0			0				1645				-3221	1489	4757

Balance Period No: 41 **East Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
12/9/97	8:00	3.567	61539	27738	-18.0	47.2													2.7		-132.9	-175.5	-84.6			
13/9/97	8:00	3.561	61155	27370															3.1	192	-102.3	-153.0	-83.8	-176		
14/9/97	8:00	3.557	60947	27126															2.5	153	-104.2	-155.2	-83.0	-91		
15/9/97	8:00	3.552	60684	26822															3.1	190	-93.6	-147.5	-82.2	-114		
16/9/97	8:00	3.547	60416	26519	-15.5	52.8													3.1	189	-88.0	-144.7	-80.5	-114		
Balance 41A			ΔS	-1219	-16.75	50.00		0			0		0			0				725	-97.0	-150.1	-82.4	-494	576	1062
17/9/97	8:00	3.542	60156	26218															2.6	157	-99.6	-157.0	-78.8	-144		
18/9/97	8:00	3.537	59935	25917			0.2	12	4.3	12.0	19	12.0							3.0	181	-97.4	-154.2	-79.0	-151		
19/9/97	8:00	3.533	59766	25678			0.1	6.0	4.3	12.0									2.9	175	-103.3	-158.5	-79.2	-70		
20/9/97	8:00	3.527	59522	25320	-13.3	54.9													3.0	180	-89.1	-145.4	-79.3	-178		
Balance 41B			ΔS	-1199	-14.40	53.85		18			19		0			0				693	-97.3	-153.8	-79.1	-542	96	640
21/9/97	8:00	3.520	59236	24904															2.5	149	-84.8	-141.1	-79.5	-267		
22/9/97	8:00	3.517	59115	24727							1	12.0							3.2	191	-89.8	-144.5	-79.7	13		
23/9/97	8:00	3.510	58809	24314							2	12.0							3.4	203	-83.3	-136.6	-81.2	-212		
24/9/97	8:00	3.506	58581	24079	-11.5	57.5	0.5	29	-2.2	12.0	9	12.0							4.0	237	-92.1	-140.4	-82.7	-35		
Balance 41C			ΔS	-1241	-12.40	56.20		29			12		0			0				780	-87.5	-140.7	-80.8	-502	118	632
Totals			ΔS	-3659				47			31		0			0				2198				-1539	790	2334

Balance Period No: 42

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
24/9/97	8:00	3.506	58581	24079	-11.5	57.5													4.0		-92.1	-140.4	-82.7			
25/9/97	8:00	3.499	58174	23671							2	12.0							4.3	250	-66.3	-119.9	-84.2	-160		
26/9/97	8:00	3.495	57969	23438			0.8	46	15.0	12.0	11	12.0							3.4	199	-73.6	-122.3	-85.7	-92		
27/9/97	8:00	3.490	57724	23149							1	12.0							2.8	163	-76.9	-121.4	-87.2	-127		
28/9/97	8:00	3.485	57486	22861	-8.1	62.2													3.3	192	-75.8	-117.8	-88.7	-96		
Balance 42A			ΔS	-1218	-9.80	59.85		46			14		0			0				803	-73.2	-120.4	-86.5	-475	333	776
29/9/97	8:00	3.479	57207	22517															3.7	209	-74.7	-115.1	-90.2	-135		
30/9/97	8:00	3.475	57025	22289															3.1	179	-83.5	-115.9	-91.7	-49		
1/10/97	8:00	3.472	56890	22118			1.9	108	-1.1	12.0	124	12.0							4.4	252	-79.2	-112.0	-93.2	-151		
2/10/97	8:00	3.467	56663	21834	-7.6	69.9													3.1	178	-66.3	-106.7	-94.7	-106		
Balance 42B			ΔS	-1027	-7.85	66.05		108			124		0			0				818	-75.9	-112.5	-92.5	-442	726	1210
3/10/97	8:00	3.460	56337	21438															3.9	218	-60.1	-102.6	-96.2	-178		
4/10/97	8:00	3.455	56120	21157															4.0	223	-69.7	-99.8	-97.7	-58		
5/10/97	8:00	3.447	55778	20710															4.8	268	-63.1	-101.7	-93.6	-179		
6/10/97	8:00	3.442	55566	20431	-2.7	77.4													5.6	314	-49.4	-100.3	-89.4	35		
Balance 42C			ΔS	-1403	-5.15	73.65		0			0		0			0				1023	-60.6	-101.1	-94.2	-380	451	781
Totals			ΔS	-3648				154			138		0			0				2644				-1296	1510	2767

Balance Period No: 43

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
6/10/97	8:00	3.442	55566	20431	-2.7	77.4													5.6		-49.4	-100.3	-89.4			
7/10/97	8:00	3.436	55308	20099															4.6	254	-64.0	-108.7	-85.7	-78		
8/10/97	8:00	3.437	55351	20154			2.7	149	1.0	12.0	304	12.0							4.1	225	-81.4	-114.2	-86.5	-174		
9/10/97	8:00	3.469	56754	21947	-2.0	76.3	15.2	863	1.0	12.0	1189	12.0							4.7	263	-75.8	-110.2	-87.3	5		
10/10/97	8:00	3.483	57393	22746	-1.7	76.6	8.9	511	2.9	12.0	805	12.0							4.9	278	-67.9	-105.7	-88.1	-239		
Balance 43A			ΔS	2315	-2.20	77.00		1523			2298		0			0				1021	-72.3	-109.7	-86.9	-486	906	1448
11/10/97	8:00	3.478	57161	22460															4.2	239	-57.9	-100.8	-88.9	-47		
12/10/97	8:00	3.470	56800	22004															3.9	220	-61.4	-99.8	-89.7	-236		
13/10/97	8:00	3.465	56571	21721															3.8	213	-63.6	-98.0	-90.5	-70		
14/10/97	8:00	3.458	56249	21326	0.9	82.7													3.4	194	-62.3	-111.2	-79.4	-201		
Balance 43B			ΔS	-1420	-0.40	79.65		0			0		0			0				866	-61.3	-102.5	-87.1	-554	380	925
15/10/97	8:00	3.451	55948	20933															4.9	275	-57.3	-106.4	-80.6	-118		
16/10/97	8:00	3.443	55608	20487															4.2	233	-54.8	-103.5	-81.7	-213		
17/10/97	8:00	3.435	55265	20043															5.0	278	-53.9	-101.6	-82.9	-166		
18/10/97	8:00	3.425	54793	19493	1.8	90.5													5.0	275	-46.6	-97.4	-84.0	-275		
Balance 43C			ΔS	-1833	1.35	86.60		0			0		0			0				1061	-53.1	-102.2	-82.3	-772	430	1236
Totals			ΔS	-938				1523			2298		0			0				2947				-1812	1716	3609

Balance Period No: 44

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	$δE_{pan}$	δE*	δA		m^3	m^3
18/10/97	8:00	3.425	54793	19493	1.8	90.5													5.0		-46.6	-97.4	-84.0			
19/10/97	8:00	3.419	54510	19165															5.1	279	-44.1	-94.9	-85.2	-49		
20/10/97	8:00	3.410	54055	18677															6.8	368	-40.7	-96.1	-77.7	-120		
21/10/97	8:00	3.402	53580	18246															4.7	253	-46.1	-104.7	-70.2	-178		
22/10/97	8:00	3.393	52839	17767	5.5	93.3													6.0	322	-45.2	-100.0	-74.9	-157		
Balance 44A			ΔS	-1726	3.65	91.90		0			0		0			0				1222	-44.0	-98.9	-77.0	-504	0	719
23/10/97	8:00	3.383	52166	17242			0.1	5.2	28.4	12.0	12	12.0							4.3	224	-52.0	-99.2	-79.5	-318		
24/10/97	8:00	3.373	51591	16723															5.2	271	-52.9	-93.1	-84.2	-248		
25/10/97	8:00	3.364	51073	16261															3.3	171	-50.5	-86.3	-88.8	-291		
26/10/97	8:00	3.357	50679	15905	7.4	104													4.6	233	-44.8	-81.8	-93.5	-123		
Balance 44B			ΔS	-1862	6.45	98.65		5			12		0			0				900	-50.0	-90.1	-86.5	-980	619	1606
27/10/97	8:00	3.349	50221	15502							4	12.0							4.8	242	-45.3	-80.5	-92.9	-165		
28/10/97	8:00	3.343	49866	15201			1.4	70	11.4	12.0	57	12.0							5.0	253	-49.0	-78.0	-92.2	-175		
29/10/97	8:00	3.331	49138	14607															5.3	263	-40.6	-80.2	-91.6	-331		
30/10/97	8:00	3.318	48300	13974	10.3	116													6.2	300	-36.7	-80.7	-91.0	-333		
Balance 44C			ΔS	-1931	8.85	110.00		70			61		0			0				1058	-42.9	-79.9	-91.9	-1004	539	1540
Totals			ΔS	-5519				75			73		0			0				3179				-2488	1158	3865

Balance 44A corresponds to start irrigation pumping

Balance Period No: 45

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
30/10/97	8:00	3.318	48300	13974	10.3	116													6.2		-36.7	-80.7	-91.0			
31/10/97	8:00	3.308	47575	13494															5.2	250	-33.2	-80.8	-90.4	-230		
1/11/97	8:00	3.297	46798	12975															4.9	231	-36.3	-77.8	-89.7	-288		
2/11/97	8:00	3.290	46315	12650															5.2	243	-38.2	-75.1	-89.1	-82		
3/11/97	8:00	3.283	45829	12327	14.0	123													5.6	259	-33.3	-81.6	-80.9	-64		
Balance 45A			ΔS	-1647	12.15	119.50		0			0		0			0				984	-35.3	-78.9	-87.5	-663	0	734
4/11/97	8:00	3.274	45237	11917															5.5	252	-35.7	-88.7	-72.6	-158		
5/11/97	8:00	3.265	44659	11513															4.4	197	-38.0	-84.3	-76.5	-207		
6/11/97	8:00	3.256	44085	11113															4.4	194	-31.8	-78.0	-80.3	-206		
7/11/97	8:00	3.244	43265	10589	17.2	134													6.4	278	-27.8	-74.9	-84.2	-246		
Balance 45B			ΔS	-1738	15.60	128.50		0			0		0			0				921	-33.3	-81.5	-78.4	-817	70	893
8/11/97	8:00	3.235	42577	10203															5.4	233	-28.8	-75.4	-80.0	-153		
9/11/97	8:00	3.227	41961	9865															5.8	247	-27.3	-77.3	-75.8	-91		
10/11/97	8:00	3.220	41400	9573															5.0	209	-27.6	-70.7	-80.4	-83		
11/11/97	8:00	3.209	40536	9122	21.1	146													5.9	244	-24.9	-65.7	-84.9	-207		
Balance 45C			ΔS	-1467	19.15	140.00		0			0		0			0				932	-27.2	-72.3	-80.3	-535	0	566
Totals			ΔS	-4852				0			0		0			0				2836				-2016	70	2193

Balance Period No: 46

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
11/11/97	8:00	3.209	40536	9122	21.1	146													5.9		-24.9	-65.7	-84.9			
12/11/97	8:00	3.197	39716	8641															6.6	264	-23.4	-61.0	-89.5	-217		
13/11/97	8:00	3.190	39251	8365	22.7	151													1.5	58	-26.2	-40.3	-94.1	-218		
14/11/97	8:00	3.184	38856	8130															2.5	98	-21.5	-42.6	-98.7	-137		
15/11/97	8:00	3.173	38128	7707	25.1	156													5.3	205	-18.6	-42.7	-103.2	-218		
Balance 46A			ΔS	-1415	22.97	151.00		0			0		0			0				624	-22.4	-46.6	-96.4	-791	0	812
16/11/97	8:00	3.164	37516	7366															6.9	260	-16.2	-42.6	-107.8	-81		
17/11/97	8:00	3.156	36973	7068															5.4	202	-14.2	-51.2	-98.3	-96		
18/11/97	8:00	3.148	36420	6775															6.3	230	-12.5	-52.1	-88.7	-63		
19/11/97	8:00	3.139	35742	6450	30.2	181													6.7	241	-10.7	-57.4	-79.2	-84		
Balance 46B			ΔS	-1257	27.65	168.50		0			0		0			0				933	-13.4	-50.8	-93.5	-324	229	546
20/11/97	8:00	3.130	35025	6132															5.4	192	-10.4	-51.8	-81.6	-126		
21/11/97	8:00	3.123	34463	5888															6.0	210	-9.6	-36.4	-84.1	-34		
22/11/97	8:00	3.131	35108	6167			5.4	190	-5.1	12.0	450	12.0							3.1	108	-8.9	-19.4	-86.5	-252		
23/11/97	8:00	3.126	34703	5992	30.6	183					1	12.0							4.0	138	-9.9	-35.4	-88.9	-37		
Balance 46C			ΔS	-458	30.40	182.00		190			451		0			0				649	-9.7	-35.7	-85.3	-450	43	492
Totals			ΔS	-3130				190			451		0			0				2206				-1565	272	1850

Balance Period No: 47

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
23/11/97	8:00	3.126	34703	5992	30.6	183													4.0		-9.9	-35.4	-88.9			
24/11/97	8:00	3.120	34218	5785															5.5	190	-8.9	-42.9	-84.5	-17		
25/11/97	8:00	3.114	33734	5582															2.5	85	-5.7	-29.7	-81.4	-118		
26/11/97	8:00	3.111	33489	5481			1.2	40	2.8	12.0	32	12.0							4.9	163	-4.2	-35.4	-78.3	-10		
27/11/97	8:00	3.103	32834	5215	33.2	198	0.1	3.3	2.8	12.0	3	12.0							3.9	128	-5.2	-46.0	-77.9	-145		
Balance 47A			ΔS	-777	31.90	190.50		43			36		0			0				567	-6.0	-38.5	-80.5	-290	0	307
28/11/97	8:00	3.095	32145	4955															4.8	156	-2.4	-43.2	-77.4	-104		
29/11/97	8:00	3.084	31107	4607															7.4	234	-1.4	-42.3	-80.5	-114		
30/11/97	8:00	3.075	30223	4332															6.9	211	1.1	-36.1	-83.6	-64		
1/12/97	8:00	3.068	29517	4122	38.5	229													6.6	196	5.6	-33.6	-78.4	-14		
Balance 47B			ΔS	-1093	35.85	213.50		0			0		0			0				797	0.7	-38.8	-80.0	-296	0	337
2/12/97	8:00	3.057	28274	3804															5.8	169	14.1	-12.2	-82.6	-149		
3/12/97	8:00	3.044	26665	3447	42.5	244													6.0	166	13.7	-14.2	-86.8	-191		
4/12/97	8:00	3.035	25596	3212															5.2	136	14.3	-6.4	-91.0	-99		
5/12/97	8:00	3.022	23869	2890	42.5	260													4.7	116	12.5	-6.7	-95.2	-206		
Balance 47C			ΔS	-1232	41.17	244.33		0			0		0			0				587	13.7	-9.9	-88.9	-645	0	693
Totals			ΔS	-3102				43			36		0			0				1951				-1230	0	1337

Balance Period No: 48

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
5/12/97	8:00	3.022	23869	2890	42.5	260													4.7		12.5	-6.7	-95.2			
6/12/97	8:00	3.009	21783	2593															7.5	171	13.7	-12.0	-96.7	-126		
7/12/97	8:00	2.997	19634	2345	47.4	282													7.4	153	17.6	-7.5	-98.1	-95		
8/12/97	8:00	2.988	18405	2174															7.2	137	20.8	-15.4	-85.0	-34		
9/12/97	8:00	2.976	17015	1962	50.3	324													6.3	111	20.8	-20.8	-81.6	-101		
Balance 48A			ΔS	-928	46.73	288.67		0			0		0			0				572	18.2	-13.9	-90.3	-356	0	370
10/12/97	8:00	2.961	15459	1718															8.3	135	19.1	-28.4	-78.2	-109		
11/12/97	8:00	2.949	14383	1539	55.0	336													7.0	104	39.0	-4.2	-74.8	-75		
12/12/97	8:00	2.936	13483	1358															6.4	89	44.6	12.4	-82.1	-92		
13/12/97	8:00	2.922	12589	1176	58.3	377													6.6	86	38.9	8.5	-89.4	-96		
Balance 48B			ΔS	-786	54.53	345.67		0			0		0			0				414	35.4	-2.9	-81.1	-372	0	432
14/12/97	8:00	2.910	11878	1029															8.9	108	39.7	11.7	-93.4	-39		
15/12/97	8:00	2.897	11013	880	61.1	419													8.3	96	35.9	-5.6	-83.3	-53		
16/12/97	8:00	2.885	10189	753															8.7	92	51.0	4.7	-73.1	-35		
17/12/97	8:00	2.871	9082	618	65.0	474													5.6	54	68.8	29.2	-75.4	-81		
Balance 48C			ΔS	-558	61.47	423.33		0			0		0			0				350	48.8	10.0	-81.3	-208	0	257
Totals			ΔS	-2272				0			0		0			0				1337				-935	0	1059

Balance Period No: 49

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
17/12/97	8:00	2.871	9082	618	65.0	474													5.6		68.8	29.2	-75.4			
18/12/97	8:00	2.861	7926	533															5.8	50	66.0	29.0	-77.7	-35		
19/12/97	8:00	2.850	7110	450	65.0	536													5.8	44	68.5	36.1	-79.9	-39		
20/12/97	8:00	2.836	6162	357	67.7	574													5.2	35	64.1	30.4	-82.2	-58		
Balance 49A			ΔS	-261	65.90	528.00		0			0		0			0				128	66.2	31.9	-79.9	-133	0	144
21/12/97	8:00	2.960	15365	1703	-0.5	220							1598	-14.0	162				6.8	73	-76.5	-107.1	-84.5	-179		
22/12/97	8:00	2.976	17015	1962	2.9	244							622	-13.6	162				5.0	81	-65.6	-102.0	-81.9	-282		
23/12/97	8:00	2.963	15656	1749															9.2	150	-45.9	-90.9	-79.3	-63		
24/12/97	8:00	2.928	12972	1253															7.6	109	-43.5	-78.6	-83.3	-387		
25/12/97	8:00	2.908	11755	1006	19.9	319													8.4	104	-31.5	-64.6	-87.3	-143		
Balance 49B			ΔS	649	9.70	269.50		0			0		2220			0				517	-52.6	-88.7	-83.3	-1054	0	1001
Totals			ΔS	388				0			0		2220			0				646				-1186	0	1145

Average lake Cl & Deuterium for Sub balance 49B caculated from Dec 21 as lake is virtually dry on December 20th

Lake isolated by clay basin, effective groundwater discharge is minimal

Balance Period No: 50

East Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Top Up (Outlets A & B)						Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
25/12/97	8:00	2.908	11755	1006	19.9	319													8.4		-31.5	-64.6	-87.3			
26/12/97	8:00	2.889	10470	794															6.7	74	-25.0	-58.7	-91.3	-138		
27/12/97	8:00	2.875	9430	655	25.7	372													7.9	79	-21.7	-49.7	-88.8	-60		
28/12/97	8:00	2.982	17661	2066									1615	-13.1	161				3.5	48	-52.8	-75.6	-86.2	-156		
29/12/97	8:00	2.989	18532	2192	0.5	215							737	-12.9	161				5.2	94	-72.4	-103.2	-85.6	-517		
Balance 50A			ΔS	1186	15.37	302.00		0			0		2352			0				295	-43.0	-71.8	-88.0	-871	0	829
30/12/97	8:00	2.962	15557	1734															6.9	117	-70.2	-98.1	-84.9	-341		
31/12/97	8:00	2.937	13547	1372	7.4	243													3.9	56	-66.9	-92.0	-84.3	-306		
1/1/98	8:00	2.912	11997	1053															5.8	75	-51.5	-82.7	-83.7	-244		
2/1/98	8:00	2.892	10676	826	16.2	282													6.6	74	-39.4	-75.1	-83.1	-153		
3/1/98	8:00	2.875	9430	655	19.3	297													6.8	68	-32.8	-70.2	-82.4	-103		
Balance 50B			ΔS	-1537	9.90	256.00		0			0		0			0				391	-52.2	-83.6	-83.7	-1146	0	1124
Totals			ΔS	-351				0			0		2352			0				686				-2017	0	1953

Appendix 6.3

West Lake Balance Sheets, Balance Periods 1-50
(one sheet for each balance period).

Appendix 6.2 (East Lake) and 6.3 (West Lake) Balance Sheets

Component	Units	Details
Day & Time		Date and time of the end of each 24 hour balance 'day'
Stage	m	Lake stage (metres above Australian Height Datum)
Area	m^2	Lake area from lake stage, refer Appendix 3.8
Volume	m^3	Lake volume from lake stage, refer Appendix 3.8
ΔS	m^3	Change in lake volume ('storage') over each 4 day sub-balance
Lake	δ	Deuterium in ‰ measured at the start and end of each 4 day sub-balance
	Cl	Chloride in mg L^{-1} measured at the start and end of each 4 day sub-balance
Rain	mm	Rainfall in mm falling on the lake surface
	m^3	Rainfall volume
	δ	Deuterium (average for each rainfall event which may span several days)
	Cl	Chloride in rain, 12mg L^{-1} being the average for Floreat
Drains	m^3	Storm drain flow (total for lake)
	δ	As per rainfall
	Cl	As per rainfall
Top Up	m^3	Individual volumes for outlets 'A' and 'B'
	δ	Deuterium for each outlet sampled during most top up events
	Cl	Chloride for each outlet sampled during most top up events
Evaporation	mm	Evaporation in mm as measured by the floating evaporation pan
	m^3	Volume of lake water evaporated
	δE_{pan}	δE as measured experimentally for Perry Lakes by pan experiments
	δE^*	δE as estimated from standard equations
	δA	δA as measured or interpolated from vapour sampling
Apparent GW Flux	m^3	Residual in the mass balance
GW In	m^3	Groundwater discharged to lake as computed by integrated balance
Lake-GW	m^3	Groundwater recharged to aquifer as computed by integrated balance

The groundwater ('GW') components are the key components which could not be measured directly. They are the reason for performing an integrated balance in the first place. The 'apparent groundwater flux' is simply the residual in the mass balance alone. It is the apparent surplus or deficit in water required to balance the equation. A negative value indicates an apparent deficit in water and is indicative of water which has flowed out of the lake as recharge to the aquifer. A positive value indicates an apparent surplus and indicates additional water which has entered the lake as groundwater discharge. We use the term 'apparent' because the true groundwater flux (discharge and recharge) cannot be measured directly, only the residual gain or loss.

Groundwater discharge ('GW In') is the groundwater discharged into the lake during flow-through conditions as measured by integrated mass-solute-isotopic balances. Under recharge conditions this figure is zero. Recharge ('Lake-GW') is lake water recharged to the aquifer under both flow-through and recharge flow regimes. Under recharge regimes the mass balance residual (a negative apparent flow) and the recharge as measured by integrated balance will generally be similar. All volumetric quantities are sub-totalled for each four day sub-balance. Each sub-balance row includes ΔS, mean lake water deuterium and chloride and mean δE_{pan} mean δE^* and mean δA. All integrated results were computed using the locally derived δE_{pan} in the isotopic balance.

Balance Period No: 1 **West Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
22/4/96	8:00	2.558	410	34.7	0.3											2.3		-43.0	-103.2	-85.2			
23/4/96	8:00	2.545	353	29.8			0.1	0.0	-1.4		17					1.4	0.5	-47.9	-105.3	-85.2	-21.2		
24/4/96	8:00	2.535	313	26.4												2.4	0.8	-40.9	-100.5	-85.2	-2.6		
25/4/96	8:00	2.538	325	27.4			0.5	0.2	-1.4		71					1.3	0.4	-51.2	-104.8	-85.2	-69.6		
26/4/96	8:00	2.542	341	28.7	4.5											1.1	0.4	-45.7	-100.7	-85.2	1.7		
Balance 1A			ΔS	-6.0	2.40			0.2			88		0				2.1	-46.4	-102.8	-85.2	-91.7		
27/4/96	8:00	2.548	366	30.8												2.3	0.8	-37.4	-97.0	-85.2	2.9		
28/4/96	8:00	2.542	341	28.7												2.9	1.0	-36.9	-96.9	-85.2	-1.1		
29/4/96	8:00	2.533	305	25.8												4.1	1.3	-32.8	-95.1	-85.2	-1.6		
30/4/96	8:00	2.533	305	25.8	4.4											3.5	1.1	-31.9	-94.8	-85.2	1.1		
Balance 1B			ΔS	-2.9	4.45			0.0			0		0				4.2	-34.7	-95.9	-85.2	1.3		
1/5/96	8:00	2.533	305	25.8												2.2	0.7	-46.3	-102.6	-85.2	0.7		
2/5/96	8:00	2.545	353	29.8									15			2.8	0.9	-36.6	-98.1	-85.2	-10.1		
3/5/96	8:00	2.555	396	33.5									15			2.4	0.9	-37.5	-99.0	-85.2	-10.4		
4/5/96	8:00	2.560	419	35.6	3.1								12			2.1	0.9	-43.5	-102.9	-85.2	-9.0		
Balance 1C			ΔS	9.8	3.75			0.0			0		42				3.4	-41.0	-100.7	-85.2	-28.8		
Totals			ΔS	0.9				0.2			88		42				9.7				-119.3	0	0

Balance Period No: 2

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
4/5/96	8:00	2.560	419	35.6	3.1											2.1		-43.5	-102.9	-85.2			
5/5/96	8:00	2.570	465	40			3.9	1.8	-1.4		537		15			2.1	0.9	-44.9	-103.6	-85.2	-548		
6/5/96	8:00	2.568	456	39.1												2.3	1.1	-34.2	-97.5	-85.2	0		
7/5/96	8:00	2.565	443	37.7												1.8	0.8	-54.0	-108.6	-85.2	-1		
8/5/96	8:00	2.580	508	44.8	4.0		14.0	7.1	-6.2		2009					5.4	2.6	-38.3	-99.7	-85.2	-2006		
Balance 2A			ΔS	9.2	3.55			8.9			2545		15				5.4	-42.9	-102.4	-85.2	-2555		
9/5/96	8:00	2.700	1286	147			4.7	6.0	-5.7		648					1.4	1.3	-52.9	-108.9	-85.2	-551		
10/5/96	8:00	2.691	1201	135			3.6	4.3	-3.5		495					2.8	3.5	-43.8	-104.3	-85.2	-508		
11/5/96	8:00	2.672	1028	114			1.5	1.5	-3.5		207					2.4	2.7	-36.3	-100.2	-85.2	-227		
12/5/96	8:00	2.654	923	96.8	2.2											1.9	1.8	-34.3	-99.4	-85.2	-15		
Balance 2B			ΔS	52	3.10			11.9			1350		0				9.3	-41.8	-103.2	-85.2	-1301		
13/5/96	8:00	2.631	778	77.1												2.1	1.8	-33.2	-98.3	-85.2	-18		
14/5/96	8:00	2.604	620	58.3												2.6	1.8	-29.5	-95.6	-85.2	-17		
15/5/96	8:00	2.578	499	43.8												2.7	1.5	-30.1	-95.5	-85.2	-13		
16/5/96	8:00	2.564	438	37.3	5.2		0.5	0.2	9.7		71					1.4	0.6	-38.1	-99.4	-85.2	-77		
Balance 2C			ΔS	-59.5	3.70			0.2			71		0				5.7	-32.7	-97.2	-85.2	-125		
Totals			ΔS	1.7				21.1			3966		15				20.4				-3980	0	0

Balance Period No: 3

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
16/5/96	8:00	2.564	438	37.3	5.2											1.4		-38.1	-99.4	-85.2			
17/5/96	8:00	2.555	396	33.5			2.5	1.0	9.7		344					1.2	0.5	-39.4	-99.9	-85.2	-348		
18/5/96	8:00	2.549	370	31.2												2.8	1.1	-25.7	-92.3	-85.2	-1.2		
19/5/96	8:00	2.553	387	32.7												1.7	0.6	-25.7	-92.3	-85.2	2.1		
20/5/96	8:00	2.556	401	33.9	6.1											1.9	0.7	-26.0	-92.3	-85.2	1.9		
Balance 3A			ΔS	-3.4	5.65			1.0			344		0				3.0	-29.2	-94.2	-85.2	-345		
21/5/96	8:00	2.558	410	34.7												1.7	0.7	-26.4	-92.1	-85.2	1.5		
22/5/96	8:00	2.554	391	33.1												1.2	0.5	-25.6	-91.2	-85.2	-1.1		
23/5/96	8:00	2.548	366	30.8												1.4	0.5	-23.9	-90.0	-85.2	-1.8		
24/5/96	8:00	2.541	337	28.4	8.0											1.7	0.6	-23.1	-89.1	-85.2	-1.8		
Balance 3B			ΔS	-5.5	7.05			0.0			0		0				2.3	-24.7	-90.6	-85.2	-3.2		
25/5/96	8:00	2.537	322	27.1												3.0	1.0	-21.3	-88.7	-85.2	-0.3		
26/5/96	8:00	2.544	349	29.4												2.8	0.9	-22.0	-89.3	-85.2	3.2		
27/5/96	8:00	2.551	378	32												2.3	0.8	-22.0	-89.7	-85.2	3.4		
28/5/96	8:00	2.550	374	31.6	7.1											1.3	0.5	-26.2	-92.0	-85.2	0.1		
Balance 3C			ΔS	3.2	7.55			0.0			0		0				3.2	-22.9	-89.9	-85.2	6.4		
Totals			ΔS	-5.7				1.0			344		0				8.5				-342	0	0

Balance Period No: 4

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
28/5/96	8:00	2.550	374	31.6	7.1											1.3		-26.2	-92.0	-85.2			
29/5/96	8:00	2.548	366	30.8												1.5	0.6	-37.7	-103.8	-85.2	0		
30/5/96	8:00	2.542	341	28.7												2.7	1.0	-37.9	-106.1	-85.2	-1		
31/5/96	8:00	2.868	9554	779			25.8	246	10.7		3990					4.8	24.0	-86.1	-149.2	-85.2	-3463		
1/6/96	8:00	2.903	14060	1192	-11.2		0.6	8	18.4		84					1.7	19.8	-73.2	-139.7	-85.2	340		
Balance 4A			ΔS	1160.4	-2.05	0.00		255			4075		0				45.3	-58.7	-124.7	-85.2	-3124		
2/6/96	8:00	2.860	8672	706												0.7	8.0	-77.0	-143.1	-85.2	-478		
3/6/96	8:00	2.815	4676	409			1.0		7.7		139					1.1	7.5	-85.0	-150.1	-85.2	-428		
4/6/96	8:00	2.782	2685	291												1.5	5.7	-59.4	-127.2	-85.2	-112		
5/6/96	8:00	2.752	1798	226	-8.3											1.1	2.5	-56.1	-124.1	-85.2	-62		
Balance 4B			ΔS	-966	-9.75	0.00		0			139		0				23.6	-69.4	-136.1	-85.2	-1081		
6/6/96	8:00	2.729	1542	188												1.1	1.8	-56.4	-124.4	-85.2	-36		
7/6/96	8:00	2.707	1348	156												1.3	1.9	-54.6	-122.7	-85.2	-30		
8/6/96	8:00	2.689	1179	133												1.8	2.2	-51.7	-120.2	-85.2	-21		
9/6/96	8:00	2.674	1043	116	-6.6		0.5	1	-9.4		71					1.3	1.4	-72.5	-138.6	-85.2	-87		
Balance 4C			ΔS	-110	-7.45	0.00		1			71		0				7.3	-58.8	-126.5	-85.2	-174		
Totals			ΔS	84.4				255			4284		0				76.2				-4379	0	0

Balance Period No: 5

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
9/6/96	8:00	2.674	1043	116	-6.6											1.3		-72.5	-138.6	-85.2			
10/6/96	8:00	2.680	1088	123			9.6	10	-9.4		1348					0.6	0.7	-140.5	-199.0	-85.2	-1351		
11/6/96	8:00	2.685	1129	128			0.2	0	-9.4		30					0.8	0.9	-81.6	-146.7	-85.2	-25		
12/6/96	8:00	2.685	1129	128			1.7	2	-9.4		234					0.8	0.9	-73.8	-139.7	-85.2	-235		
13/6/96	8:00	2.676	1059	118	-5.5											0.7	0.8	-60.5	-127.9	-85.2	-9		
Balance 5A			ΔS	2	-6.05	0.00		13			1612		0				3.2	-89.1	-153.3	-85.2	-1620		
14/6/96	8:00	2.668	1000	110												0.7	0.7	-59.1	-126.6	-85.2	-7		
15/6/96	8:00	2.655	929	97.7												1.0	0.9	-62.2	-129.3	-85.2	-11		
16/6/96	8:00	2.660	955	102			6.6	6	-12.1		915					1.9	1.8	-69.0	-135.4	-85.2	-916		
17/6/96	8:00	2.655	929	97.7	-4.6		2.2	2	-12.1		302					1.0	0.9	-71.1	-137.2	-85.2	-308		
Balance 5B			ΔS	-20.3	-5.05	0.00		8			1218		0				4.4	-65.4	-132.1	-85.2	-1242		
18/6/96	8:00	2.964	21886	2281			19.8	433	-12.1		2939					3.1	35	-76.9	-143.1	-85.2	-1154		
19/6/96	8:00	3.113	36046	6655			32.5	1171	-15.4		5293					3.6	103	-122.9	-185.5	-85.2	-1987		
20/6/96	8:00	3.224	45471	11203			30.1	1369	-21.0		4809					3.0	123	-106.4	-171.3	-85.2	-1507		
21/6/96	8:00	3.262	48469	12988	-12.1		19.5	945	-21.0		2889					3.4	158	-83.9	-151.2	-85.2	-1892		
Balance 5C			ΔS	12890.3	-8.35	0.00		3919			15930		0				419	-97.5	-162.8	-85.2	-6540		
22/6/96	8:00	3.262	48469	12988			11	533	-29.8		1554					1.8	85	-100.4	-166.4	-85.2	-2003		
23/6/96	8:00	3.228	45772	11386			1.7	78	-29.8		234					0.3	13	-128.2	-192.1	-85.2	-1901		
24/6/96	8:00	3.215	44778	10797			6	269	-29.8		831					0.4	19	-114.5	-179.5	-85.2	-1669		
25/6/96	8:00	3.182	42334	9360	-12.6											0.7	30	-72.8	-141.0	-85.2	-1407		
Balance 5D			ΔS	-3628	-12.35	0.00		880			2619		0				148	-104.0	-169.7	-85.2	-6979		
Totals			ΔS	9244				4819			21379		0				574				-16380	0	0

Balance Period No: 6

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
25/6/96	8:00	3.182	42334	9360	-12.6											0.7		-72.8	-141.0	-85.2			
26/6/96	8:00	3.154	39880	8207												1.1	43	-82.5	-150.0	-85.2	-1110		
27/6/96	8:00	3.187	42721	9573			15	641	-9.9		2164					1.2	49	-158.8	-220.5	-85.2	-1390		
28/6/96	8:00	3.195	43303	9917			7.5	325	-9.9		1044					2.0	84	-104.1	-170.0	-85.2	-940		
29/6/96	8:00	3.164	40865	8611	-13.8		0.4	16	-0.6		57					1.5	62	-95.1	-161.7	-85.2	-1318		
Balance 6A			ΔS	-749	-13.20	0.00		982			3265		0				238	-110.1	-175.6	-85.2	-4757		
30/6/96	8:00	3.200	43662	10134			12	524	-0.6		1704					2.0	83	-116.8	-181.7	-85.2	-622		
1/7/96	8:00	3.173	41615	8983			1	42	-0.6		139					1.7	74	-82.6	-150.0	-85.2	-1257		
2/7/96	8:00	3.161	40594	8489			2.6	106	-24.4		357					1.2	50	-112.2	-177.2	-85.2	-907		
3/7/96	8:00	3.262	48469	12988	-13.8		26.5	1284	-24.4		4120					3.8	170	-124.6	-188.6	-85.2	-735		
Balance 6B			ΔS	4377	-13.80	0.00		1956			6320		0				378	-109.1	-174.4	-85.2	-3521		
4/7/96	8:00	3.262	48469	12988			7.6	368	-24.4		1058					1.9	93	-90.7	-157.2	-85.2	-1334		
5/7/96	8:00	3.244	47006	12128			3	141	-24.4		412					0.6	29	-121.4	-185.1	-85.2	-1384		
6/7/96	8:00	3.218	45010	10932			0.1	4.5	-26.9		17					1.2	56	-81.4	-148.3	-85.2	-1161		
7/7/96	8:00	3.195	43303	9917	-12.5											2.7	119	-63.2	-131.5	-85.2	-896		
Balance 6C			ΔS	-3071	-13.15	0.00		514			1487		0				297	-89.2	-155.5	-85.2	-4775		
Totals			ΔS	557				3451			11072		0				913				-13053	0	0

Balance Period No: 7

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
7/7/96	8:00	3.195	43303	9917	-12.5											2.7		-63.2	-131.5	-85.2			
8/7/96	8:00	3.271	49046	13427			24.4	1197	-26.9		3778					2.3	108	-134.9	-196.7	-85.2	-1356		
9/7/96	8:00	3.244	47006	12128							45					1.8	88	-74.4	-141.6	-85.2	-1256		
10/7/96	8:00	3.222	45315	11113							24					1.4	64	-66.3	-134.2	-85.2	-975		
11/7/96	8:00	3.202	43807	10221	-13.8						27					1.7	74	-60.3	-128.7	-85.2	-845		
Balance 7A			ΔS	304	-13.15	0.00		1197			3874		0				334	-84.0	-150.3	-85.2	-4433		
12/7/96	8:00	3.182	42334	9360							22					3.2	139	-59.0	-127.5	-85.2	-744		
13/7/96	8:00	3.166	41039	8693			1.1	45	-18.8		106					0.4	18	-156.4	-215.4	-85.2	-800		
14/7/96	8:00	3.150	39438	8049							18					1.2	49	-97.3	-161.7	-85.2	-613		
15/7/96	8:00	3.135	37962	7468	-13.2						13					1.1	44	-113.0	-175.5	-85.2	-550		
Balance 7B			ΔS	-2753	-13.50	0.00		45			159		0				250	-106.5	-170.0	-85.2	-2708		
16/7/96	8:00	3.175	41775	9066			14.4	602	-18.8		1652					1.7	69	-163.2	-220.4	-85.2	-586		
17/7/96	8:00	3.220	45162	11022			16.5	745	-18.8		2171					3.8	166	-100.5	-164.0	-85.2	-794		
18/7/96	8:00	3.202	43807	10221			2.8	123	5.6		237					3.0	135	-79.9	-145.5	-85.2	-1025		
19/7/96	8:00	3.197	43447	10004	-13.8		4.0	174	5.6		470					2.0	87	-102.3	-165.3	-85.2	-773		
Balance 7C			ΔS	2536	-13.50	0.00		1643			4530		0				459	-111.5	-173.8	-85.2	-3179		
Totals			ΔS	87				2885			8563		0				1042				-10319	0	0

Balance Period No: 8

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
19/7/96	8:00	3.197	43447	10004	-13.8											2.0		-102.3	-165.3	-85.2			
20/7/96	8:00	3.181	42256	9318			0.6	25	5.6		140					0.9	37	-109.8	-171.5	-85.2	-814		
21/7/96	8:00	3.177	41935	9150			4.0	168	-2.6		420					1.0	40	-132.5	-190.9	-85.2	-715		
22/7/96	8:00	3.192	43085	9787			7.6	327	-2.6		1148					1.0	44	-124.5	-164.3	-89.9	-794		
23/7/96	8:00	3.187	42721	9573	-11.3		3.7	158	-2.6		519					2.5	108	-78.8	-138.8	-87.2	-783		
Balance 8A			ΔS	-431	-12.55	0.00		679			2227		0				230	-111.4	-166.4	-86.9	-3106		
24/7/96	8:00	3.235	46301	11708			16.6	769	-18.2		2711					2.9	128	-87.7	-151.8	-84.5	-1217		
25/7/96	8:00	3.249	47459	12364			8.4	399	-18.2		1321					2.0	94	-80.4	-150.9	-81.8	-970		
26/7/96	8:00	3.232	46075	11570			0.3	14	-18.2		89					1.9	90	-76.6	-152.6	-79.1	-807		
27/7/96	8:00	3.336	52489	16725	-8.9		25.8	1354	-6.8		4511					3.7	180	-78.9	-161.4	-76.4	-530		
Balance 8B			ΔS	7152	-10.10	0.00		2535			8632		0				491	-80.9	-154.2	-80.5	-3524		
28/7/96	8:00	3.338	52605	16830			7.5	395	-6.8		1338					2.3	119	-73.8	-161.1	-73.7	-1509		
29/7/96	8:00	3.317	51440	15738			0.3	15	-6.7		133					2.3	118	-67.9	-158.7	-71.0	-1123		
30/7/96	8:00	3.340	52726	16936			11.1	585	-6.7		2115					1.7	86	-142.7	-248.0	-76.0	-1416		
31/7/96	8:00	3.335	52432	16673	-5.5		4.7	246	-6.7		814					3.0	156	-52.5	-122.7	-80.9	-1168		
Balance 8C			ΔS	-52	-7.20	0.00		1242			4400		0				478	-84.2	-172.6	-75.4	-5216		
1/8/96	8:00	3.328	52041	16307			4.4	229	-6.7		646					2.8	145	-61.0	-122.3	-85.9	-1096		
2/8/96	8:00	3.316	51388	15687			1.5	77	-6.7		478					2.3	117	-72.0	-118.0	-90.8	-1058		
3/8/96	8:00	3.302	50653	14972			0.7	35	-33.3		217					2.1	107	-64.8	-104.2	-95.8	-861		
4/8/96	8:00	3.311	51129	15430	-4.9		6.2	317	-33.3		1073					2.2	111	-70.3	-92.9	-100.7	-821		
Balance 8D			ΔS	-1243	-5.20	0.00		659			2414		0				480	-67.0	-109.3	-93.3	-3836		
5/8/96	8:00	3.312	51181	15482			5.7	292	-33.3		871					1.6	80	-63.9	-83.3	-105.7	-1031		
6/8/96	8:00	3.320	51598	15893			4.6	237	-33.3		1166					1.4	72	-56.1	-90.3	-103.1	-921		
7/8/96	8:00	3.325	51873	16151			5.0	259	3.5		829					0.8	41	-72.3	-91.5	-100.5	-790		
8/8/96	8:00	3.312	51181	15482	-4.2		0.1	5.12	3.5		42					1.7	90	-57.2	-97.6	-97.9	-626		
Balance 8E			ΔS	52	-4.55	0.00		794			2908		0				282	-62.4	-90.7	-101.8	-3368		
Totals			ΔS	5478				5908			20581		0				1961				-19050	0	0

Balance Period No: 9

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
8/8/96	8:00	3.312	51181	15482	-4.2											1.7		-57.2	-97.6	-97.9			
9/8/96	8:00	3.297	50389	14720							39					1.9	97	-51.6	-100.2	-95.3	-704		
10/8/96	8:00	3.285	49778	14119							65					2.3	118	-47.7	-101.9	-92.6	-548		
11/8/96	8:00	3.332	52262	16516			17.7	925	2.6		1998					1.5	75	-80.3	-117.6	-90.0	-451		
12/8/96	8:00	3.318	51492	15790	-2.4		0.7	36	2.6		181					1.9	99	-48.9	-107.6	-87.4	-844		
Balance 9A			ΔS	308	-3.30	0.00		961			2283		0				390	-57.1	-106.8	-91.3	-2546		
13/8/96	8:00	3.335	52432	16673			10.0	524	-12.8		977					2.2	113	-59.2	-118.1	-84.8	-505		
14/8/96	8:00	3.324	51816	16100			1.5	78	-12.8		296					1.9	100	-43.6	-109.3	-82.2	-847		
15/8/96	8:00	3.315	51336	15635			1.2	62	1.4		211					1.0	54	-56.8	-125.9	-79.2	-684		
16/8/96	8:00	3.302	50653	14972	-1.8		1.2	61	1.4		77					1.3	67	-57.3	-131.7	-76.2	-734		
Balance 9B			ΔS	-818	-2.10	0.00		724			1561		0				333	-54.2	-121.3	-80.6	-2770		
17/8/96	8:00	3.295	50286	14619			0.3	15	1.4		149					1.7	88	-51.6	-128.8	-73.3	-429		
18/8/96	8:00	3.284	49728	14069							73					2.8	139	-39.4	-113.7	-70.3	-484		
19/8/96	8:00	3.273	49160	13525							58					3.2	159	-39.5	-115.9	-67.3	-443		
20/8/96	8:00	3.274	49216	13574	-0.8		2.8	138	-3.2		394					2.9	141	-50.8	-132.0	-70.0	-342		
Balance 9C			ΔS	-1398	-1.30	0.00		153			674		0				527	-45.3	-122.6	-70.2	-1697		
Totals			ΔS	-1908				1838			4518		0				1250				-7014	0	0

Balance Period No: 10 **West Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
20/8/96	8:00	3.274	49216	13574	-0.8											2.9		-50.8	-132.0	-70.0			
21/8/96	8:00	3.297	50389	14720			9.4	474	-3.2		1180					1.0	52	-68.2	-152.8	-72.8	-456		
22/8/96	8:00	3.290	50032	14368			1.0	50	-3.2		170					1.6	79	-53.6	-126.9	-75.5	-493		
23/8/96	8:00	3.281	49575	13920							74					1.7	87	-54.9	-123.1	-78.2	-435		
24/8/96	8:00	3.304	50760	15074	0.7		9.8	497	-0.2		1209					1.7	83	-69.9	-130.3	-80.9	-470		
Balance 10A			ΔS	1500	-0.05	0.00		1021			2633		0				300	-61.7	-133.3	-76.9	-1854		
25/8/96	8:00	3.294	50235	14569							106					2.8	141	-40.9	-102.5	-83.7	-470		
26/8/96	8:00	3.283	49677	14019							70					2.0	100	-41.6	-100.1	-86.4	-520		
27/8/96	8:00	3.278	49423	13772			1.8	89	-1.0		227					1.9	95	-57.9	-111.6	-84.5	-468		
28/8/96	8:00	3.272	49104	13476	0.8		1.0	49	-1.0		160					2.1	103	-61.1	-117.6	-82.5	-402		
Balance 10B			ΔS	-1598	0.75	0.00		138			563		0				438	-50.4	-108.0	-84.3	-1861		
29/8/96	8:00	3.263	48539	13037							77					1.8	89	-50.5	-112.6	-80.6	-427		
30/8/96	8:00	3.255	47974	12650							65					2.1	101	-49.7	-114.6	-78.6	-351		
31/8/96	8:00	3.278	49423	13772			9.0	445	5.8		1022					2.2	106	-52.0	-119.7	-76.7	-239		
1/9/96	8:00	3.269	48920	13329	2.0	22.2					75					3.1	152	-42.4	-111.1	-74.7	-366		
Balance 10C			ΔS	-147	1.40			445			1239		0				448	-48.6	-114.5	-77.7	-1383		
Totals			ΔS	-245				1604			4435		0				1186				-5098	0	0

Balance Period No: 11

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
1/9/96	8:00	3.269	48920	13329	2.0	22.2										3.1		-42.4	-111.1	-74.7			
2/9/96	8:00	3.260	48332	12891							55	12.0				2.1	102	-42.1	-112.6	-72.8	-391		
3/9/96	8:00	3.264	48606	13085			3.0	146	1.2	12.0	488	12.0				3.1	150	-45.9	-116.6	-73.4	-290		
4/9/96	8:00	3.255	47974	12650							87	12.0				3.1	149	-41.4	-110.0	-74.0	-373		
5/9/96	8:00	3.248	47357	12317	3.0	23.9					63	12.0				2.5	117	-40.2	-107.6	-74.6	-279		
Balance 11A			ΔS	-1012	2.50	23.03		146			693		0				518	-42.4	-111.7	-73.7	-1333	69	1411
6/9/96	8:00	3.257	48120	12747			5.2	250	8.0	12.0	618	12.0				3.5	165	-45.7	-113.1	-75.3	-273		
7/9/96	8:00	3.258	48192	12795			2.5	120	8.0	12.0	333	12.0				3.5	171	-43.1	-109.1	-75.9	-235		
8/9/96	8:00	3.261	48400	12940			3.3	160	8.0	12.0	311	12.0				0.7	35	-54.2	-119.4	-76.5	-291		
9/9/96	8:00	3.272	49104	13476	5.1	25.5	5.0	246	-13.4	12.0	621	12.0				2.4	115	-48.1	-111.6	-77.1	-215		
Balance 11B			ΔS	1159	4.05	24.70		776			1883		0				486	-47.8	-113.3	-76.2	-1013	152	1154
10/9/96	8:00	3.304	50760	15074			11.2	569	-13.4	12.0	1431	12.0				3.2	159	-48.6	-112.3	-76.8	-242		
11/9/96	8:00	3.354	53478	17679			19.0	1016	-13.4	12.0	2247	12.0				2.8	147	-46.5	-110.4	-76.4	-511		
12/9/96	8:00	3.342	52877	17041			0.2	11	1.2	12.0	129	12.0				1.7	92	-46.0	-110.0	-76.1	-686		
13/9/96	8:00	3.334	52375	16620	4.3	27.2					40	12.0				1.8	96	-45.8	-109.8	-75.8	-365		
Balance 11C			ΔS	3144	4.70	26.37		1595			3847		0				494	-46.7	-110.6	-76.3	-1804	323	2065
Totals			ΔS	3291				2517			6423		0				1499				-4150	544	4630

	GW In	Lake-GW
	m^3	m^3
Total balance period calculation	540	4629

Balance Period No: 12

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
13/9/96	8:00	3.334	52375	16620	4.3	27.2										1.8		-45.8	-109.8	-75.8			
14/9/96	8:00	3.330	52151	16411			2	104	1.2	12.0	304	12.0				4.1	214	-46.7	-111.0	-75.5	-403		
15/9/96	8:00	3.334	52375	16620			5	262	7.7	12.0	573	12.0				3.6	190	-58.7	-123.8	-75.1	-436		
16/9/96	8:00	3.345	53014	17200			5	265	7.7	12.0	1101	12.0				2.2	115	-54.6	-119.9	-74.8	-671		
17/9/96	8:00	3.339	52665	16883	7.5	28.0	1	53	7.7	12.0	114	12.0				2.9	154	-48.8	-111.2	-75.8	-330		
Balance 12A			ΔS	263	5.90	27.58		684			2092		0				673	-52.2	-116.5	-75.3	-1840	137	1963
18/9/96	8:00	3.341	52790	16989			4.5	238	5.2	12.0	456	12.0				2.5	134	-57.7	-116.3	-76.8	-453		
19/9/96	8:00	3.331	52207	16464			1.5	78	5.2	12.0	160	12.0				4.4	229	-36.8	-96.7	-77.9	-534		
20/9/96	8:00	3.323	51760	16048			0.1	5.2	5.2	12.0	71	12.0				3.3	170	-36.5	-94.9	-78.9	-322		
21/9/96	8:00	3.315	51336	15635	8.5	28.7					55	12.0				2.6	136	-36.4	-93.4	-79.9	-332		
Balance 12B			ΔS	-1248	8.00	28.35		321			742		0				670	-41.9	-100.3	-78.4	-1641	37	1692
22/9/96	8:00	3.384	55286	19310			22	1216	-13.9	12.0	3113	12.0				5.6	296	-47.0	-97.0	-80.9	-358		
23/9/96	8:00	3.371	54472	18597							72	12.0				3.5	190	-34.4	-91.1	-80.8	-595		
24/9/96	8:00	3.361	53853	18055							28	12.0				3.0	163	-38.5	-92.9	-80.7	-407		
25/9/96	8:00	3.350	53274	17466	8.6	29.5					33	12.0				2.6	141	-35.5	-91.5	-80.6	-481		
Balance 12C			ΔS	1831	8.55	29.12		1216			3246		0				790	-38.8	-93.1	-80.7	-1842	237	2010
Totals			ΔS	846				2221			6080		0				2133				-5322	411	5665

	GW In	Lake-GW
	m^3	m^3
Total balance period calculation	412	5671

Balance Period No: 13

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
25/9/96	8:00	3.350	53274	17466	8.6	29.5										2.6		-35.5	-91.5	-80.6			
26/9/96	8:00	3.341	52790	16989							29	12.0				3.1	164	-34.9	-91.1	-80.5	-342		
27/9/96	8:00	3.404	56531	20428			19.2	1085	-13.2	12.0	3070	12.0				1.5	85	-60.4	-104.9	-80.3	-632		
28/9/96	8:00	3.391	55718	19699			0.1	5.6	-13.2	12.0	65	12.0				4.0	225	-46.5	-97.5	-80.2	-575		
29/9/96	8:00	3.382	55166	19200	8.3	35.9	1.7	94	1.5	12.0	155	12.0				3.8	212	-37.7	-92.7	-80.1	-536		
Balance 13A			ΔS	1734	8.45	32.70		1185			3319		0				685	-44.9	-96.5	-80.3	-2084	0	1390
30/9/96	8:00	3.371	54472	18597							62	12.0				4.0	219	-34.5	-90.8	-80.0	-446		
1/10/96	8:00	3.361	53853	18055							40	12.0				2.2	120	-37.5	-92.0	-79.9	-462		
2/10/96	8:00	3.354	53478	17679							36	12.0				1.9	101	-40.3	-95.3	-78.1	-311		
3/10/96	8:00	3.345	53014	17200	9.4	36.6					29	12.0				3.3	175	-36.0	-93.9	-76.2	-333		
Balance 13B			ΔS	-2000	8.85	36.25		0			167		0				615	-37.1	-93.0	-78.5	-1552	0	1605
4/10/96	8:00	3.340	52726	16936							112	12.0				3.4	178	-36.5	-95.7	-74.4	-198		
5/10/96	8:00	3.331	52207	16464							43	12.0				3.9	202	-34.9	-95.7	-72.5	-313		
6/10/96	8:00	3.322	51705	15996							36	12.0				3.3	170	-33.7	-95.7	-70.7	-334		
7/10/96	8:00	3.317	51440	15738	11.2	37.5					37	12.0				3.7	190	-32.1	-95.1	-68.8	-105		
Balance 13C			ΔS	-1462	10.30	37.05		0			228		0				741	-34.3	-95.6	-71.6	-949	691	2712
Totals			ΔS	-1728				1185			3714		0				2041				-4586	691	5707

	GW In m^3	Lake-GW m^3
Total balance period calculation	576	4712

Balance Period No: 14

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
7/10/96	8:00	3.317	51440	15738	11.2	37.5										3.7		-32.1	-95.1	-68.8			
8/10/96	8:00	3.310	51077	15379							28	12.0				4.5	231	-33.3	-96.9	-68.3	-156		
9/10/96	8:00	3.302	50653	14972							83	12.0				3.7	188	-38.9	-105.0	-67.7	-302		
10/10/96	8:00	3.309	51025	15328			4.5	230	0.4	12.0	373	12.0				3.0	150	-34.7	-99.5	-67.2	-97		
11/10/96	8:00	3.307	50921	15226	12.0	38.4	2.6	132	0.4	12.0	289	12.0				3.9	201	-32.3	-96.2	-66.6	-323		
Balance 14A			ΔS	-512	11.60	37.93		362			773		0				770	-34.8	-99.4	-67.4	-877	55	941
12/10/96	8:00	3.299	50495	14821							67	12.0				3.3	166	-30.7	-94.2	-66.1	-306		
13/10/96	8:00	3.295	50286	14619							40	12.0				3.7	186	-30.9	-95.0	-65.5	-56		
14/10/96	8:00	3.288	49931	14268			0.2	10.0	0.4	12.0	45	12.0				3.4	168	-34.4	-101.3	-65.0	-238		
15/10/96	8:00	3.284	49728	14069	14.0	39.2					97	12.0				2.7	135	-34.9	-99.3	-67.3	-161		
Balance 14B			ΔS	-1157	13.00	38.80		10			249		0				656	-32.7	-97.4	-66.0	-760	0	817
16/10/96	8:00	3.277	49373	13722							49	12.0				4.0	199	-29.6	-89.8	-69.7	-197		
17/10/96	8:00	3.271	49046	13427							64	12.0				3.9	194	-28.3	-86.5	-72.0	-165		
18/10/96	8:00	3.263	48539	13037							55	12.0				3.4	168	-31.6	-86.5	-74.4	-277		
19/10/96	8:00	3.258	48192	12795	15.8	40.1					53	12.0				3.4	167	-30.3	-82.7	-76.7	-128		
Balance 14C			ΔS	-1274	14.90	39.67		0			221		0				727	-30.0	-86.4	-73.2	-768	0	859
Totals			ΔS	-2943				372			1243		0				2153				-2405	55	2617

	GW In m^3	Lake-GW m^3
Total balance period calculation	0	2407

Balance Period No: 15

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
19/10/96	8:00	3.258	48192	12795	15.8	40.1										3.4		-30.3	-82.7	-76.7			
20/10/96	8:00	3.254	47900	12603							41	12.0				3.9	189	-30.2	-79.5	-79.1	-44		
21/10/96	8:00	3.288	49931	14268			15.0	749	-22.1	12.0	1686	12.0				5.5	269	-40.3	-82.5	-81.4	-501		
22/10/96	8:00	3.306	50867	15175			4.6	234	-22.1	12.0	642	12.0				1.9	95	-52.9	-88.5	-79.0	126		
23/10/96	8:00	3.331	52207	16464	14.0	41.7	10.2	533	-7.2	12.0	1165	12.0				4.2	216	-40.8	-89.0	-76.5	-193		
Balance 15A			ΔS	3669	14.90	40.88		1515			3534		0				768	-41.1	-84.9	-79.0	-612	512	1022
24/10/96	8:00	3.332	52262	16516			4.0	209	-7.2	12.0	505	12.0				3.4	180	-36.2	-89.4	-74.1	-482		
25/10/96	8:00	3.322	51705	15996							90	12.0				4.1	213	-30.4	-87.1	-71.6	-397		
26/10/96	8:00	3.313	51233	15533							69	12.0				4.2	215	-30.2	-88.4	-69.2	-317		
27/10/96	8:00	3.305	50814	15125	15.4	43.2					61	12.0				4.8	243	-31.0	-91.2	-66.7	-226		
Balance 15B			ΔS	-1339	14.70	42.45		209			725		0				851	-32.0	-89.0	-70.4	-1422	61	1479
28/10/96	8:00	3.298	50442	14770							42	12.0				4.8	241	-31.3	-93.7	-64.3	-156		
29/10/96	8:00	3.290	50032	14368							30	12.0				5.3	268	-30.4	-90.0	-67.0	-164		
30/10/96	8:00	3.282	49626	13970							70	12.0				5.2	262	-29.6	-86.6	-69.6	-206		
31/10/96	8:00	3.275	49270	13624	17.0	44.8	0.2	10	22.1	12.0	96	12.0				3.7	182	-34.9	-87.7	-72.3	-269		
Balance 15C			ΔS	-1501	16.20	44.02		10			238		0				953	-31.5	-89.5	-68.3	-796	0	886
Totals			ΔS	829				1734			4497		0				2572				-2830	573	3387

Lawn irrigation and East Lake top up commence sub balance 15A

	GW In m^3	Lake-GW m^3
Total balance period calculation	535	3276

Balance Period No: 16

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
31/10/96	8:00	3.275	49270	13624	17.0	44.8										3.7		-34.9	-87.7	-72.3			
1/11/96	8:00	3.269	48920	13329							72	12.0				4.3	209	-28.1	-80.4	-75.0	-158		
2/11/96	8:00	3.261	48400	12940							61	12.0				4.6	223	-26.8	-77.1	-77.7	-227		
3/11/96	8:00	3.253	47824	12555							52	12.0				5.0	241	-25.9	-74.0	-80.3	-196		
4/11/96	8:00	3.245	47091	12175	19.7	47.9					37	12.0				6.2	296	-23.7	-72.0	-83.0	-121		
Balance 16A			ΔS	-1449	18.35	46.37		0			222		0				969	-26.1	-75.9	-79.0	-702	11	717
5/11/96	8:00	3.235	46301	11708							46	12.0				7.2	337	-23.4	-74.5	-79.8	-176		
6/11/96	8:00	3.254	47900	12603			8.5	407	9.5	12.0	860	12.0				3.6	170	-29.4	-76.2	-76.5	-202		
7/11/96	8:00	3.272	49104	13476			5.0	246	9.5	12.0	800	12.0				0.4	20	-43.1	-86.0	-73.3	-153		
8/11/96	8:00	3.264	48606	13085	19.1	51.1					167	12.0				3.6	176	-33.6	-87.4	-70.0	-382		
Balance 16B			ΔS	910	19.40	49.50		653			1873		0				703	-32.4	-81.1	-74.9	-913	399	1319
9/11/96	8:00	3.255	47974	12650							47	12.0				4.6	222	-27.7	-85.6	-66.8	-260		
10/11/96	8:00	3.246	47177	12222							60	12.0				5.0	238	-25.5	-86.5	-63.5	-250		
11/11/96	8:00	3.237	46451	11801							43	12.0				6.2	292	-22.2	-83.9	-60.3	-172		
12/11/96	8:00	3.225	45547	11249	23.1	54.2					61	12.0				6.1	279	-21.3	-81.9	-62.5	-334		
Balance 16C			ΔS	-1836	21.10	52.63		0			211		0				1031	-24.2	-84.5	-63.3	-1016	0	1065
Totals			ΔS	-2375				653			2306		0				2703				-2631	410	3101

	GW In m^3	Lake-GW m^3
Total balance period calculation	375	3020

Balance Period No: 17

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
12/11/96	8:00	3.225	45547	11249	23.1	54.2										6.1		-21.3	-81.9	-62.5			
13/11/96	8:00	3.218	45010	10932			0.4	18	-24.9	12.0	93	12.0				5.0	226	-20.5	-79.6	-64.8	-202		
14/11/96	8:00	3.212	44548	10663			0.3	13	-24.9	12.0	82	12.0				4.0	180	-18.6	-75.1	-67.0	-184		
15/11/96	8:00	3.300	50547	14871			22.0	1112	-24.9	12.0	3907	12.0				4.4	211	-35.5	-89.5	-69.3	-600		
16/11/96	8:00	3.340	52726	16936	17.3	64.9	14.8	780	-24.9	12.0	2077	12.0				5.5	284	-38.7	-88.6	-71.5	-509		
Balance 17A			ΔS	5687	20.20	59.57		1924			6159		0				901	-28.3	-83.2	-68.2	-1495	1915	3119
17/11/96	8:00	3.325	51873	16151							26	12.0				4.1	214	-32.8	-82.0	-73.8	-597		
18/11/96	8:00	3.314	51285	15584												4.0	207	-31.2	-78.5	-76.0	-360		
19/11/96	8:00	3.304	50760	15074												4.6	234	-32.7	-77.2	-76.5	-276		
20/11/96	8:00	3.295	50286	14619	19.5	75.7					10	12.0				4.4	224	-31.9	-75.5	-77.0	-241		
Balance 17B			ΔS	-2317	18.40	70.30		0			36		0				880	-32.2	-78.3	-75.8	-1473	476	1944
21/11/96	8:00	3.283	49677	14019							11	12.0				4.7	234	-31.9	-74.9	-77.5	-377		
22/11/96	8:00	3.272	49104	13476												4.9	243	-32.5	-74.2	-77.9	-300		
23/11/96	8:00	3.262	48469	12988												5.1	248	-32.5	-73.7	-78.4	-240		
24/11/96	8:00	3.253	47824	12555	19.5	86.4	1.1	53	2.7	12.0	56	12.0				5.1	245	-29.4	-74.0	-78.9	-297		
Balance 17C			ΔS	-2064	19.50	81.03		53			67		0				969	-31.6	-74.2	-78.2	-1214	353	1605
Totals			ΔS	1306				1976			6262		0				2750				-4183	2744	6668

	GW In m^3	Lake-GW m^3
Total balance period calculation	2810	6719

Balance Period No: 18

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
24/11/96	8:00	3.253	47824	12555	19.5	86.4										5.1		-29.4	-74.0	-78.9			
25/11/96	8:00	3.243	46921	12081												5.7	268	-26.5	-73.1	-79.4	-206		
26/11/96	8:00	3.233	46150	11616												5.1	237	-27.1	-70.3	-80.4	-228		
27/11/96	8:00	3.225	45547	11249							12	12.0				5.0	229	-25.3	-68.8	-81.5	-150		
28/11/96	8:00	3.214	44701	10752	22.4	108.2					14	12.0				4.4	200	-25.3	-65.5	-82.5	-311		
Balance 18A			ΔS	-1803	20.95	97.30		0			26		0				934	-26.1	-69.4	-80.9	-895	801	1681
29/11/96	8:00	3.205	44026	10353							19	12.0				5.1	226	-25.6	-63.8	-83.5	-192		
30/11/96	8:00	3.198	43519	10047			0.7	30	-9.4	12.0	20	12.0				5.2	230	-26.9	-60.3	-84.5	-127		
1/12/96	8:00	3.196	43375	9960			3.3	143	-9.4	12.0	252	12.0				4.0	172	-29.5	-53.9	-85.6	-310		
2/12/96	8:00	3.192	43085	9787	22.8	130.0	2.5	108	-9.4	12.0	181	12.0				3.5	151	-28.4	-53.9	-86.6	-311		
Balance 18B			ΔS	-965	22.60	119.10		281			472		0				778	-27.6	-58.0	-85.1	-940	1142	2056
3/12/96	8:00	3.190	42941	9701			1.4	60	4.5	12.0	237	12.0				4.3	186	-23.1	-62.0	-85.0	-197		
4/12/96	8:00	3.178	42017	9192							13	12.0				5.2	220	-21.1	-63.3	-83.5	-302		
5/12/96	8:00	3.169	41290	8817							13	12.0				5.5	231	-20.2	-62.4	-81.9	-157		
6/12/96	8:00	3.158	40292	8368	26.2	156.0					20	12.0				5.5	226	-18.3	-63.7	-80.3	-243		
Balance 18C			ΔS	-1419	24.50	143.00		60			283		0				863	-20.7	-62.9	-82.7	-899	963	1831
7/12/96	8:00	3.149	39334	8009							21	12.0				5.5	218	-18.1	-63.9	-78.7	-162		
8/12/96	8:00	3.138	38247	7583							19	12.0				5.9	230	-18.0	-63.8	-77.2	-215		
9/12/96	8:00	3.131	37598	7317							29	12.0				5.2	196	-18.4	-62.8	-75.6	-99		
10/12/96	8:00	3.122	36811	6983	27.4	172.0					20	12.0				5.3	198	-17.8	-60.6	-77.3	-156		
Balance 18D			ΔS	-1385	26.80	164.00		0			89		0				842	-18.1	-62.8	-77.2	-632	17	675
Totals			ΔS	-5572				341			870		0				3417				-3367	2923	6243

	GW In m^3	Lake-GW m^3
Total balance period calculation	3080	6412

Balance Period No: 19

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
10/12/96	8:00	3.122	36811	6983	27.4	172.0										5.3		-17.8	-60.6	-77.3			
11/12/96	8:00	3.112	35961	6619							18	12.0				5.2	191	-17.3	-58.2	-79.1	-191		
12/12/96	8:00	3.120	36640	6909			5.8	213	-16.3	12.0	539	12.0				4.9	179	-16.7	-55.8	-80.8	-282		
13/12/96	8:00	3.114	36131	6691			0.5	18	-1.8	12.0	126	12.0				4.8	174	-16.5	-50.4	-82.6	-188		
14/12/96	8:00	3.106	35443	6404	28.7	187.0					26	12.0				5.1	182	-15.6	-51.4	-84.3	-131		
Balance 19A			ΔS	-579	28.05	179.50		231			709		0				727	-16.5	-54.0	-81.7	-792	965	1707
15/12/96	8:00	3.098	34741	6124							27	12.0				5.5	195	-14.4	-49.1	-86.1	-112		
16/12/96	8:00	3.085	33546	5680							27	12.0				8.1	275	-13.1	-52.5	-87.8	-196		
17/12/96	8:00	3.077	32820	5414							24	12.0				7.4	247	-12.1	-49.6	-87.8	-43		
18/12/96	8:00	3.065	31772	5027	31.3	195.0					28	12.0				8.1	263	-11.2	-52.1	-87.8	-152		
Balance 19B			ΔS	-1377	30.00	191.00		0			106		0				980	-12.7	-50.8	-87.4	-503		
19/12/96	8:00	3.053	30776	4651							25	12.0				8.0	250	-10.5	-54.7	-87.8	-151		
20/12/96	8:00	3.044	30013	4378							28	12.0				6.8	208	-9.1	-45.5	-87.7	-93		
21/12/96	8:00	3.035	29214	4111							49	12.0				6.5	191	-7.3	-36.5	-87.7	-125		
22/12/96	8:00	3.026	28432	3852	33.7	212.0										9.0	259	-7.4	-46.2	-87.7	-0.5		
Balance 19C			ΔS	-1175	32.50	203.50		0			102		0				908	-8.6	-45.7	-87.7	-369		
Totals			ΔS	-3131				231			917		0				2614				-1665		

Integrated balances end sub-balance 19A
Commencing sub-bal 19B West Lake breaks up into disjointed ponds

Balance Period No: 20

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
22/12/96	8:00	3.026	28432	3852	33.7	212										9.0		-7.4	-46.2	-87.7			
23/12/96	8:00	3.018	27706	3627												6.1	171	-5.6	-40.7	-87.7	-53.8		
24/12/96	8:00	3.010	26955	3409												8.3	228	-4.5	-41.5	-86.6	10.0		
25/12/96	8:00	3.001	26045	3170												7.0	185	-4.1	-45.4	-85.6	-53.8		
26/12/96	8:00	2.995	25409	3016	36.8	233										5.8	150	-2.6	-43.7	-84.5	-3.7		
Balance 20A			ΔS	-836	35.25	222.50		0			0		0				735	-4.2	-42.8	-86.1	-101.3		
27/12/96	8:00	2.989	24781	2865												5.8	147	-0.6	-40.7	-83.4	-4.4		
28/12/96	8:00	2.980	23815	2647												7.9	193	1.4	-38.3	-82.3	-25.4		
29/12/96	8:00	2.973	23011	2483												7.4	173	2.6	-38.5	-81.3	9.4		
30/12/96	8:00	2.965	22010	2303	40.1	254										5.8	131	5.0	-35.6	-80.2	-48.5		
Balance 20B			ΔS	-713	38.45	243.50		0			0		0				644	2.1	-38.3	-81.8	-69.0		
31/12/96	8:00	2.955	20700	2089												6.5	138	4.1	-37.8	-81.7	-75.9		
1/1/97	8:00	2.943	18984	1851												7.4	147	4.1	-37.8	-83.2	-91.1		
2/1/97	8:00	2.931	17410	1632												7.4	135	7.7	-27.8	-84.7	-84.2		
3/1/97	8:00	2.919	15969	1432	41.6	268										7.1	118	9.9	-21.2	-86.1	-81.6		
Balance 20C			ΔS	-871	40.85	261.00		0			0		0				538	6.4	-31.2	-83.9	-332.8		
Totals			ΔS	-2420				0			0		0				1917				-503.1	0	0

Balance Period No: 21

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
3/1/97	8:00	2.919	15969	1432	41.6	268										7.1		9.9	-21.2	-86.1			
4/1/97	8:00	2.906	14432	1235												8.3	126.8	10.1	-19.7	-87.6	-70.2		
5/1/97	8:00	2.897	13258	1110												7.5	104.0	7.9	-25.5	-89.1	-21.0		
6/1/97	8:00	2.890	12390	1020												6.0	77.6	6.5	-29.1	-90.6	-12.4		
7/1/97	8:00	2.880	11096	903	42	294										6.3	73.5	3.9	-38.4	-89.9	-43.5		
Balance 21A			ΔS	-529	41.80	281.00		0			0		0				381.9	7.1	-28.2	-89.3	-147.1		
8/1/97	8:00	2.870	9796	798												7.0	73.0	6.2	-34.1	-89.1	-32.0		
9/1/97	8:00	2.857	8371	680												6.6	59.7	10.8	-23.9	-88.4	-58.3		
10/1/97	8:00	2.847	7406	602												5.6	44.4	19.0	-5.3	-87.7	-33.6		
11/1/97	8:00	2.837	6525	532	44.8	348										6.7	46.5	19.0	-8.9	-87.0	-23.5		
Balance 21B			ΔS	-371	43.40	321.00		0			0		0				223.6	13.8	-18.1	-88.1	-147.4		
12/1/97	8:00	2.826	5604	465												8.1	49.3	19.9	-6.7	-86.2	-17.7		
13/1/97	8:00	2.828	5767	477												7.1	40.3	14.4	-20.0	-85.5	52.3		
14/1/97	8:00	2.811	4383	391												6.2	31.2	10.1	-28.4	-87.1	-54.8		
15/1/97	8:00	2.805	3947	366	43	304										5.4	22.6	11.0	-23.6	-88.7	-2.4		
Balance 21C			ΔS	-166	43.90	326.00		0			0		0				143.5	13.8	-19.7	-86.9	-22.5		
Totals			ΔS	-1066				0			0		0				749.0				-317.0	0	0

Balance Period No: 22

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
15/1/97	8:00	2.805	3947	366	43.0	304										5.4		11.0	-23.6	-88.7			
16/1/97	8:00	2.795	3321	329												5.8	21.2	10.5	-24.5	-90.3	-15.8		
17/1/97	8:00	2.783	2731	293												5.5	16.7	9.4	-27.4	-91.9	-19.3		
18/1/97	8:00	2.774	2340	271												6.8	17.2	13.5	-14.5	-93.5	-4.8		
19/1/97	8:00	2.768	2149	257	43.7	317										8.0	18.0	18.9	2.9	-95.1	4.0		
Balance 22A			ΔS	-109	43.35	310.50		0			0		0				73.2	13.1	-15.9	-92.7	-35.8		
20/1/97	8:00	2.761	1974	243			0.2	0.4	15.5	12.0						9.4	19.3	11.7	-16.3	-96.7	4.9		
21/1/97	8:00	2.756	1867	233												4.7	9.0	9.8	-21.4	-96.0	-1.0		
22/1/97	8:00	2.749	1760	220												5.6	10.2	5.6	-34.2	-95.3	-2.8		
23/1/97	8:00	2.741	1667	207	41.2	306										7.4	12.7	8.5	-22.8	-94.6	-0.3		
Balance 22B			ΔS	-50	42.45	311.50		0.4			0		0				51.3	8.9	-23.7	-95.7	0.9		
24/1/97	8:00	2.732	1573	192												10.4	16.9	7.9	-27.0	-93.9	1.9		
25/1/97	8:00	2.722	1478	177												7.4	11.3	9.6	-23.5	-93.2	-3.7		
26/1/97	8:00	2.718	1443	171												4.0	5.8	13.0	-15.0	-92.5	-0.2		
27/1/97	8:00	2.713	1399	164	42.2	304										5.2	7.4	9.2	-28.5	-91.8	0.4		
Balance 22C			ΔS	-43	41.70	305.00		0			0		0				41.4	9.9	-23.5	-92.9	-1.6		
Totals			ΔS	-202				0.4			0		0				165.8				-36.6	0	0

Balance Period No: 23

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
27/1/97	8:00	2.713	1399	164	42.2	304										5.2		9.2	-28.5	-91.8			
28/1/97	8:00	2.713	1399	164												6.0	8.5	7.9	-32.8	-91.0	8.5		
29/1/97	8:00	2.705	1331	153												7.1	9.7	7.6	-34.2	-90.2	-1.3		
30/1/97	8:00	2.698	1268	144												5.5	7.2	15.0	-14.4	-89.4	-1.8		
31/1/97	8:00	2.691	1201	135	41.6	308										6.8	8.4	11.2	-25.5	-88.7	-0.6		
Balance 23A			ΔS	-29	41.90	306.00		0			0		0				33.7	10.4	-26.7	-89.8	4.7		
1/2/97	8:00	2.685	1129	128												5.1	6.0	10.0	-28.5	-87.9	-1.0		
2/2/97	8:00	2.679	1080	122												6.9	7.6	13.9	-18.2	-87.1	1.6		
3/2/97	8:00	2.672	1028	114												3.4	3.6	23.5	6.7	-86.3	-4.4		
4/2/97	8:00	2.668	1000	110	39.6	318										3.8	3.8	18.8	-4.3	-86.1	-0.2		
Balance 23B			ΔS	-25	40.60	313.00		0			0		0				21.0	16.5	-11.1	-86.9	-4.0		
5/2/97	8:00	2.658	945	100												7.1	6.9	9.8	-29.6	-86.0	-3.1		
6/2/97	8:00	2.648	890	91.3												5.8	5.4	10.6	-29.4	-85.8	-3.3		
7/2/97	8:00	2.639	833	83.6												5.8	5.0	12.8	-25.5	-85.7	-2.7		
8/2/97	8:00	2.630	772	76.4	41	330										6.2	4.9	15.6	-20.6	-85.5	-2.3		
Balance 23C			ΔS	-33.6	40.30	324.00		0			0		0				22.2	12.2	-26.3	-85.8	-11.4		
Totals			ΔS	-87.6				0			0		0				76.9				-10.7	0	0

Balance Period No: 24

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
8/2/97	8:00	2.630	772	76.4	41.0	330										6.2		15.6	-20.6	-85.5			
9/2/97	8:00	2.623	728	71.1												5.3	4.0	9.5	-35.2	-85.4	-1.3		
10/2/97	8:00	2.618	698	67.6												4.8	3.4	14.7	-23.9	-85.2	-0.1		
11/2/97	8:00	2.615	679	65.5												6.7	4.6	11.3	-32.1	-85.1	2.5		
12/2/97	8:00	2.609	646	61.5	40.7	331										5.7	3.8	11.2	-32.6	-85.0	-0.2		
Balance 24A			ΔS	-14.9	40.85	330.50		0			0		0				15.8	11.7	-30.9	-85.2	0.9		
13/2/97	8:00	2.606	630	59.6												5.2	3.3	15.4	-23.0	-84.9	1.4		
14/2/97	8:00	2.598	591	54.7												6.3	3.8	13.7	-26.3	-84.7	-1.1		
15/2/97	8:00	2.595	577	53.0												5.2	3.0	10.4	-33.3	-84.6	1.3		
16/2/97	8:00	2.590	554	50.1	38.8	323										4.5	2.5	13.2	-26.6	-84.5	-0.4		
Balance 24B			ΔS	-11.4	39.75	327.00		0			0		0				12.7	13.2	-27.3	-84.7	1.3		
17/2/97	8:00	2.588	544	49.0												6.2	3.4	15.5	-20.2	-84.4	2.3		
18/2/97	8:00	2.586	535	48.0												4.6	2.5	10.0	-30.7	-85.6	1.5		
19/2/97	8:00	2.584	526	46.9												6.5	3.4	12.1	-22.5	-86.9	2.3		
20/2/97	8:00	2.585	530	47.4	36.3	306	0.2	0.1	15.2	12.0						2.9	1.5	12.0	-19.1	-88.1	1.9		
Balance 24C			ΔS	-2.7	37.55	314.50		0			0		0				10.8	12.4	-23.1	-86.3	8.0		
Totals			ΔS	-29				0.1			0		0				39.4				10.3	0	0

Balance Period No: 25

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
20/2/97	8:00	2.585	530	47.4	36.3	306										2.9		12.0	-19.1	-88.1			
21/2/97	8:00	2.581	512	45.3												4.7	2.4	7.3	-22.6	-89.4	0.3		
22/2/97	8:00	2.581	512	45.3												3.9	2.0	2.2	-27.5	-90.6	2.0		
23/2/97	8:00	2.577	495	43.3												2.7	1.4	-3.4	-37.4	-91.9	-0.6		
24/2/97	8:00	2.583	521	46.4	27.7	266	1.1	0.6	-25.2	12.0	131	12.0				2.5	1.2	-3.3	1.8	-93.1	3.8	refer note	
Balance 25A			ΔS	-1	32.00	286.00		0.6			131		0				7.0	0.7	-21.4	-91.2	5.5		
25/2/97	8:00	2.590	554	50.1												2.3	1.2	-2.7	-5.8	-92.6	4.9		
26/2/97	8:00	2.585	530	47.4												1.3	0.7	-4.2	-28.4	-92.2	-2.0		
27/2/97	8:00	2.574	482	41.9												4.7	2.4	-4.2	-35.7	-91.7	-3.1		
28/2/97	8:00	2.562	429	36.4	28.8	258										5.2	2.4	-3.3	-35.9	-91.2	-3.1		
Balance 25B			ΔS	-10	28.25	262.00		0			0		0				6.7	-3.6	-26.5	-91.9	-3.3		
1/3/97	8:00	2.548	366	30.8												6.9	2.7	-4.4	-52.0	-90.7	-2.9		
2/3/97	8:00	2.543	345	29.1												2.5	0.9	2.4	-30.1	-90.3	-0.8		
3/3/97	8:00	2.540	333	28.1												6.0	2.1	2.1	-38.6	-89.8	1.1		
4/3/97	8:00	2.540	333	28.1	32.8	270										6.4	2.1	1.2	-48.1	-87.4	2.1		
Balance 25C			ΔS	-8.3	30.80	264.00		0			0		0				7.8	0.3	-42.2	-89.5	-0.5		
Totals			ΔS	-19.3				0.6			131		0				21.5				1.6	0	0

Drain mass excluded from 25A, no water reached SW pond

Balance Period No: 26

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
4/3/97	8:00	2.540	333	28.1	32.8	270										6.4		1.2	-48.1	-87.4			
5/3/97	8:00	2.545	353	29.8												4.7	1.6	-0.1	-51.1	-84.9	3.3		
6/3/97	8:00	2.547	361	30.5												5.1	1.8	-0.6	-52.0	-82.5	2.5		
7/3/97	8:00	2.548	366	30.8			0.2	0.1	34.4	12.0	20	12.0				6.3	2.3	-1.3	-53.9	-80.1	2.5	refer note	
8/3/97	8:00	2.547	361	30.5	28.4	217										3.8	1.4	-3.6	-59.7	-77.7	1.1		
Balance 26A			ΔS	2.4	30.60	243.50		0.1			20		0				7.1	-1.4	-54.2	-81.3	9.4		
9/3/97	8:00	2.550	374	31.6												5.8	2.1	-3.0	-61.1	-75.2	3.2		
10/3/97	8:00	2.547	361	30.5												4.4	1.6	-1.8	-63.1	-72.8	0.5		
11/3/97	8:00	2.547	361	30.5												5.6	2.0	-2.0	-61.7	-74.1	2.0		
12/3/97	8:00	2.538	325	27.4	27.1	202										4.7	1.6	-4.9	-64.2	-75.3	-1.5		
Balance 26B			ΔS	-3.1	27.75	209.50		0			0		0				7.4	-2.9	-62.5	-74.4	4.3		
13/3/97	8:00	2.531	296	25.2												4.7	1.5	-4.1	-63.1	-76.6	-0.7		
14/3/97	8:00	2.523	260	23												3.3	0.9	-1.1	-58.1	-77.9	-1.3		
15/3/97	8:00	2.512	215	20.4												6.7	1.6	-1.4	-59.0	-79.2	-1.0		
16/3/97	8:00	2.511	212	20.2	30.0	221					106					5.8	1.2	4.9	-47.7	-80.4	1.0	refer note	
Balance 26C			ΔS	-7.2	28.55	211.50		0			106		0				5.2	-0.4	-57.0	-78.5	-2.0		
Totals			ΔS	-7.9				0.1			126		0				19.7				11.7	0	0

Drain flow is seepage from lawn and road verge irrigation

Drain mass excluded from 26A and 26C, no water reached SW pond

Balance Period No: 27 **West Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
16/3/97	8:00	2.511	212	20.2	30.0	221										5.8		4.9	-47.7	-80.4			
17/3/97	8:00	2.733	1583	194			4.5	7.1	-3.4	12.0	628		330	-10.3	186	4.0	3.6	-86.4	-134.7	-81.7	-159.7	refer note	
18/3/97	8:00	2.682	1103	125							12					3.9	5.2	-73.0	-123.9	-81.8	-63.8		
19/3/97	8:00	2.640	841	84.4												4.8	4.7	-62.3	-115.3	-81.8	-35.9		
20/3/97	8:00	2.600	600	55.9	-1.1	240										3.9	2.8	-60.9	-113.0	-81.9	-25.7		
Balance 27A			ΔS	35.7	14.45	230.50		7.1			640		330				16.2	-70.6	-121.7	-81.8	-285.2		
21/3/97	8:00	2.565	443	37.7												3.3	1.7	-57.1	-109.1	-81.9	-16.5		
22/3/97	8:00	2.536	318	26.8												6.0	2.3	-55.1	-106.0	-82.0	-8.6		
23/3/97	8:00	2.522	256	22.7												3.5	1.0	-44.5	-98.3	-82.0	-3.1		
24/3/97	8:00	2.515	225	21.1	7.4											4.5	1.1	-40.9	-94.3	-82.1	-0.5		
Balance 27B			ΔS	-34.8	3.15	0.00		0			0		0				6.1	-49.4	-101.9	-82.0	-28.7		
25/3/97	8:00	2.523	260	23.0												2.8	0.7	-39.7	-93.5	-81.2	2.6		
26/3/97	8:00	2.522	256	22.7												5.0	1.3	-34.4	-90.8	-80.3	1.0		
27/3/97	8:00	2.523	260	23.0												3.4	0.9	-28.5	-87.7	-79.4	1.2		
28/3/97	8:00	2.521	251	22.5	13.1											3.9	1.0	-23.5	-84.9	-78.4	0.5		
Balance 27C			ΔS	1.4	10.25	0.00		0			0		0				3.8	-31.5	-89.2	-79.8	5.2		
Totals			ΔS	2.3				7.1			640		330				26.2				-309	0	0

Drain mass excluded from 27A, no water reached SW pond

Balance Period No: 28

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
28/3/97	8:00	2.521	251	22.5	13.1											3.9		-23.5	-84.9	-78.4			
29/3/97	8:00	2.552	383	32.3			16.0	6	-12.0		2060					2.6	0.8	-26.3	-86.9	-77.5	-2056		
30/3/97	8:00	3.125	37069	7093			40.2	1490	-12.0		6651		3530	-16.8	149	2.6	49	-148.9	-210.2	-76.6	-4562		
31/3/97	8:00	3.077	32820	5414							80					2.5	87	-91.7	-156.7	-75.7	-1672		
1/4/97	8:00	3.034	29127	4082	-6.8						21					3.9	120	-89.8	-143.5	-80.9	-1233		
Balance 28A			ΔS	4059.5	3.15	0.00		1496			8812		3530				257	-89.2	-149.3	-77.7	-9522		
2/4/97	8:00	3.000	25939	3144							26					3.0	83	-62.4	-115.7	-86.2	-881		
3/4/97	8:00	2.973	23011	2483							18					3.9	94	-61.2	-109.4	-91.4	-585		
4/4/97	8:00	2.940	18561	1794			0.5	9	-26.1		29					3.1	64	-72.9	-105.3	-96.6	-663		
5/4/97	8:00	2.908	14674	1264	-6.5						28					2.8	47	-85.1	-95.5	-101.8	-511		
Balance 28B			ΔS	-2818	-6.65	0.00		9			101		0				289	-70.4	-106.5	-94.0	-2639		
6/4/97	8:00	2.895	13008	1084			4.7	61	-39.5		709					1.8	26	-91.8	-83.4	-107.1	-925		
7/4/97	8:00	2.875	10465	849			0.3	3.1	-40.2		15					4.2	49	-93.5	-71.3	-112.3	-204		
8/4/97	8:00	2.926	16818	1547			5.9	99	-40.2		1905					1.3	17	-102.0	-81.7	-107.7	-1289		
9/4/97	8:00	2.903	14060	1192	-8.0						27					4.7	72	-75.2	-98.2	-103.1	-310		
Balance 28C			ΔS	-72	-7.25	0.00		164			2656		0				164	-90.6	-83.7	-107.5	-2727		
Totals			ΔS	1169.5				1669			11569		3530				710				-14889	0	0

Balance Period No: 29

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
9/4/97	8:00	2.903	14060	1192	-8.0											4.7		-75.2	-98.2	-103.1			
10/4/97	8:00	2.876	10592	859							21					2.8	34.7	-83.1	-106.2	-98.5	-319		
11/4/97	8:00	2.854	8079	656			4.5	36.4	-71.0		452					1.7	15.8	-102.5	-121.1	-93.8	-676		
12/4/97	8:00	2.824	5439	454			0.5	2.7	-71.0		170					1.9	12.6	-68.7	-117.5	-89.2	-362		
13/4/97	8:00	2.801	3689	350	-7.1		0.2	0.7	-71.0		12					3.2	14.7	-61.0	-119.0	-84.6	-102		
Balance 29A			ΔS	-842	-7.55	0.00		39.8			655		0				77.9	-78.9	-116.0	-91.5	-1459		
14/4/97	8:00	2.781	2639	288												4.2	13.2	-64.3	-127.6	-80.0	-48.8		
15/4/97	8:00	2.753	1813	228												2.8	6.3	-64.9	-126.2	-81.4	-53.7		
16/4/97	8:00	2.744	1698	212												3.3	5.9	-60.4	-120.4	-82.9	-10.1		
17/4/97	8:00	2.725	1505	181	-4.3						60					1.8	2.8	-62.6	-119.8	-84.3	-88.2		
Balance 29B			ΔS	-169	-5.70	0.00		0			60		0				28.2	-63.1	-123.5	-82.1	-201		
18/4/97	8:00	2.710	1374	160												3.0	4.4	-62.7	-117.3	-85.7	-16.6		
19/4/97	8:00	2.693	1222	138												2.1	2.7	-64.2	-115.3	-87.1	-19.3		
20/4/97	8:00	2.682	1103	125												2.6	3.0	-60.8	-110.5	-88.6	-10.0		
21/4/97	8:00	2.698	1268	144	-2.3		8.9	11	-8.0		1702					3.4	4.0	-67.0	-109.6	-90.0	-1690		
Balance 29C			ΔS	-37	-3.30	0.00		11			1702		0				14.1	-63.7	-113.2	-87.9	-1736		
Totals			ΔS	-1048				51.1			2417		0				120				-3396	0	0

Balance Period No: 30

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
21/4/97	8:00	2.698	1268	144	-2.3											3.4		-67.0	-109.6	-90.0			
22/4/97	8:00	2.710	1374	160							27					1.7	2.2	-49.2	-104.5	-88.5	-8.8		
23/4/97	8:00	2.710	1374	160												2.3	3.2	-50.3	-106.6	-87.0	3.2		
24/4/97	8:00	2.708	1357	157												1.9	2.6	-51.8	-109.4	-85.5	-0.4		
25/4/97	8:00	2.695	1241	140	-0.4						30					2.9	3.8	-50.4	-110.7	-84.1	-43.2		
Balance 30A			ΔS	-4.0	-1.35	0.00		0			57		0				11.7	-50.4	-107.8	-86.3	-49.3		
26/4/97	8:00	2.695	1241	140												2.3	2.8	-54.0	-115.7	-82.6	2.8		
27/4/97	8:00	2.678	1073	121			0.2	0.2	7.9		33					2.3	2.6	-57.7	-122.2	-81.1	-49.6		
28/4/97	8:00	2.671	1021	113							24					1.7	1.7	-38.5	-106.7	-79.6	-30.3		
29/4/97	8:00	2.658	945	101	3.5						10					4.0	3.9	-38.3	-106.2	-80.1	-18.1		
Balance 30B			ΔS	-39	1.55	0.00		0.2			67		0				11.1	-47.1	-112.7	-80.8	-95.1		
30/4/97	8:00	2.656	934	98.6			3.5	3.3	7.9		328					2.0	1.9	-53.7	-120.8	-80.5	-332		
1/5/97	8:00	2.672	1028	114			6.5	6.7	4.0		779					1.2	1.2	-67.4	-132.9	-81.0	-769		
2/5/97	8:00	2.677	1066	120							17					1.9	2.0	-35.6	-102.5	-81.4	-9.0		
3/5/97	8:00	2.686	1141	129	3.4		6.5	7.4	-5.8		677					2.6	2.8	-41.9	-107.7	-81.9	-673		
Balance 30C			ΔS	28	3.45	0.00		17.4			1801		0				7.9	-49.6	-116.0	-81.2	-1782		
Totals			ΔS	-15.0				17.6			1925		0				30.7				-1927	0	0

Balance Period No: 31

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
3/5/97	8:00	2.686	1141	129	3.4											2.6		-41.9	-107.7	-81.9			
4/5/97	8:00	2.689	1179	133							57					1.7	1.9	-34.4	-100.6	-82.3	-51		
5/5/97	8:00	2.687	1154	131												2.9	3.4	-31.7	-97.8	-82.8	1		
6/5/97	8:00	2.681	1095	124												1.7	1.9	-31.4	-90.2	-88.3	-5		
7/5/97	8:00	2.674	1043	116	6.0											2.9	3.1	-26.2	-84.1	-93.8	-5		
Balance 31A			ΔS	-13	4.70	0.00		0			57		0				10.3	-30.9	-93.2	-86.8	-60		
8/5/97	8:00	2.660	955	102												4.6	4.6	-25.1	-80.4	-99.3	-9		
9/5/97	8:00	2.652	912	95												3.4	3.2	-25.7	-74.3	-104.9	-4		
10/5/97	8:00	2.648	890	91.3												2.1	1.9	-27.1	-63.8	-110.4	-2		
11/5/97	8:00	2.644	866	87.8	6.3											2.1	1.8	-30.0	-44.6	-115.9	-2		
Balance 31B			ΔS	-28.2	6.15	0.00		0			0		0				11.5	-27.0	-65.8	-107.6	-17		
12/5/97	8:00	2.644	866	87.8			1.2	1.0	-50.5		140					0.8	0.7	-42.5	3.2	-121.4	-140		
13/5/97	8:00	2.651	907	94.0			2.5	2.3	-50.5		280					0.7	0.6	-78.7	110.5	-120.7	-275		
14/5/97	8:00	2.643	860	87.0							57					2.5	2.2	-43.2	-28.6	-120.0	-62		
15/5/97	8:00	2.640	841	84.4	1.7						27					2.2	1.9	-45.4	-35.6	-119.3	-28		
Balance 31C			ΔS	-3.4	4.00	0.00		3.3			504		0				5.4	-52.5	12.4	-120.4	-505		
Totals			ΔS	-44.6				3.3			561		0				27.2				-582	0	0

Balance Period No: 32

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
15/5/97	8:00	2.640	841	84.4	1.7											2.2		-45.4	-35.6	-119.3			
16/5/97	8:00	2.636	812	81.1							41					1.7	1.4	-49.9	-28.4	-118.7	-43		
17/5/97	8:00	2.633	792	78.7							74					1.9	1.5	-47.3	-38.5	-118.0	-75		
18/5/97	8:00	2.644	866	87.8			2.7	2.3	-35.5		231					1.1	0.9	-65.4	-3.2	-117.3	-223		
19/5/97	8:00	2.657	939	99.6	0.5		4.5	4.2	-35.5		722					1.7	1.6	-48.7	-42.8	-116.6	-713		
Balance 32A			ΔS	15.2	1.10	0.00		6.6			1068		0				5.4	-52.8	-28.2	-117.6	-1054		
20/5/97	8:00	2.665	982	107							106					0.9	0.9	-54.3	-42.8	-112.7	-98		
21/5/97	8:00	2.659	950	102							76					2.3	2.2	-39.7	-73.1	-108.8	-79		
22/5/97	8:00	2.656	934	98.6							27					2.9	2.8	-46.8	-72.2	-104.9	-28		
23/5/97	8:00	2.666	988	108	-0.1						952					3.1	3.0	-45.1	-81.5	-100.9	-940		
Balance 32B			ΔS	8.4	0.20	0.00		0.0			1161		0				8.9	-46.5	-67.4	-106.8	-1144		
24/5/97	8:00	2.744	1698	212			14.8	25.1	-3.0		992					1.3	1.8	-55.1	-87.3	-97.0	-911		
25/5/97	8:00	2.764	2044	249			5.2	10.6	-3.0		539					1.5	2.8	-67.6	-99.9	-93.1	-510		
26/5/97	8:00	2.758	1907	237			0.2	0.4	-7.5		102					1.6	3.1	-45.8	-104.7	-89.2	-111		
27/5/97	8:00	2.750	1772	222	-1.3		0.3	0.5	-7.5		131					1.8	3.2	-54.9	-106.1	-90.6	-143		
Balance 32C			ΔS	114	-0.70	0.00		36.7			1764		0				10.9	-55.8	-99.5	-92.5	-1676		
Totals			ΔS	137.6				43.2			3993		0				25.1				-3874	0	0

Balance Period No: 33 **West Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
27/5/97	8:00	2.750	1772	222	-1.3											1.8		-54.9	-106.1	-90.6			
28/5/97	8:00	2.892	12636	1045			16.8	212	-7.5		2113					1.4	10	-58.2	-103.7	-92.0	-1492		
29/5/97	8:00	2.890	12390	1020							117					3.0	38	-44.0	-97.9	-93.4	-104		
30/5/97	8:00	2.855	8177	664							114					2.2	23	-39.6	-95.6	-94.9	-447		
31/5/97	8:00	3.050	30521	4560	-1.4		32.9	1004	-3.0		4485					3.5	68	-56.5	-92.5	-96.3	-1525		
Balance 33A			ΔS	4338	-1.35	0.00		1216			6829		0				138	-49.6	-97.4	-94.2	-3569		
1/6/97	8:00	3.067	31941	5091			11.0	351	-21.0		1748					0.7	22	-73.9	-92.0	-97.7	-1546		
2/6/97	8:00	3.187	42721	9573			29.2	1247	-21.0		4991					1.7	65	-128.0	-87.5	-99.1	-1691		
3/6/97	8:00	3.164	40865	8611			2.6	106	-21.0		415					3.1	130	-72.7	-101.5	-97.9	-1353		
4/6/97	8:00	3.155	39992	8247	-6.7		9.2	368	-1.3		945					0.2	7	-65.9	-107.3	-96.7	-1670		
Balance 33B			ΔS	3687	-4.05	0.00		2073			8099		0				225	-85.1	-97.0	-97.8	-6260		
5/6/97	8:00	3.145	38932	7853			4.5	175	-1.3		671					1.9	77	-68.2	-110.3	-95.5	-1164		
6/6/97	8:00	3.126	37156	7130			1.7	63	-0.5		274					0.0	1	-104.1	-125.0	-94.3	-1060		
7/6/97	8:00	3.102	35091	6263			1.1	39	-0.5		144					0.2	6	-109.7	-132.4	-93.1	-1043		
8/6/97	8:00	3.127	37243	7168	-6.3		10.5	391	-41.4		1491					2.0	71	-67.1	-117.9	-91.9	-906		
Balance 33C			ΔS	-1079	-6.50	0.00		668			2580		0				155	-87.2	-121.4	-93.7	-4172		
9/6/97	8:00	3.179	42098	9234			12.4	522	-41.4		3084					0.9	36	-71.8	-123.6	-90.7	-1504		
10/6/97	8:00	3.153	39767	8168							23					2.6	107	-58.1	-116.4	-90.6	-982		
11/6/97	8:00	3.148	39231	7970			6.4	251	-4.0		705					0.5	18	-82.7	-130.7	-90.6	-1136		
12/6/97	8:00	3.147	39130	7931	-7.0		5.7	223	-4.0		809					0.3	12	-70.3	-124.1	-90.5	-1059		
Balance 33D			ΔS	763	-6.65	0.00		996			4621		0				172	-70.7	-123.7	-90.6	-4682		
13/6/97	8:00	3.129	37419	7242			0.2	7	-4.0		67					1.4	55	-85.0	-134.1	-90.5	-708		
14/6/97	8:00	3.107	35532	6440							28					1.8	65	-54.7	-116.7	-90.4	-765		
15/6/97	8:00	3.085	33546	5680							23					2.4	83	-50.6	-114.8	-90.4	-700		
16/6/97	8:00	3.068	32026	5122	-10.3						29					1.9	62	-62.7	-123.3	-90.3	-525		
Balance 33E			ΔS	-2809	-8.65	0.00		7			147		0				264	-63.2	-122.2	-90.4	-2699		
Totals			ΔS	4900				4961			22276		0				954				-21383	0	0

Balance Period No: 34

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
16/6/97	8:00	3.068	32026	5122	-10.3											1.9		-62.7	-123.3	-90.3			
17/6/97	8:00	3.052	30691	4621							16					1.8	56	-71.6	-130.5	-89.5	-461		
18/6/97	8:00	3.038	29477	4199							24					2.9	88	-57.5	-121.7	-88.7	-358		
19/6/97	8:00	3.025	28344	3824			1.4	40	4.2		100					1.3	38	-72.4	-134.1	-87.9	-477		
20/6/97	8:00	3.016	27522	3572	-9.2		2.0	55	4.2		131					1.9	53	-71.9	-135.3	-87.1	-385		
Balance 34A			ΔS	-1550	-9.75	0.00		95			271		0				234	-68.3	-130.4	-88.3	-1681		
21/6/97	8:00	3.005	26459	3275			1.8	48	4.2		170					1.0	26	-91.1	-153.2	-86.3	-488		
22/6/97	8:00	2.996	25513	3041			0.2	5	-0.1		39					1.0	27	-75.5	-135.1	-88.2	-251		
23/6/97	8:00	2.991	24991	2915			2.5	62	-0.1		248					1.4	35	-89.5	-138.8	-90.1	-402		
24/6/97	8:00	2.983	24142	2718	-7.8						54					0.8	20	-63.5	-127.6	-87.2	-231		
Balance 34B			ΔS	-854	-8.50	0.00		115			511		0				108	-79.9	-138.7	-88.0	-1372		
25/6/97	8:00	2.974	23130	2506			0.2	5	13.8		40					1.3	32	-73.8	-143.1	-84.3	-225		
26/6/97	8:00	2.965	22010	2303							24					1.1	26	-68.6	-144.3	-81.4	-201		
27/6/97	8:00	2.956	20839	2110							25					1.1	25	-69.9	-137.1	-85.3	-193		
28/6/97	8:00	2.948	19720	1947	-8.3						22					1.7	34	-81.7	-136.7	-89.2	-151		
Balance 34C			ΔS	-771	-8.05	0.00		5			111		0				116	-73.5	-140.3	-85.0	-770		
Totals			ΔS	-3175				215			893		0				459				-3823	0	0

Balance Period No: 35

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
28/6/97	8:00	2.948	19720	1947	-8.3											1.7		-81.7	-136.7	-89.2			
29/6/97	8:00	2.940	18561	1794							24					0.7	14	-71.4	-120.4	-93.0	-163		
30/6/97	8:00	2.933	17650	1668							26					1.8	32	-52.6	-106.5	-96.9	-120		
1/7/97	8:00	2.925	16695	1530							25					2.1	36	-46.0	-105.2	-96.3	-127		
2/7/97	8:00	2.918	15849	1416	-7.5						25					2.5	41	-41.9	-104.3	-95.7	-98		
Balance 35A			ΔS	-531	-7.90	0.00		0			100		0				123	-53.0	-109.1	-95.5	-508		
3/7/97	8:00	2.938	18298	1757			8.0	146	-44.2		844					2.6	44	-53	-109.4	-95.1	-605.4		
4/7/97	8:00	2.955	20700	2089							28					2.1	41	-104	-132.0	-94.6	344.7		
5/7/97	8:00	2.947	19568	1928			0.3	6	-15.2		81					1.6	31	-122	-144.3	-94.0	-216.6		
6/7/97	8:00	3.057	31110	4775	-10.8		19.0	591	-15.2		3429					1.5	39	-129	-152.7	-93.4	-1134.0		
Balance 35B			ΔS	3359	-9.15	0.00		743			4382		0				155	-102.2	-134.6	-94.3	-1611		
7/7/97	8:00	3.107	35532	6440			11.0	391	-15.2		1678					2.4	80	-80.9	-129.8	-92.8	-324		
8/7/97	8:00	3.094	34386	5985			3.0	103	2.9		254					0.5	19	-60.6	-123.6	-89.3	-793		
9/7/97	8:00	3.138	38247	7583			8.6	329	-14.7		1950					1.2	44	-67.3	-118.5	-95.8	-637		
10/7/97	8:00	3.118	36470	6836	-12.2						17					2.2	82	-64.7	-108.8	-102.3	-682		
Balance 35C			ΔS	2061	-11.50	0.00		823			3899		0				225	-68.4	-120.2	-95.1	-2436		
Totals			ΔS	4889				1566			8381		0				502				-4556	0	0

Balance Period No: 36

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
10/7/97	8:00	3.118	36470	6836	-12.2											2.2		-64.7	-108.8	-102.3			
11/7/97	8:00	3.103	35179	6299							24					1.0	37	-60.0	-111.2	-99.4	-524		
12/7/97	8:00	3.088	33838	5781							18					2.5	86	-61.4	-114.9	-96.5	-450		
13/7/97	8:00	3.110	35792	6547			14.5	519	-0.4		2458					0.5	19	-106.8	-141.2	-93.6	-2192		
14/7/97	8:00	3.157	40193	8328	-11.3		6.3	253	-0.4		1240					0.6	22	-121.2	-159.7	-90.7	309		
Balance 36A			ΔS	1492	-11.75	0.00		772			3740		0				164	-87.3	-131.8	-95.1	-2856		
15/7/97	8:00	3.140	38445	7659							20					2.0	78	-58.4	-128.8	-83.0	-611		
16/7/97	8:00	3.125	37069	7093							10					2.5	95	-58.9	-138.3	-75.2	-481		
17/7/97	8:00	3.112	35961	6619							10					1.7	61	-54.6	-139.1	-68.4	-423		
18/7/97	8:00	3.100	34916	6193	-11.0						9					1.9	67	-55.5	-137.8	-71.0	-368		
Balance 36B			ΔS	-2135	-11.15	0.00		0			49		0				300	-56.9	-136.0	-74.4	-1884		
19/7/97	8:00	3.087	33738	5747							15					1.5	50	-59.4	-140.7	-73.6	-411		
20/7/97	8:00	3.077	32820	5414							15					1.0	35	-60.0	-138.3	-76.1	-313		
21/7/97	8:00	3.068	32026	5122							15					1.8	57	-56.1	-130.3	-78.7	-250		
22/7/97	8:00	3.059	31275	4838	-10.0						13					2.1	66	-50.4	-125.3	-76.6	-231		
Balance 36C			ΔS	-1355	-10.50	0.00		0			58		0				208	-56.5	-133.6	-76.2	-1205		
Totals			ΔS	-1998				772			3847		0				672				-5945	0	0

Balance Period No: 37

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
22/7/97	8:00	3.059	31275	4838	-10.0											2.1		-50.4	-125.3	-76.6			
23/7/97	8:00	3.051	30606	4590							13					2.8	87	-47.4	-120.0	-78.5	-174		
24/7/97	8:00	3.069	32111	5155			8.0	257	-13.6		609					2.6	81	-65.7	-138.5	-80.4	-220		
25/7/97	8:00	3.099	34828	6158			9.1	317	-13.6		1111					2.2	74	-95.4	-164.7	-82.3	-351		
26/7/97	8:00	3.093	34297	5951	-8.6		1.8	62	-11.8		252					1.4	48	-97.2	-159.9	-84.2	-473		
Balance 37A			ΔS	1113	-9.30	0.00		636			1985		0				290	-76.4	-145.8	-81.4	-1218		
27/7/97	8:00	3.109	35706	6511			6.5	232	-11.8		805					1.1	38	-96.6	-152.5	-86.1	-439		
28/7/97	8:00	3.099	34828	6158							33					2.2	77	-69.6	-126.9	-88.0	-309		
29/7/97	8:00	3.090	34025	5849			1.0	34	-3.8		34					2.2	75	-76.5	-134.3	-86.7	-302		
30/7/97	8:00	3.081	33181	5546							10					1.8	60	-68.6	-130.5	-85.4	-253		
Balance 37B			ΔS	-405	-4.30	0.00		266			882		0				250	-77.8	-136.1	-86.5	-1303		
31/7/97	8:00	3.073	32456	5284	-6.6						8					1.6	51	-63.3	-128.3	-84.0	-219		
1/8/97	8:00	3.065	31772	5027							8					2.3	74	-62.3	-129.3	-82.7	-191		
2/8/97	8:00	3.057	31110	4775							9					2.9	92	-56.5	-125.6	-81.4	-169		
3/8/97	8:00	3.052	30691	4621	-4.7						8					0.7	23	-68.6	-125.3	-86.6	-139		
Balance 37C			ΔS	-925	-2.35	0.00		0			33		0				239	-62.7	-127.1	-83.7	-719		
Totals			ΔS	-217				902			2900		0				779				-3240	0	0

Balance Period No: 38

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE$_{pan}$	δE*	δA		m^3	m^3
3/8/97	8:00	3.052	30691	4621	-4.7											0.7		-68.6	-125.3	-86.6			
4/8/97	8:00	3.119	36555	6872			19.5	713	-14.0		1894					1.3	43	-102.7	-126.3	-91.8	-313		
5/8/97	8:00	3.140	38445	7659			7.0	269	-10.5		1002					2.8	106	-73.6	-113.6	-92.4	-378		
6/8/97	8:00	3.138	38247	7583			2.7	103	-2.8		301					1.9	72	-64.5	-109.3	-93.0	-408		
7/8/97	8:00	3.130	37509	7280	-5.1		1.9	71	-2.8		222					2.0	77	-78.0	-112.0	-93.6	-520		
Balance 38A			ΔS	2659	-4.90	0.00		1156			3419						297	-79.7	-115.3	-92.7	-1620		
8/8/97	8:00	3.126	37156	7130			1.9	71	-2.8		184					1.4	51	-79.2	-110.4	-94.3	-353		
9/8/97	8:00	3.145	38932	7853			11.6	452	-19.9		1360					2.4	90	-69.3	-106.5	-94.9	-999		
10/8/97	8:00	3.243	46921	12081			21.5	1009	-19.9		3722					1.5	63	-64.5	-104.1	-95.5	-440		
11/8/97	8:00	3.227	45697	11340	-4.9						47					1.9	87	-48.7	-100.8	-96.1	-701		
Balance 38B			ΔS	4060	-5.00	0.00		1531			5313		0				291	-65.4	-105.5	-95.2	-2493		
12/8/97	8:00	3.211	44472	10619							11					1.5	66	-56.7	-109.0	-91.5	-666		
13/8/97	8:00	3.200	43662	10134							10					2.3	101	-55.3	-110.0	-90.7	-394		
14/8/97	8:00	3.190	42941	9701							9					3.1	135	-74.5	-121.0	-89.8	-307		
15/8/97	8:00	3.261	48400	12940	-6.6		16.7	808	-5.9		3602					3.3	151	-98.5	-136.3	-89.0	-1021		
Balance 38C			ΔS	1600	-5.75	0.00		808			3632						453	-71.2	-119.1	-90.3	-2387		
16/8/97	8:00	3.260	48332	12891			4.8	232	-5.9		580					2.1	101	-65.6	-119.4	-88.2	-760		
17/8/97	8:00	3.247	47265	12269							21					2.2	105	-52.0	-112.1	-87.3	-538		
18/8/97	8:00	3.235	46301	11708							8					2.7	127	-53.1	-113.4	-86.5	-442		
19/8/97	8:00	3.225	45547	11249	-6.4						1					2.5	115	-55.7	-123.3	-79.1	-345		
Balance 38D			ΔS	-1691	-6.50	0.00		232			610						447	-56.6	-117.0	-85.3	-2086		
Totals			ΔS	6628				3728			12974		0				1489				-8585	0	0

Balance Period No: 39

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
19/8/97	8:00	3.225	45547	11249	-6.4											2.5		-55.7	-123.3	-79.1			
20/8/97	8:00	3.216	44856	10842							8					1.8	80	-53.8	-117.3	-82.7	-335		
21/8/97	8:00	3.206	44099	10397							11					3.0	135	-56.5	-114.6	-86.3	-321		
22/8/97	8:00	3.200	43662	10134							5					2.1	92	-63.8	-112.7	-89.8	-176		
23/8/97	8:00	3.193	43158	9831	-4.3						11					2.1	91	-61.1	-104.9	-93.4	-223		
Balance 39A			ΔS	-1418	-5.35	0.00		0			35		0				397	-58.8	-112.4	-88.0	-1056		
24/8/97	8:00	3.185	42570	9488							14					2.4	103	-47.4	-107.0	-86.8	-254		
25/8/97	8:00	3.178	42017	9192							9					2.4	101	-50.1	-115.0	-80.2	-204		
26/8/97	8:00	3.171	41454	8899							1					4.3	178	-45.6	-109.2	-81.9	-116		
27/8/97	8:00	3.166	41039	8693	-2.9		0.7	29	-24.5		20					2.8	115	-67.2	-123.0	-83.6	-139		
Balance 39B			ΔS	-1138	-3.60	0.00		29			44		0				498	-52.6	-113.5	-83.1	-713		
28/8/97	8:00	3.231	45999	11524			13.7	630	-24.5		3062					1.5	66	-67.4	-119.3	-85.2	-796		
29/8/97	8:00	3.234	46226	11662			3.9	180	-24.5		509					1.8	84	-56.5	-109.8	-86.9	-467		
30/8/97	8:00	3.224	45471	11203							26					2.3	105	-62.2	-109.4	-88.6	-380		
31/8/97	8:00	3.216	44856	10842	-2.2						5					2.4	108	-51.5	-99.7	-92.8	-258		
Balance 39C			ΔS	2149	-2.55	0.00		810			3602						363	-59.4	-109.5	-88.4	-1900		
Totals			ΔS	-407				839			3681		0				1258				-3669	0	0

Balance Period No: 40 **West Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
31/8/97	8:00	3.216	44856	10842	-2.2											2.4		-51.5	-99.7	-92.8			
1/9/97	8:00	3.207	44173	10441							2					3.2	144	-49.4	-95.5	-97.0	-259		
2/9/97	8:00	3.243	46921	12081			13.0	610	-28.4		1579					1.3	61	-62.4	-98.0	-95.7	-488		
3/9/97	8:00	3.260	48332	12891			7.9	382	-2.4		1048					2.0	94	-69.6	-101.7	-94.4	-526		
4/9/97	8:00	3.250	47562	12412	-3.5		0.1	4.8	-2.4		31					2.0	95	-59.7	-102.8	-93.1	-420		
Balance 40A			ΔS	1570	-2.85	0.00		997			2660		0				394	-60.3	-99.5	-95.0	-1693		
5/9/97	8:00	3.242	46839	12034							7.000					2.3	108	-61.3	-104.2	-91.7	-277		
6/9/97	8:00	3.387	55469	19476			38.8	2152	-54.8		7302					2.1	108	-155.9	-177.8	-90.4	-1904		
7/9/97	8:00	3.371	54472	18597			0.5	27	-22.6		72					3.0	164	-95.7	-142.4	-89.1	-814		
8/9/97	8:00	3.455	58474	23366	-17.9		28.0	1637	-22.6		4650					3.0	167	-124.2	-162.8	-87.8	-1351		
Balance 40B			ΔS	10954	-10.70	0.00		3817			12031		0				547	-109.3	-146.8	-89.8	-4347		
9/9/97	8:00	3.488	59564	25315			15.2	905	-22.6		2186					3.3	193	-124.0	-164.7	-87.0	-949		
10/9/97	8:00	3.492	59667	25554			8.0	477	-26.2		880					2.6	152	-96.0	-146.5	-86.2	-966		
11/9/97	8:00	3.478	59301	24721			0.1	5.9	-26.2		53					2.3	135	-94.8	-146.8	-85.4	-757		
12/9/97	8:00	3.467	58887	24071	-20.2		1.0	59	-23.9		62					2.7	157	-140.0	-182.6	-84.6	-614		
Balance 40C			ΔS	705	-19.05	0.00		1448			3181		0				638	-113.7	-160.1	-85.8	-3285		
Totals			ΔS	13229				6261			17872		0				1579				-9325	0	0

Balance Period No: 41

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
12/9/97	8:00	3.467	58887	24071	-20.2											2.7		-140.0	-182.6	-84.6			
13/9/97	8:00	3.452	58374	23191							13					3.1	183	-108.8	-159.6	-83.8	-710		
14/9/97	8:00	3.443	58098	22667							12					2.5	146	-112.3	-163.4	-83.0	-390		
15/9/97	8:00	3.435	57851	22203							8					3.1	181	-102.1	-156.0	-82.2	-291		
16/9/97	8:00	3.424	57470	21569	-19.8						6					3.1	180	-97.1	-153.8	-80.5	-460		
Balance 41A			ΔS	-2502	-20.00	0.00		0			39		0				691	-105.1	-158.2	-82.4	-1850		
17/9/97	8:00	3.415	57087	21053							7					2.6	149	-111.1	-168.5	-78.8	-374		
18/9/97	8:00	3.406	56652	20541			0.4	23	4.3		8					3.0	172	-109.5	-166.3	-79.0	-371		
19/9/97	8:00	3.398	56155	20090			0.2	11.2	4.3		8					2.9	165	-117.3	-172.6	-79.2	-306		
20/9/97	8:00	3.390	55656	19643	-19.0						11					3.0	169	-101.9	-158.2	-79.3	-289		
Balance 41B			ΔS	-1926	-19.40	0.00		34			34		0				655	-110.0	-166.4	-79.1	-1339		
21/9/97	8:00	3.381	55106	19145							6					2.5	139	-97.0	-153.3	-79.5	-365		
22/9/97	8:00	3.373	54604	18706							8					3.2	177	-102.9	-157.6	-79.7	-270		
23/9/97	8:00	3.366	54161	18325							8					3.4	187	-95.4	-148.7	-81.2	-202		
24/9/97	8:00	3.360	53793	18001	-17.2		0.7	38	-2.2		157					4.0	218	-105.8	-154.2	-82.7	-300		
Balance 41C			ΔS	-1642	-18.10	0.00		38			179		0				722	-100.3	-153.4	-80.8	-1137		
Totals			ΔS	-6070				72			252		0				2067				-4326	0	0

Balance Period No: 42

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
24/9/97	8:00	3.360	53793	18001	-17.2											4.0		-105.8	-154.2	-82.7			
25/9/97	8:00	3.353	53427	17626							51					4.3	229	-76.0	-129.6	-84.2	-197		
26/9/97	8:00	3.348	53171	17359			1.4	74	15.0		88					3.4	182	-85.2	-133.8	-85.7	-247		
27/9/97	8:00	3.342	52877	17041			0.1	5.29	15.0		161					2.8	149	-89.5	-134.0	-87.2	-335		
28/9/97	8:00	3.336	52489	16725	-14.3						18					3.3	176	-88.8	-130.8	-88.7	-158		
Balance 42A			ΔS	-1276	-15.75	0.00		80			318		0				737	-84.9	-132.1	-86.5	-937		
29/9/97	8:00	3.330	52151	16411							6					3.7	191	-87.4	-127.8	-90.2	-129		
30/9/97	8:00	3.325	51873	16151							117					3.1	163	-97.8	-130.2	-91.7	-214		
1/10/97	8:00	3.324	51816	16100			2.4	124	-1.1		258					4.4	229	-92.5	-125.3	-93.2	-204		
2/10/97	8:00	3.317	51440	15738	-13.6						29					3.1	162	-77.0	-117.4	-94.7	-229		
Balance 42B			ΔS	-987	-13.95	0.00		124			410		0				745	-88.7	-125.2	-92.5	-777		
3/10/97	8:00	3.310	51077	15379							11					3.9	198	-69.9	-112.3	-96.2	-172		
4/10/97	8:00	3.305	50814	15125							52					4.0	202	-82.0	-112.0	-97.7	-104		
5/10/97	8:00	3.298	50442	14770							10					4.8	243	-74.4	-113.0	-93.6	-122		
6/10/97	8:00	3.290	50032	14368	-8.8						5					5.6	283	-58.0	-109.0	-89.4	-124		
Balance 42C			ΔS	-1370	-11.20	0.00		0			78		0				926	-71.1	-111.6	-94.2	-522		
Totals			ΔS	-3633				204			806		0				2407				-2236	0	0

Balance Period No: 43 **West Lake**

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
6/10/97	8:00	3.290	50032	14368	-8.8											5.6		-58.0	-109.0	-89.4			
7/10/97	8:00	3.285	49778	14119							5					4.6	229	-75.6	-120.2	-85.7	-25		
8/10/97	8:00	3.291	50083	14418			3.4	170	1.0		476					4.1	203	-96.6	-129.4	-86.5	-145		
9/10/97	8:00	3.335	52432	16673			15.6	818	1.0		1916					4.7	241	-89.1	-123.5	-87.3	-238		
10/10/97	8:00	3.357	53631	17840	-7.0		9.5	509	2.9		1376					4.9	258	-79.3	-117.1	-88.1	-460		
Balance 43A			ΔS	3472	-7.90	0.00		1498			3773		0				931	-85.1	-122.5	-86.9	-868		
11/10/97	8:00	3.346	53067	17253							23					4.2	223	-67.7	-110.7	-88.9	-387		
12/10/97	8:00	3.336	52489	16725							9					3.9	204	-72.5	-110.9	-89.7	-333		
13/10/97	8:00	3.327	51985	16255							8					3.8	196	-75.7	-110.1	-90.5	-282		
14/10/97	8:00	3.320	51598	15893	-5.0						84					3.4	178	-74.7	-123.6	-79.4	-268		
Balance 43B			ΔS	-1947	-6.00	0.00		0			124		0				801	-72.7	-113.8	-87.1	-1270		
15/10/97	8:00	3.311	51129	15430							6					4.9	252	-68.0	-117.1	-80.6	-217		
16/10/97	8:00	3.302	50653	14972							9					4.2	212	-64.5	-113.2	-81.7	-255		
17/10/97	8:00	3.296	50337	14669							15					5.0	253	-62.9	-110.7	-82.9	-65		
18/10/97	8:00	3.286	49829	14169	-3.1						9					5.0	251	-53.7	-104.5	-84.0	-258		
Balance 43C			ΔS	-1724	-4.05	0.00		0			39		0				968	-62.3	-111.4	-82.3	-795		
Totals			ΔS	-199				1498			3936		0				2699				-2933	0	0

Balance Period No: 44

West Lake

Day & Time		Stage	Area	Volume	Lake				Rain		Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
18/10/97	8:00	3.286	49829	14169	-3.1											5.0		-53.7	-104.5	-84.0			
19/10/97	8:00	3.278	49423	13772							7					5.1	254	-50.6	-101.4	-85.2	-150		
20/10/97	8:00	3.268	48859	13280							6					6.8	333	-46.3	-101.8	-77.7	-165		
21/10/97	8:00	3.260	48332	12891							48					4.7	228	-52.7	-111.3	-70.2	-209		
22/10/97	8:00	3.251	47661	12459	1.6						6					6.0	290	-51.5	-106.2	-74.9	-148		
Balance 44A			ΔS	-1710	-0.75	0.00		0			67		0				1105	-50.3	-105.2	-77.0	-672		
23/10/97	8:00	3.243	46921	12081			0.1	4.7	28.4		77					4.3	202	-59.9	-107.2	-79.5	-258		
24/10/97	8:00	3.237	46451	11801							84					5.2	243	-61.4	-101.6	-84.2	-121		
25/10/97	8:00	3.230	45923	11478							18					3.3	154	-58.9	-94.8	-88.8	-187		
26/10/97	8:00	3.221	45238	11067	3.0						14					4.6	209	-52.3	-89.3	-93.5	-216		
Balance 44B			ΔS	-1392	2.30	0.00		4.7			193		0				809	-58.1	-98.2	-86.5	-781		
27/10/97	8:00	3.215	44778	10797							8					4.8	216	-53.2	-88.4	-92.9	-62		
28/10/97	8:00	3.209	44321	10530			1.8	79.8	11.4		103					5.0	225	-58.1	-87.1	-92.2	-225		
29/10/97	8:00	3.200	43662	10134							18					5.3	234	-47.9	-87.5	-91.6	-180		
30/10/97	8:00	3.188	42795	9616	5.8						9					6.2	266	-43.3	-87.3	-91.0	-261		
Balance 44C			ΔS	-1451	4.40	0.00		79.8			138		0				941	-50.7	-87.6	-91.9	-728		
Totals			ΔS	-4553				84.5			398		0				2855				-2181	0	0

Balance 44A corresponds to start irrigation pumping

Balance Period No: 45

West Lake

Day & Time		Stage	Area	Volume	Lake				Rain		Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
30/10/97	8:00	3.188	42795	9616	5.8											6.2		-43.3	-87.3	-91.0			
31/10/97	8:00	3.178	42017	9192							7					5.2	221	-39.1	-86.8	-90.4	-210		
1/11/97	8:00	3.170	41372	8858							12					4.9	204	-43.5	-85.0	-89.7	-142		
2/11/97	8:00	3.162	40687	8530							13					5.2	214	-46.4	-83.3	-89.1	-127		
3/11/97	8:00	3.156	40096	8287	9.5						6					5.6	227	-40.3	-88.6	-80.9	-22		
Balance 45A			ΔS	-1329	7.65	0.00		0			38		0				867	-42.3	-85.9	-87.5	-500		
4/11/97	8:00	3.148	39231	7970							39					5.5	219	-44.1	-97.1	-72.6	-137		
5/11/97	8:00	3.140	38445	7659							12					4.4	170	-47.9	-94.3	-76.5	-153		
6/11/97	8:00	3.132	37688	7355							8					4.4	167	-40.0	-86.2	-80.3	-145		
7/11/97	8:00	3.123	36897	7019	12.3						17					6.4	237	-34.9	-82.0	-84.2	-116		
Balance 45B			ΔS	-1268	10.90	0.00		0			76		0				793	-41.7	-89.9	-78.4	-551		
8/11/97	8:00	3.115	36215	6727							41					5.4	198	-37.3	-83.9	-80.0	-135		
9/11/97	8:00	3.108	35620	6476							12					5.8	210	-36.1	-86.1	-75.8	-53		
10/11/97	8:00	3.102	35091	6263							5					5.0	177	-38.0	-81.1	-80.4	-41		
11/11/97	8:00	3.095	34475	6020	15.4						33					5.9	207	-34.8	-75.5	-84.9	-69		
Balance 45C			ΔS	-999	13.85	0.00		0			91		0				792	-36.5	-81.7	-80.3	-298		
Totals			ΔS	-3596				0			205		0				2452				-1349	0	0

Balance Period No: 46

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
11/11/97	8:00	3.095	34475	6020	15.4											5.9		-34.8	-75.5	-84.9			
12/11/97	8:00	3.085	33546	5680							30					6.6	223	-33.0	-70.7	-89.5	-147		
13/11/97	8:00	3.080	33091	5513	16.9						51					1.5	49	-39.8	-54.0	-94.1	-169		
14/11/97	8:00	3.075	32636	5349							29					2.5	82	-33.9	-54.9	-98.7	-111		
15/11/97	8:00	3.066	31856	5059	18.1						56					5.3	172	-30.6	-54.7	-103.2	-174		
Balance 46A			ΔS	-961	16.80	0.00		0			166		0				526	-34.3	-58.6	-96.4	-601		
16/11/97	8:00	3.059	31275	4838							43					6.9	217	-27.6	-53.9	-107.8	-47		
17/11/97	8:00	3.052	30691	4621							21					5.4	168	-25.1	-62.1	-98.3	-70		
18/11/97	8:00	3.045	30099	4408							59					6.3	190	-24.8	-64.4	-88.7	-82		
19/11/97	8:00	3.036	29301	4141	22.2						27					6.7	198	-23.2	-69.9	-79.2	-96		
Balance 46B			ΔS	-918	20.15	0.00		0			150		0				774	-25.2	-62.6	-93.5	-294		
20/11/97	8:00	3.027	28519	3880							26					5.4	157	-24.6	-66.1	-81.6	-130		
21/11/97	8:00	3.019	27798	3655							24					6.0	170	-29.1	-55.9	-84.1	-79		
22/11/97	8:00	3.037	29388	4170			5.2	153	-5.1		690					3.1	89	-32.8	-43.3	-86.5	-239		
23/11/97	8:00	3.030	28780	3966	22.7						26					4.0	115	-26.8	-52.3	-88.9	-115		
Balance 46C			ΔS	-175	22.45	0.00		153			766		0				532	-28.3	-54.4	-85.3	-562		
Totals			ΔS	-2054				153			1082		0				1831				-1458	0	0

Balance Period No: 47

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
23/11/97	8:00	3.030	28780	3966	22.7											4.0		-26.8	-52.3	-88.9			
24/11/97	8:00	3.024	28255	3795							13					5.5	158	-25.2	-59.2	-84.5	-26		
25/11/97	8:00	3.016	27522	3572							99					2.5	70	-29.9	-53.9	-81.4	-252		
26/11/97	8:00	3.013	27242	3490			1.0	27.2	2.8		70					4.9	133	-28.7	-59.9	-78.3	-46		
27/11/97	8:00	3.004	26357	3249	24.2		0.1	2.6	2.8		25					3.9	103	-23.8	-64.6	-77.9	-165		
Balance 47A			ΔS	-717	23.45	0.00		29.9			207		0				464	-26.9	-59.4	-80.5	-490		
28/11/97	8:00	2.996	25513	3041							15					4.8	124	-23.1	-63.9	-77.4	-99		
29/11/97	8:00	2.987	24570	2816							65					7.4	185	-20.8	-61.7	-80.5	-105		
30/11/97	8:00	2.980	23815	2647							28					6.9	167	-20.1	-57.3	-83.6	-30		
1/12/97	8:00	2.973	23011	2483	26.2						30					6.6	154	-20.3	-59.4	-78.4	-40		
Balance 47B			ΔS	-766	25.20	0.00		0.0			138		0				630	-21.1	-60.6	-80.0	-274		
2/12/97	8:00	2.965	22010	2303							83					5.8	131	-20.3	-46.6	-82.6	-132		
3/12/97	8:00	2.954	20566	2068							79					6.0	129	-17.7	-45.7	-86.8	-185		
4/12/97	8:00	2.945	19275	1889							68					5.2	104	-16.6	-37.4	-91.0	-143		
5/12/97	8:00	2.934	17772	1685	28.8						54					4.7	87	-15.1	-34.3	-95.2	-171		
Balance 47C			ΔS	-798	18.33	0.00		0.0			284		0				451	-17.4	-41.0	-88.9	-631		
Totals			ΔS	-2281				29.9			629		0				1545				-1395	0	0

Balance Period No: 48

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
5/12/97	8:00	2.934	17772	1685	28.8											4.7		-15.1	-34.3	-95.2			
6/12/97	8:00	2.923	16445	1497												7.5	128	-13.8	-39.5	-96.7	-60		
7/12/97	8:00	2.915	15483	1369												7.4	118	-12.9	-37.9	-98.1	-10		
8/12/97	8:00	2.908	14674	1264												7.2	109	-11.9	-48.2	-85.0	4		
9/12/97	8:00	2.896	13133	1097	31.1											6.3	87	-11.1	-52.7	-81.6	-80		
Balance 48A			ΔS	-588	19.97	0.00		0			0		0				442	-12.4	-44.6	-90.3	-146		
10/12/97	8:00	2.881	11225	914												8.3	102	-10.2	-57.7	-78.2	-81		
11/12/97	8:00	2.868	9554	779												7.0	73	-7.5	-50.7	-74.8	-62		
12/12/97	8:00	2.856	8274	672												6.4	57	-5.6	-37.8	-82.1	-50		
13/12/97	8:00	2.844	7127	580	34.3											6.6	51	-5.2	-35.6	-89.4	-41		
Balance 48B			ΔS	-517	21.80	0.00		0			0		0				282	-7.1	-45.5	-81.1	-235		
14/12/97	8:00	2.835	6357	519												8.9	60	-4.4	-32.3	-93.4	-1		
15/12/97	8:00	2.828	5767	477												8.3	51	-4.3	-45.8	-83.3	9		
16/12/97	8:00	2.819	5002	428												8.7	47	-1.1	-47.4	-73.1	-2		
17/12/97	8:00	2.809	4239	382	36.9											5.6	26	2.7	-36.9	-75.4	-20		
Balance 48C			ΔS	-198	23.73	0.00		0			0		0				183	-1.8	-40.6	-81.3	-15		
Totals			ΔS	-1303				0			0		0				907				-396	0	0

Balance Period No: 49

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
17/12/97	8:00	2.809	4239	382	36.9											5.6		2.7	-36.9	-75.4			
18/12/97	8:00	2.798	3508	340												5.8	22.6	1.7	-35.2	-77.7	-19.4		
19/12/97	8:00	2.788	2951	308												5.8	18.9	1.7	-30.7	-79.9	-13.1		
20/12/97	8:00	2.779	2545	283												5.2	14.3	-0.5	-34.2	-82.2	-10.7		
Balance 49A			ΔS	-99	12.30	0.00		0			0		0				55.8	1.0	-33.4	-79.9	-43.2		
21/12/97	8:00	2.774	2340	271	36.1											6.8	16.6	-0.8	-31.5	-84.5	4.6		
22/12/97	8:00	2.771	2238	264												5.0	11.5	-0.1	-36.5	-81.9	4.5		
23/12/97	8:00	2.760	1951	241												9.2	19.2	-1.4	-46.4	-79.3	-3.8		
24/12/97	8:00	2.745	1710	214												7.6	13.9	2.9	-32.2	-83.3	-13.1		
25/12/97	8:00	2.735	1604	197	39.3											8.4	14.0	3.5	-29.6	-87.3	-3.0		
Balance 49B			ΔS	-86	37.70	0.00		0			0		0				75.2	0.8	-35.2	-83.3	-10.8		
Totals			ΔS	-185				0			0		0				131.0				-54.0	0	0

Balance Period No: 50

West Lake

Day & Time		Stage	Area	Volume	Lake		Rain				Drains		Summer Top Up			Evaporation					Apparent GW Flux	GW In	Lake-GW
		m AHD	m^2	m^3	δ	Cl	mm	m^3	δ	Cl	m^3	Cl	m^3	δ	Cl	mm	m^3	δE_{pan}	δE*	δA		m^3	m^3
25/12/97	8:00	2.735	1604	197	39.3											8.4		3.5	-29.6	-87.3			
26/12/97	8:00	2.729	1542	188												6.7	10.5	1.0	-32.7	-91.3	1.5		
27/12/97	8:00	2.724	1496	180												7.9	12.0	2.3	-25.7	-88.8	4.0		
28/12/97	8:00	2.725	1505	181												3.5	5.3	3.6	-19.2	-86.2	6.3		
29/12/97	8:00	2.722	1478	177	36.6											5.2	7.8	0.0	-30.7	-85.6	3.8		
Balance 50A			ΔS	-20	25.30	0.00		0			0		0				35.6	1.7	-27.1	-88.0	15.6		
30/12/97	8:00	2.714	1408	165												6.9	9.9	1.1	-26.8	-84.9	-2.1		
31/12/97	8:00	2.704	1322	152												3.9	5.3	2.2	-22.9	-84.3	-7.7		
1/1/98	8:00	2.692	1212	137												5.8	7.4	0.5	-30.7	-83.7	-7.6		
2/1/98	8:00	2.686	1141	129	36.4											6.6	7.7	-0.7	-36.4	-83.1	-0.3		
3/1/98	8:00	2.682	1103	125												6.8	7.6	-1.2	-38.6	-82.4	3.6		
Balance 50B			ΔS	-52	18.30	0.00		0			0		0				37.9	0.4	-31.1	-83.7	-14.1		
Totals			ΔS	-72				0			0		0				73.6				1.6	0	0

Appendices 6.4 & 6.5

Appendix 6.4 Deuterium and Chloride in Nested Piezometer Waters

Appendix 6.5 Rainfall Data at Perry Lakes (5 gauges) plus Deuterium in Rain – (sampling data and results)

Appendix 6.4 Deuterium and Chloride in Nested Piezometer Waters

The five nested piezometers (three wells per piezometer) were sampled monthly. Temperature profiles were also taken in the deepest 'c' piezometer at each site. Initially (March 1996) a small electric submersible pump was used. This required a petrol generator and was not always available. All sampling from September 1996 onwards was done manually. Each well was bailed with a two metre long sludge pump designed to fit snugly within 50mm PVC. Water equivalent to a minimum three well volumes was removed. Water was sampled in the lowermost screened section of each piezometer using a position sampler.

Appendix 6.5 Rainfall and Deuterium in Rain

Initial measurements in April 1996 used only three rain gauges, one with the Class A evaporation pan in the UWA Field Station, and one each in East Lake and West Lake. All rain gauges suffer from errors due to modification of the wind field (Maidment 1993). Given these well known difficulties a second gauge was added to East Lake in August 1996 about 10 metres from the initial gauge. Both were about 20 metres out in the lake on the eastern side. This is the 'downwind' side of the lake during the passage of winter cold frontal systems and well away from the rain shadow effects of fringing trees. The floating Class A evaporation pan was located off shore from the south side of East Lake. This was the only practical location for it despite it being a known rain and wind shadow in southwest winds. A separate rain gauge was fitted in April 1997 to independently monitor winter rain. Rainfall here was 83.4% of that recorded in the primary gauges, proof of the extreme effect trees and other obstacles can have on local rainfall patterns (refer table). Total annual catch in the two primary East Lake gauges differed by only 0.14% (0.9mm). Refer table below.

A single gauge was used in West Lake located in a clear area surrounded by *Baumea articulata* thus shielding it from view and vandals. This area was dry in summer and flooded during winter. Rainfall collected for deuterium was stored below silicon oil. The collector was in a clear area in the CSIRO complex, about 100 metres west of the UWA Field Station rain gauge. Total water volume was measured for each sample. All gauges were read nominally at 08:00 each day. Trace amounts ('TR') were treated as nil.

Total Rainfall Perry Lakes 1997

UWA Field Stn	East Lake #1	East Lake #2	East Lake Pan	West Lake
644.5	651.4	650.5	542.8	646.0

Deuterium and Chloride Nested Piezometer Waters

Deuterium

Year	Month	N1a	N1b	N1c	N2a	N2b	N2c	N3a	N3b	N3c	N4a	N4b	N4c	N5a	N5b	N5c
1996	March	-11.6	-9.4	3.2	-6.1	0.6	-3.7	-14.9	-14.5	-13.6	7.4	-3.1	1.4	-10.4	15.0	14.6
	September	-12.4	-9.5	-0.7	4.9	-0.4	-5.0	-13.6	-15.1	-13.7	-7.0	-1.9	-0.2	-10.2	15.4	4.3
	October	-11.8	-9.8	-2.1	-0.7	-2.1	-5.5	-15.6	-11.9	-14.7	-6.1	-1.8	2.1	-9.3	16.7	12.7
	November	-12.2	-10.4	0.8	-1.9	-1.2	-4.6	-14.4	-11.6	-14.2	-11.8	2.0	0.7	-11.4	14.7	11.8
	December	-13.6	-9.1	-0.3	-3.8	-3.1	-4.3	-13.7	-8.4	-13.7	-0.1	-1.1	0.6	-9.3	16.2	15.0
1997	January	-11.4	-8.0	0.3	-2.4	-3.2	-5.9	-16.0	-9.5	-14.4	1.0	3.7	0.3	-10.3	15.4	15.6
	February	-11.3	-9.3	1.6	1.7	-2.4	-4.6	-16.5	-10.5	-15.8	8.3	2.1	-1.0	-10.2	15.4	15.1
	March	-12.4	-10.1	1.5	4.2	-0.5	-5.4	-16.3	-10.8	-15.8	9.7	-3.2	0.4	-10.8	14.7	14.4
	April	-12.6	-10.6	1.4	5.1	-1.6	-4.1	-15.0	-8.2	-14.8	3.7	-2.8	0.1	-9.7	15.8	16.2
	May	-12.7	-11.3	1.1	0.3	-0.8	-5.5	-16.6	-9.9	-13.7	-1.2	-2.9	0.8	-9.7	16.0	24.6
	June	-11.9	-11.1	2.8	0.2	-3.8	-6.2	-17.5	-7.3	-16.7	-4.4	-4.2	-0.2	-11.2	15.3	15.5
	July	-11.6	-9.4	0.6	-0.1	-4.1	-6.9	-15.2	-11.1	-16.7	-5.3	-5.6	-0.7	-11.2	15.3	15.7
	August	-11.0	-9.4	2.0	2.6	-2.7	-5.6	-13.6	-7.6	-14.2	-3.5	-4.9	0.5	-8.8	15.8	15.7
	September	-8.4	-6.7	-0.1	2.5	-4.1	-5.2	-12.7	-9.2	-14.0	-1.1	-4.1	0.1	-10.9	14.6	14.6
	October	-15.3	-12.0	-1.0	-3.7	-4.3	-6.1	-9.6	-9.9	-15.5	-4.3	-3.4	0.5	-12.3	14.6	14.3
	November	-13.5	-12.2	0.0	-6.3	-5.9	-7.8	-10.5	-10.6	-17.5	-6.0	-7.1	-1.8	-11.9	12.7	13.4
	December	-11.2	-11.7	2.1	-5.4	-2.8	-4.1	-10.3	-11.1	-15.1	-3.8	-5.3	0.7	-10.9	14.4	14.9
	Average not including March 1996 data															
	Average	-12.1	-10.0	0.6	-0.2	-2.7	-5.4	-14.2	-10.2	-15.0	-2.0	-2.5	0.2	-10.5	15.2	14.6
	Average including March 1996 data															
		-10.7	-8.9	0.8	0.2	-2.5	-4.9	-12.5	-8.7	-13.3	-1.4	-2.2	0.3	-9.3	15.2	14.6

All data permil

Chloride

Year	Month	N1a	N1b	N1c	N2a	N2b	N2c	N3a	N3b	N3c	N4a	N4b	N4c	N5a	N5b	N5c
1996	March	313	228	322	153	163	187	289	208	194	197	161	204	307	400	400
	September	415	223	292	142	180	197	341	216	202	196	154	203	343	410	302
	October	471	220	280	154	178	189	315	243	199	173	156	200	356	408	350
	November	328	220	298	120	182	192	254	222	205	115	183	198	356	408	363
	December	307	224	311	143	168	177	305	273	188	183	157	194	356	382	372
1997	January	315	222	315	125	176	192	280	263	191	109	189	196	350	395	393
	February	341	223	328	128	194	197	258	266	196	139	208	199	348	397	406
	March	372	224	346	129	194	201	237	262	199	188	182	199	309	356	408
	April	359	227	354	116	194	204	202	281	191	203	192	187	350	356	395
	May	372	220	356	123	186	206	237	302	200	232	204	196	348	400	393
	June	382	227	343	124	196	195	243	292	202	221	199	199	341	395	404
	July	432	230	348	154	176	200	278	261	203	205	189	194	367	406	389
	August	428	240	318	131	198	197	330	256	203	190	182	198	356	408	382
	September	475	232	315	171	202	202	387	236	203	195	184	208	369	413	384
	October	328	232	309	213	200	203	348	230	201	174	200	190	413	384	363
	November	363	242	324	176	206	198	380	233	205	157	168	210	346	413	402
	December	400	243	337	167	207	221	387	256	207	159	169	210	337	419	408
	Average	376	228	323	145	188	198	298	253	199	179	181	199	350	397	383

All data mg l^{-1}

Rainfall (mm) Including Deuterium in Rainfall

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
1996								
April	23	0.1	0.1			0.1		
	24							
	25	0.7	0.6			0.5		
	26							
	27							
	28							
	29							
	30							
May	01							
	02							
	03							
	04							
	05	4.0	3.7			3.9		
	06						R001	-1.4
	07							
	08	15.2	13.4			14.0	R002	-6.2
	09	4.5	4.5			4.7	R003	-5.7
	10	4.9	4.0			3.6		
	11	1.5	1.3			1.5	R004	-3.5
	12							
	13							
	14							
	15							
	16	TR	0.2			0.5		
	17	4.0	2.9			2.5		
	18						R005	9.7
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							
	30							
	31	27.4	25.8			25.8	R006	10.7
June	01	0.9	0.5			0.6		
	02	TR	TR			TR	R007	18.4
	03	2.9	1.0			1.0		
	04						R008	7.7
	05							
	06							
	07							
	08							
	09	0.5	0.5			0.5		
	10	8.0	7.7			9.6		
	11	0.5	0.5			0.2		
	12	1.1	1.5			1.7		
	13	TR	0.1			TR	R009	-9.4
	14							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	15							
	16	8.4	7.2			6.6		
	17	2.5	2.0			2.2		
	18	22.0	19.5			19.8	R010	-12.1
	19	34.5	32.4			32.5	R011	-15.4
	20	27.2	25.9			30.1		
	21	20.9	18.0			19.5	R012	-21.0
	22	16.3	14.7			11.0		
	23	1.5	1.5			1.7		
	24	7.6	7.1			6.0	R013	-29.8
	25	TR	TR			TR		
	26							
	27	13.5	13.5			15.0		
	28	8.9	7.9			7.5	R014	-9.9
	29	0.2	0.2			0.4		
	30	12.5	11.8			12.0		
July	01	1.2	1.1			1.0	R015	-0.6
	02	3.4	2.9			2.6		
	03	22.2	22.9			26.5		
	04	7.2	8.3			7.6		
	05	3.5	3.4			3.0	R016	-24.4
	06	TR	TR			0.1		
	07							
	08	23.0	22.0			24.4		
	09						R017	-26.9
	10							
	11							
	12							
	13	1.2	1.2			1.1		
	14							
	15							
	16	14.3	14.3			14.4		
	17	14.9	14.6			16.5	R018	-18.8
	18	4.6	2.9			2.8		
	19	4.8	4.8			4.0		
	20	0.7	1.0			0.6	R019	5.6
	21	4.5	4.8			4.0		
	22	8.2	7.4			7.6		
	23	4.0	3.9			3.7	R020	-2.6
	24	19.1	18.5			16.6		
	25	12.9	10.4			8.4		
	26	0.5	0.5			0.3	R 021	-18.2
	27	25.6	23.7			25.8		
	28	7.4	7.5			7.5	R 022	-6.8
	29	0.0	0.3			0.3		
	30	10.6	10.5			11.1		
	31	3.9	4.0			4.7		
August	01	3.4	3.4			4.4		
	02	1.2	1.2			1.5	R 023	-6.7
	03	1.2	1.0			0.7		
	04	6.7	6.7			6.2		
	05	3.7	4.3			5.7		
	06	5.5	5.9			4.6	R 024	-33.3
	07	5.2	5.4			5.0		
	08		TR			0.1	R 025	3.5
	09							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	10							
	11	19.7	18.0			17.7		
	12	0.6	0.5			0.7	R 026	2.6
	13	10.7	9.7			10.0		
	14	1.5	1.5	Data starts		1.5	R 027	-12.8
	15	1.2	1.6	1.5		1.2		
	16	1.2	1.0	0.9		1.2		
	17	1.2	0.7	0.7		0.3	R 028	1.4
	18							
	19							
	20	3.2	3.5	3.3		2.8		
	21	8.2	8.3	8.0		9.4		
	22	0.9	0.9	0.8		1.0	R 029	-3.2
	23							
	24	10.2	9.0	8.8		9.8		
	25						R 030	-0.2
	26							
	27	4.8	2.6	2.5		1.8		
	28	1.8	1.6	1.5		1.0		
	29						R 031	-1.0
	30							
	31	8.7	9.0	8.7		9.0		
September	01						R 032	5.8
	02							
	03	2.5	2.8	2.8		3.0		
	04						R 033	1.2
	05							
	06	6.9	5.8	6.0		5.2		
	07	2.1	2.1	2.0		2.5		
	08	3.0	3.2	2.7		3.3	R 034	8.0
	09	5.7	5.5	5.5		5.0		
	10	11.3	10.1	10.1		11.2		
	11	13.2	17.9	17.9		19.0	R 035	-13.4
	12	1.1	0.2	0.2		0.2		
	13							
	14	2.5	2.1	2.4		2.0	R 036	1.2
	15	5.0	4.4	4.4		5.0		
	16	4.7	3.5	3.5		5.0		
	17	2.0	1.3	1.3		1.0	R 037	7.7
	18	4.0	4.9	4.7		4.5		
	19	1.4	1.2	1.2		1.5	R 038	5.2
	20	0.2	0.1	0.1		0.1		
	21							
	22	25.2	22.4	22.5		22.0	R 039	-13.9
	23	0.2	0.1	0.1		TR		
	24	0.1	0.1	TR		TR		
	25							
	26							
	27	18.5	17.9	17.7		19.2		
	28	0.2	TR	TR		0.1	R 040	-13.2
	29	1.8	1.5	1.5		1.7		
	30							
October	01	0.1	0.1	0.1		TR		
	02						R 041	1.5
	03							
	04							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	05							
	06							
	07							
	08							
	09							
	10	4.5	4.2	4.0		4.5		
	11	4.3	3.4	2.7		2.6	R 042	0.4
	12							
	13							
	14	0.1	0.1	0.1		0.2		
	15							
	16							
	17							
	18							
	19							
	20							
	21	10.0	14.2	14.2		15.0		
	22	9.4	4.5	4.5		4.6	R 043	-22.1
	23	10.3	10.0	10.2		10.2		
	24	6.6	5.8	6.0		4.0	R 044	-7.2
	25							
	26							
	27							
	28							
	29							
	30							
	31	0.5	0.3	0.3		0.2	R 045	22.1
November	01							
	02							
	03							
	04							
	05							
	06	6.0	7.7	7.6		8.5		
	07	8.4	6.0	6.0		5.0	R 046	9.5
	08							
	09							
	10							
	11							
	12							
	13	0.4	0.3	0.3		0.4		
	14	0.1	0.2	0.2		0.3		
	15	19.3	18.9	19.5		22.0		
	16	20.1	17.5	18.0		14.8		
	17	TR	0.1	0.1		TR	R 047	-24.9
	18							
	19							
	20							
	21							
	22							
	23							
	24	1.2	1.0	1.0		1.1	R 048	2.7
	25							
	26							
	27							
	28							
	29							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	30	0.7	0.5	0.5		0.7		
December	01	4.0	2.7	3.0		3.3		
	02	0.7	1.0	1.0		2.5	R 049	-9.4
	03	0.5	0.5	0.5		1.4		
	04						R 050	4.5
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12	6.0	5.5	5.5		5.8	R 051	-16.3
	13	1.1	1.0	1.0		0.5		
	14						R 052	-1.8
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							
	30							
	31							
1997								
January	01							
	02							
	03							
	04							
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20	0.5	0.3	0.3		0.2		
	21						R 053	15.5
	22							
	23							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	24							
	25							
	26							
	27							
	28							
	29							
	30							
	31							
February	01							
	02							
	03							
	04							
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20	0.2	0.3	0.3		0.2		
	21	0.2	0.2	0.2		0.2		
	22							
	23							
	24	0.9	1.0	1.0		1.1		
	25	0.3					R 054	-25.2
	26							
	27							
	28							
March	01							
	02							
	03							
	04							
	05							
	06							
	07	0.1	0.2	0.2		0.2	R 055	34.4
	08							
	09							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17	3.6	5.8	5.6		4.5	R 056	-3.4
	18							
	19							
	20							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29	18.6	20.3	20.1		16.0		
	30	39.9	43.5	43.3		40.2	R 057	-12.0
	31							
April	01							
	02							
	03							
	04		0.7	0.7		0.5		
	05	0.6	0.1	0.1		TR	R 058	-26.1
	06	7.5	5.5	5.5		4.7	R 059	-39.5
	07	0.2	0.2	0.2		0.3		
	08	9.2	6.6	6.7		5.9	R 060	-40.2
	09							
	10				Data starts			
	11	4.2	4.3	4.3	4.3	4.5		
	12	0.5	0.5	0.5	0.2	0.5	R 061	-71.0
	13	0.1	0.2	0.2	0.2	0.2		
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21	6.4	9.5	9.6	9.4	8.9	R 062	-8.0
	22							
	23							
	24							
	25							
	26							
	27	0.2	0.2	0.2	0.2	0.2		
	28							
	29							
	30	3.1	2.5	2.5	2.0	3.5	R 063	7.9
May	01	6.3	5.9	6.0	5.4	6.5		
	02						R 064	4.0
	03	6.4	6.1	6.1	6.0	6.5		
	04						R 065	-5.8
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12	1.1	1.1	1.1	1.2	1.2		
	13	2.5	2.6	2.6	2.5	2.5	R 066	-50.5
	14							
	15							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	16							
	17							
	18	2.2	2.9	2.9	2.7	2.7		
	19	4.2	4.5	4.5	3.7	4.5	R 067	-35.5
	20							
	21							
	22							
	23							
	24	14.8	14.5	14.5	13.3	14.8		
	25	5.0	5.5	5.5	4.0	5.2	R 068	-3.0
	26	0.1	0.2	0.2	0.1	0.2		
	27	1.0	0.5	0.5	0.3	0.3		
	28	14.8	14.0	13.8	13.5	16.8	R 069	-7.5
	29							
	30							
	31	29.6	28.4	28.1	27.7	32.9	R 070	-3.0
June	01	12.2	15.7	15.7	15.0	11.0		
	02	23.3	28.9	28.7	27.4	29.2		
	03	13.0	2.8	2.6	2.7	2.6	R 071	-21.0
	04	6.0	9.0	9.1	8.0	9.2		
	05	7.5	4.3	4.3	3.4	4.5	R 072	-1.3
	06	2.3	2.7	2.6	2.1	1.7		
	07	1.0	1.1	1.0	0.8	1.1	R 073	-0.5
	08	8.2	10.2	10.2	9.9	10.5		
	09	15.7	12.3	12.2	10.7	12.4	R 074	-41.4
	10							
	11	6.9	6.8	6.7	6.2	6.4		
	12	4.9	6.0	6.0	5.2	5.7		
	13	0.6	0.6	0.6	0.5	0.2	R 075	-4.0
	14							
	15							
	16							
	17							
	18							
	19	1.4	1.4	1.4	1.3	1.4		
	20	1.9	2.0	2.0	1.6	2.0		
	21	3.1	2.0	1.9	1.6	1.8	R 076	4.2
	22	0.1	0.2	0.2	0.2	0.2		
	23	2.6	2.3	2.3	1.9	2.5		
	24						R 077	-0.1
	25	0.2	0.2	0.2	0.2	0.2		
	26						R 078	13.8
	27							
	28							
	29							
	30							
July	01							
	02							
	03	8.2	8.0	8.1	8.0	8.0	R 079	-44.2
	04							
	05	0.5	0.3	0.3	0.3	0.3		
	06	17.2	17.4	17.4	17.5	19.0		
	07	9.0	9.8	9.8	9.5	11.0	R 080	-15.2
	08	1.8	2.2	2.2	2.0	3.0	R 081	2.9
	09	9.3	13.4	13.4	13.3	8.6	R 082	-14.7
	10							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	11							
	12							
	13	6.8	6.9	6.9	6.8	14.5		
	14	13.5	14.0	13.8	13.5	6.3	R 083	-0.4
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22							
	23							
	24	7.2	8.4	8.2	8.0	8.0		
	25	8.4	9.0	9.5	9.0	9.1	R 084	-13.6
	26	1.9	1.7	1.6	1.6	1.8		
	27	5.7	6.4	6.2	6.0	6.5	R 085	-11.8
	28							
	29	1.1	U/S	0.8	0.5	1.0		
	30						R 086	-3.8
	31							
August	01							
	02							
	03							
	04	22.6	22.0	22.0	21.5	19.5	R 087	-14.0
	05	6.8	7.5	7.5	7.1	7.0	R 088	-10.5
	06	4.5	2.6	2.5	2.5	2.7		
	07	2.5	1.6	1.5	1.5	1.9		
	08	1.8	2.0	2.0	2.0	1.9	R 089	-2.8
	09	6.2	5.5	5.4	5.6	11.6		
	10	23.7	24.6	24.8	24.0	21.5	R 090	-19.9
	11							
	12							
	13							
	14							
	15	18.6	17.5	17.1	18.5	16.7	R 091	-5.9
	16	4.8	5.0	5.0	4.9	4.8		
	17						R 092	-18.0
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27	0.6	N/R (birds)	0.5	0.5	0.7		
	28	8.3	9.0	9.0	8.6	13.7		
	29	5.9	5.9	6.2	6.0	3.9	R 093	-24.5
	30							
	31							
September	01							
	02	13.9	12.8	13.0	12.6	13.0	R 094	-28.4
	03	6.2	7.5	7.6	7.4	7.9		
	04	0.6	0.1	0.1	0.1	0.1	R 095	-2.4

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	05							
	06	39.7	39.3	39.0	38.2	38.8	R 096	-54.8
	07	0.9	1.0	1.0	1.0	0.5		
	08	24.5	26.3	26.3	25.9	28.0		
	09	10.2	14.3	14.4	13.5	15.2	R 097	-22.6
	10	13.5	12.7	12.9	13.3	8.0		
	11	0.7	0.6	0.6	0.6	0.1	R 098	-26.2
	12	1.5	1.2	1.2	1.2	1.0		
	13						R 099	-23.9
	14							
	15							
	16							
	17							
	18	0.5	0.2	0.2	0.2	0.4		
	19	0.2	0.1	0.1		0.2		
	20						R 100	4.3
	21							
	22							
	23							
	24	0.6	0.5	0.5	0.5	0.7	R 101	-2.2
	25							
	26	0.8	0.8	0.8	0.5	1.4		
	27	0.3				0.1	R 102	15.0
	28							
	29							
	30							
October	01	1.3	1.7	1.9	1.4	2.4		
	02						R 103	-1.1
	03							
	04							
	05							
	06							
	07							
	08	3.0	2.7	2.7	2.6	3.4		
	09	15.5	15.2	14.8	13.8	15.6	R 104	1.0
	10	9.5	8.9	8.6	8.0	9.5		
	11						R 105	2.9
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22							
	23	0.2	0.1	0.1	0.1	0.1	R 106	28.4
	24							
	25							
	26							
	27							
	28	1.4	1.4	1.4	1.5	1.8	R 107	11.4
	29							
	30							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	31							
November	01							
	02							
	03							
	04							
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22	5.5	5.4	5.3	5.1	5.2	R 108	-5.1
	23	0.2						
	24							
	25							
	26	1.3	1.2	1.2	1.1	1.0		
	27	0.1	0.1	0.1	0.1	0.1	R 109	2.8
	28							
	29							
	30							
December	01							
	02							
	03							
	04							
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17	0.3	0.0	0.0	0.0	TR	R 110	23.4
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							

Month	Day	UWA Field Stn	East Lake Gauge #1	East Lake Gauge #2	Floating Pan	West Lake	Isotope Sample	Deuterium permil
	26							
	27							
	28							
	29							
	30							
	31							
1998								
January	01							
	02							
	03							
	04							
	05							
	06							
	07							
	08							
	09							
	10							
	11							
	12							
	13							
	14	0.5	0.5	0.5	0.5	1.4	R 111	11.4
	15							
	16	TR	TR	TR	TR	Not read		
	17	1.5	1.6	1.6	1.5	1.8	R 112	-1.1
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							
	30				Maximum deuterium enrichment			34.4
	31	Data ends			Maximum deuterium depletion			-71.0
Totals 1997		644.5	651.4	650.5	542.8*	646.0		

*Floating pan was in a slight rain shadow from trees. It was essential it had its own gauge

CHAPTER
7

APPENDICES

All piezometers and water table monitoring wells in Perry lakes reserve were read manually once a week regardless of whether they were equipped with a water level data logger or not. There were a number of reasons for this:

- many wells had no data logger, therefore weekly data was a minimum requirement for plotting local flow nets
- manual data provided calibration data for the data loggers which were known to drift in response to seasonal (probably temperature) changes
- manual data would fill gaps where data loggers failed (as they inevitably did)

Over time the number of wells monitored was expanded to include a number of nearby abandoned bores and some irrigation bores which could be monitored over winter. Refer to Figure 3.3 (in thesis text) and Appendix 2.1 for well locations.

Column 2 includes the top of casing (TOC) elevation in metres AHD. This was optically levelled from Department of Lands bench marks and surveyed points within Perry Lakes Reserve including Water Authority control point 1413 on the concrete apron of the East Lake flood remediation station (Figure 3.10a) and Australian Survey Office plan AO-495 Control Point 27 located in the asphalt road adjacent to West Lake (Figure 3.10b). All collar heights and manual SWL measurements are considered accurate to ± 1mm.

All levels were read with an electronic sounder in which the slightly saline groundwater completes the circuit between two electrodes in a small weighted probe. When data loggers are removed from a well, water levels read low until the water displaced by the logger sensor is replaced. All such wells were allowed to re-establish equilibrium before reading, a process which took up to 10 minutes per well.

Manual Well Levels Appendix 7.1

Well	TOC	2-5-96	29-5-96	19-6-96	4-7-96	22-7-96	29-7-96	5-8-96
PL1	7.079	2.779	2.844		3.210	3.329	3.434	3.491
WL1	5.722	2.717	2.784	2.897	3.158	3.232	3.410	3.434
WL2	5.480	2.720	2.765	2.910	3.190	3.271	3.401	3.410
WL3	5.308	2.688	2.726	2.941	3.202	3.222	3.378	3.380
N1a	4.857	2.672	2.700	2.977				
N1b	4.945	2.675	2.704	2.967				
N1c	5.013	2.673	2.704	2.955				
N2a	5.083	2.328	2.286	2.532				
N2b	5.138	2.353	2.311	2.578				
N2c	5.214	2.364	2.315	2.574				
WL4	5.806	2.271	2.237	2.418	2.636	2.700	2.804	2.848
WL5	7.426	2.156	2.126	2.254	2.438	2.526	2.590	2.652
WL6	3.427							
WL7	3.507							
WL8	3.489							
WL9	4.221							
WL10	4.955	2.510	2.459	2.777	3.023	3.045	3.173	3.190
WL11	5.345	2.480	2.424	2.716	2.973	2.989	3.122	3.147
WL12	5.836	2.421	2.362	2.614	2.877	2.930	3.041	3.074
PL2	4.953							
WL13	5.228	2.758	2.706	2.948	3.209	3.208	3.338	3.360
WL14	5.212	2.792	2.777	2.977	3.229	3.238	3.400	3.387
WL15	5.327	2.847	2.824	2.976	3.236	3.257	3.412	3.402
WL16	5.288	2.903	2.884	2.996	3.250	3.274	3.428	3.418
WL17	5.088	2.898	2.963	3.034	3.274	3.297	3.443	3.444
W26A	3.812							
WL18	5.746	2.846	2.881	3.089	3.364	3.446	3.586	3.596
WL19	5.726	2.866	2.928	3.081	3.357	3.412	3.555	3.554
WL20	5.439	2.889	2.956	3.112	3.349	3.383	3.518	3.514
N3a	4.982	2.877	2.939	3.109				
N3b	5.106	2.901	2.967	3.126				
N3c	5.254	2.894	2.967	3.124				
N4a	4.655	2.895	2.887	2.952				
N4b	4.800	2.890	2.881	2.957				
N4c	4.905	2.740	2.660	2.848				
WL21	5.071	2.831	2.793	2.904	3.127	3.165	3.301	3.313
WL22	5.067	2.747	2.668	2.845	3.073	3.091	3.247	3.265
WL23	5.096	2.506	2.276	2.671	2.914	2.950	3.114	3.130
WL24	5.170	2.375	1.954	2.592	2.816	2.880	3.018	3.032
WL25	2.817							
N5a	11.075	1.950	1.897	2.037				
N5b	11.111	1.971	1.916	2.054				
N5c	11.130	1.965	1.918	2.052				
W27	3.125							
Abd Bore #8	6.159			2.884	3.142	3.255	3.362	3.401
CSIRO #1	18.660							
Ag (old bore)	12.661							
Ag (old well)	16.914							
Lemnos St	8.401							
GE1 Bold Park	15.301							
City Beach HS	47.744							
Tennis Ct #11	9.864							
Chandler Dr #10	9.022							
McLean Park #12	9.867							
McGillivray #85	9.094							
Henderson Pk	11.370							

Well	13-8-96	19-8-96	26-8-96	02-9-96	09-9-96	16-9-96	22-9-96	1-10-96
PL1	3.521	3.548	3.561	3.569	3.581	3.615	3.641	3.679
WL1	3.432	3.474	3.484	3.469	3.494	3.540	3.561	3.596
WL2	3.422	3.433	3.437	3.438	3.443	3.492	3.511	3.542
WL3	3.396	3.389	3.390	3.382	3.393	3.443	3.465	3.485
N1a			3.352	3.345	3.351	3.411	3.434	3.443
N1b			3.360	3.353	3.361	3.420	3.443	3.455
N1c			3.363	3.355	3.364	3.420	3.444	3.456
N2a			2.978	2.984	2.995	3.046	3.058	3.075
N2b			3.010	3.009	3.026	3.077	3.086	3.104
N2c			3.009	3.011	3.027	3.076	3.086	3.104
WL4	2.863	2.880	2.883	2.893	2.903	2.952	2.965	2.986
WL5	2.686	2.704	2.720	2.726	2.748	2.788	2.798	2.822
WL6		3.295	3.307	3.297	3.294	3.344	3.349	3.365
WL7		3.285	3.287	3.273	3.278	3.338	3.371	3.362
WL8		3.275	3.281	3.265	3.261	3.337	3.363	3.364
WL9		3.104	3.226	3.207	3.211	3.252	3.292	3.322
WL10	3.201	3.180	3.181	3.171	3.189	3.248	3.259	3.267
WL11	3.161	3.147	3.149	3.140	3.159	3.214	3.221	3.233
WL12	3.088	3.083	3.086	3.078	3.098	3.147	3.151	3.170
PL2			3.328	3.317	3.325	3.385	3.409	3.414
WL13	3.378	3.358	3.356	3.345	3.350	3.410	3.431	3.442
WL14	3.401	3.381	3.379	3.368	3.374	3.427	3.452	3.463
WL15	3.411	3.400	3.394	3.385	3.388	3.442	3.463	3.479
WL16	3.436	3.420	3.415	3.403	3.409	3.461	3.484	3.499
WL17	3.461	3.442	3.440	3.430	3.433	3.485	3.511	3.521
W26A								
WL18	3.609	3.636	3.636	3.638	3.646	3.684	3.708	3.741
WL19	3.566	3.568	3.568	3.568	3.574	3.621	3.634	3.661
WL20	3.540	3.523	3.525	3.512	3.529	3.574	3.592	3.614
N3a			3.467	3.464	3.468	3.509	3.534	3.544
N3b			3.497	3.493	3.498	3.542	3.566	3.579
N3c			3.499	3.494	3.501	3.545	3.569	3.582
N4a			3.335	3.323	3.328	3.378	3.405	3.407
N4b			3.337	3.328	3.333	3.385	3.408	3.412
N4c			3.268	3.264	3.273	3.318	3.338	3.347
WL21	3.331	3.315	3.313	3.300	3.308	3.355	3.377	3.383
WL22	3.281	3.274	3.269	3.259	3.268	3.315	3.333	3.340
WL23	3.150	3.151	3.154	3.146	3.163	3.205	3.219	3.231
WL24	3.057	3.045	3.060	3.056	3.079	3.121	3.137	3.142
WL25	2.257	2.285	2.357	2.347	2.369	2.397	2.412	2.437
N5a			2.553	2.581	2.601	2.628	2.640	2.668
N5b			2.571	2.598	2.617	2.644	2.657	2.683
N5c			2.572	2.598	2.619	2.647	2.660	2.686
W27								
Abd Bore #8	3.428	3.457	3.467	3.477	3.491	3.530	3.549	3.587
CSIRO #1	3.228	3.283	3.328	3.365	3.392	3.422	3.443	3.472
Ag (old bore)	3.391	3.441	3.479	3.518	3.549	3.586	3.608	3.619
Ag (old well)	3.354	3.404	3.429	3.478	3.510	3.544	3.568	3.555
Lemnos St				3.079	3.107	3.134	3.163	3.187
GE1 Bold Park								
City Beach HS								
Tennis Ct #11								
Chandler Dr #10								
McLean Park #12								
McGillivray #85								
Henderson Pk								

Well	7-10-96	14-10-96	21-10-96	28-10-96	04-11-96	11-11-96	18-11-96	25-11-96
PL1	3.684	3.680	3.643	3.667	3.617	3.594	3.613	3.539
WL1	3.592	3.560	3.547	3.573	3.493	3.452	3.517	3.395
WL2	3.533	3.509	3.490	3.515	3.442	3.416	3.486	3.378
WL3	3.463	3.444	3.433	3.447	3.388	3.375	3.429	3.355
N1a	3.415	3.396	3.394	3.398	3.343	3.330	3.390	3.320
N1b	3.427	3.407	3.404	3.409	3.353	3.341	3.400	3.327
N1c	3.434	3.410	3.411	3.417	3.357	3.340	3.404	3.321
N2a	3.062	3.056	3.036	3.053	3.020	2.996	3.055	3.021
N2b	3.088	3.079	3.061	3.078	3.041	3.013	3.075	3.030
N2c	3.089	3.080	3.061	3.079	3.044	3.011	3.075	3.025
WL4	2.977	2.973	2.950	2.972	2.945	2.923	2.967	2.941
WL5	2.827	2.828	2.814	2.832	2.816	2.793	2.813	2.797
WL6	3.365	3.350	3.338	3.345	3.329	3.316	3.322	3.312
WL7	3.331	3.317	3.348	3.319	3.265	3.240	3.317	3.244
WL8	3.335	3.306	3.339	3.305	3.253	3.231	3.310	3.236
WL9	3.309	3.299	3.283	3.281	3.273	3.260	3.261	3.252
WL10	3.240	3.225	3.205	3.221	3.177	3.141	3.222	3.155
WL11	3.209	3.195	3.167	3.189	3.145	3.107	3.188	3.125
WL12	3.150	3.136	3.098	3.131	3.089	3.048	3.124	3.068
PL2	3.384	3.365	3.374	3.366	3.313	3.297	3.363	3.300
WL13	3.413	3.392	3.399	3.398	3.341	3.329	3.391	3.338
WL14	3.436	3.415	3.428	3.420	3.363	3.353	3.412	3.352
WL15	3.452	3.429	3.436	3.439	3.378	3.376	3.429	3.370
WL16	3.473	3.449	3.461	3.463	3.400	3.402	3.451	3.386
WL17	3.494	3.469	3.494	3.490	3.419	3.430	3.475	3.392
W26A								
WL18	3.737	3.726	3.681	3.724	3.668	3.612	3.699	3.625
WL19	3.651	3.633	3.619	3.633	3.583	3.557	3.629	3.582
WL20	3.592	3.576	3.580	3.592	3.530	3.515	3.578	3.521
N3a	3.524	3.505	3.527	3.524	3.462	3.465	3.509	3.409
N3b	3.558	3.539	3.557	3.557	3.495	3.498	3.543	3.437
N3c	3.561	3.542	3.559	3.560	3.497	3.499	3.544	3.484
N4a	3.382	3.360	3.379	3.378	3.318	3.296	3.366	3.290
N4b	3.386	3.364	3.382	3.382	3.322	3.295	3.368	3.291
N4c	3.326	3.309	3.297	3.315	3.262	3.168	3.296	3.206
WL21	3.360	3.340	3.343	3.351	3.293	3.244	3.337	3.261
WL22	3.322	3.304	3.289	3.309	3.256	3.169	3.295	3.212
WL23	3.215	3.198	3.141	3.189	3.147	2.914	3.178	3.069
WL24	3.127	3.115	3.042	3.102	3.062	2.646	3.086	2.957
WL25	2.447	2.456	2.450	2.453	2.442	2.430	2.423	2.410
N5a	2.673	2.678	2.638	2.666	2.648	2.606	2.625	2.597
N5b	2.691	2.695	2.656	2.682	2.664	2.622	2.641	2.613
N5c	2.691	2.695	2.654	2.681	2.664	2.621	2.639	2.609
W27								
Abd Bore #8	3.590	3.578	3.556	3.575	3.517	3.490	3.516	3.361
CSIRO #1	3.482	3.489	3.451	3.482	3.444	3.437	3.422	3.389
Ag (old bore)		3.659	3.631	3.659	3.610	3.588	3.600	3.573
Ag (old well)		3.596	3.567	3.598	3.567	3.530	3.562	3.555
Lemnos St	3.196	3.195	3.179	3.197	3.163	3.165	3.185	3.154
GE1 Bold Park								
City Beach HS								
Tennis Ct #11								
Chandler Dr #10								
McLean Park #12								
McGillivray #85								
Henderson Pk								

Well	02-12-96	09-12-96	16-12-96	23-12-96	24-12-96	30-12-96	06-01-97	13-01-97
PL1	3.524	3.441	3.427	3.356		3.334	3.314	3.210
WL1	3.433	3.278	3.314	3.218		3.205	3.232	3.092
WL2	3.393	3.277	3.291	3.212		3.182	3.188	3.073
WL3	3.339	3.257	3.248	3.188		3.149	3.135	3.036
N1a	3.297	3.237	3.204	3.156		3.119	3.099	3.009
N1b	3.307	3.232	3.212	3.159		3.121	3.104	3.010
N1c	3.313	3.228	3.213	3.145		3.112	3.099	3.003
N2a	2.970	2.909	2.863	2.795		2.752	2.695	2.643
N2b	2.987	2.920	2.879	2.815		2.770	2.715	2.659
N2c	2.986	2.917	2.881	2.795		2.775	2.725	2.668
WL4	2.894	2.839	2.797	2.746		2.706	2.652	2.603
WL5	2.760	2.716	2.677	2.640		2.609	2.563	2.520
WL6	3.294	3.270	3.250	3.224		3.195	3.164	3.128
WL7	3.219	3.150	3.118	3.059		3.010	2.981	2.891
WL8	3.206	3.139	3.107	3.041		2.993	2.952	2.868
WL9	3.229	3.198	3.165	3.133		3.098	3.054	3.014
WL10	3.116	3.044	3.007	2.938		2.892	2.845	2.774
WL11	3.084	3.014	2.976	2.908		2.863	2.813	2.747
WL12	3.024	2.957	2.915	2.854		2.812	2.757	2.696
PL2	3.265	3.203	3.176	3.125		3.068	3.065	2.956
WL13	3.292	3.233	3.211	3.161		3.104	3.120	2.998
WL14	3.313	3.254	3.239	3.181		3.133	3.161	3.034
WL15	3.332	3.275	3.266	3.200		3.153	3.189	3.052
WL16	3.360	3.294	3.300	3.226		3.189	3.200	3.083
WL17	3.390	3.321	3.341	3.258		3.223	3.220	3.124
W26A								
WL18	3.598	3.531	3.501	3.429		3.400	3.361	3.304
WL19	3.534	3.476	3.463	3.387		3.345	3.308	3.246
WL20	3.480	3.428	3.420	3.344		3.301	3.267	3.206
N3a	3.421	3.362	3.364	3.286		3.245	3.215	3.155
N3b	3.452	3.393	3.398	3.313		3.272	3.244	3.183
N3c	3.454	3.395	3.398	3.316		3.272	3.246	3.184
N4a	3.277	3.206	3.234	3.147		3.084	3.082	3.027
N4b	3.279	3.203	3.232	3.147		3.081	3.079	3.024
N4c	3.191	3.058	3.120	3.028		2.953	2.968	2.895
WL21	3.241	3.150	3.183	3.096		3.032	3.031	2.975
WL22	3.189	3.069	3.117	3.026	3.061	2.960	2.964	2.911
WL23	3.038	2.792	2.930	2.788	2.897	2.710	2.776	2.726
WL24	2.926	2.538	2.806	2.582	2.792	2.491	2.656	2.603
WL25	2.387	2.350	2.322	2.294		2.269	2.234	2.207
N5a	2.559	2.498	2.467	2.429		2.406	2.360	2.318
N5b	2.575	2.514	2.484	2.446		2.423	2.379	2.336
N5c	2.573	2.511	2.482	2.441		2.417	2.373	2.331
W27								
Abd Bore #8	3.436		3.367		3.279		3.245	
CSIRO #1	3.392	3.361	3.329	3.275	3.275	3.265	3.236	3.165
Ag (old bore)	3.580	3.553	3.532	3.498		3.483	3.450	3.388
Ag (old well)	3.572	3.508	3.488	3.462		3.486	3.457	3.457
Lemnos St	3.138	3.109	3.072	3.046		3.017	2.977	2.929
GE1 Bold Park								
City Beach HS								
Tennis Ct #11								
Chandler Dr #10								
McLean Park #12								
McGillivray #85								
Henderson Pk								

Well	16-01-97	18-01-97	20-01-97	21-01-97	27-01-97	03-02-97	10-02-97	17-02-97
PL1			3.156		3.125	3.025	2.955	2.916
WL1			3.016		3.026	2.873	2.804	2.779
WL2			2.999		2.992	2.867	2.812	2.782
WL3			2.973		2.951	2.849	2.796	2.768
N1a			2.950		2.921	2.829	2.775	2.751
N1b			2.948		2.924	2.828	2.777	2.752
N1c			2.933		2.915	2.818	2.766	2.740
N2a			2.598		2.579	2.528	2.475	2.435
N2b			2.609		2.590	2.534	2.484	2.448
N2c			2.615		2.596	2.539	2.490	2.454
WL4			2.563		2.538	2.492	2.442	2.407
WL5			2.483		2.453	2.414	2.370	2.336
WL6	3.110	3.102	3.089		3.050	3.020	2.976	2.699
WL7	2.843	2.864	2.830		2.804	2.735	2.691	2.670
WL8	2.823	2.841	2.806		2.781	2.715	2.669	2.647
WL9	2.998	2.986	2.972		2.933	2.893	2.853	2.565
WL10	2.729	2.746	2.710		2.693	2.622	2.577	2.542
WL11	2.706	2.721	2.685		2.668	2.598	2.552	2.521
WL12	2.665	2.679	2.640		2.623	2.557	2.509	2.471
PL2			2.893		2.862	2.786	2.745	2.728
WL13			2.929		2.893	2.820	2.777	2.765
WL14			2.960		2.922	2.845	2.805	2.799
WL15			2.993		2.946	2.867	2.841	2.831
WL16			3.015		2.980	2.899	2.868	2.876
WL17			3.046		3.018	2.935	2.910	2.929
W26A								
WL18			3.199		3.170	3.102	3.090	2.980
WL19			3.160		3.126	3.064	3.034	2.986
WL20			3.131		3.092	3.031	3.000	2.982
N3a			3.084		3.047	2.981	2.956	2.949
N3b			3.105		3.073	3.005	2.979	2.972
N3c			3.105		3.072	3.005	2.980	2.972
N4a			2.946		2.943	2.868	2.867	2.870
N4b			2.942		2.940	2.863	2.862	2.863
N4c			2.798		2.836	2.724	2.721	2.681
WL21			2.883		2.894	2.807	2.803	2.791
WL22			2.797	2.865	2.830	2.727	2.724	2.690
WL23			2.488	2.692	2.656	2.477	2.467	2.388
WL24			2.177	2.574	2.543	2.270	2.272	2.166
WL25			2.175		2.150	2.122	2.089	2.060
N5a			2.282		2.255	2.212	2.166	2.117
N5b			2.297		2.273	2.231	2.183	2.137
N5c			2.291		2.269	2.225	2.178	2.131
W27								
Abd Bore #8					3.051			
CSIRO #1			3.104		3.044	2.994	2.946	2.896
Ag (old bore)			3.334		3.283	3.216	3.166	3.119
Ag (old well)			3.354		3.257	3.176	3.117	3.087
Lemnos St			2.897		2.848	2.798	2.738	2.709
GE1 Bold Park								
City Beach HS								
Tennis Ct #11								
Chandler Dr #10								
McLean Park #12								
McGillivray #85								
Henderson Pk								

Well	24-02-97	03-03-97	10-03-97	17-03-97	24-03-97	31-03-97	07-04-97	14-04-97
PL1	2.961	2.916	2.880	2.781	2.833	2.894	2.983	3.012
WL1	2.886	2.848	2.808	2.663	2.770	2.885	2.955	2.961
WL2	2.861	2.812	2.776	2.690	2.741	2.897	2.934	2.929
WL3	2.826	2.770	2.735	2.713	2.701	2.918	2.911	2.893
N1a	2.799	2.740	2.710	2.729	2.675	2.949	2.901	2.872
N1b	2.800	2.745	2.715	2.721	2.677	2.941	2.902	2.874
N1c	2.793	2.738	2.711	2.690	2.675	2.926	2.893	2.866
N2a	2.445	2.382	2.381	2.383	2.329	2.550	2.542	2.496
N2b	2.456	2.390	2.399	2.408	2.348	2.585	2.573	2.525
N2c	2.461	2.394	2.405	2.413	2.356	2.587	2.579	2.532
WL4	2.403	2.351	2.341	2.339	2.293	2.450	2.470	2.432
WL5	2.317	2.274	2.260	2.248	2.215	2.288	2.329	2.306
WL6	2.889	2.699	2.682	2.645	2.597	2.939	2.916	2.876
WL7	2.684	2.633	2.624	2.639	2.593	2.931	2.860	2.804
WL8	2.659	2.606	2.605	2.632	2.570	2.947	2.851	2.789
WL9	2.762	2.651	2.548	2.535	2.498	2.723	2.819	2.757
WL10	2.558	2.484	2.507	2.550	2.513	2.793	2.748	2.684
WL11	2.531	2.455	2.481	2.527	2.437	2.737	2.712	2.652
WL12	2.482	2.407	2.433	2.513	2.388	2.638	2.648	2.590
PL2	2.743	2.694	2.671	2.671	2.647	2.953	2.894	2.849
WL13	2.776	2.730	2.702	2.690	2.681	2.971	2.943	2.882
WL14	2.808	2.769	2.729	2.710	2.768	2.990	2.943	2.909
WL15	2.834	2.805	2.752	2.721	2.757	3.007	2.962	2.930
WL16	2.872	2.855	2.785	2.749	2.805	3.041	2.991	2.963
WL17	2.911	2.915	2.823	2.780	2.871	3.085	3.030	3.001
W26A								
WL18	3.076	2.976	2.991	2.857	2.902	3.087	3.121	3.127
WL19	3.030	2.961	2.948	2.853	2.906	3.137	3.100	3.088
WL20	3.001	2.950	2.914	2.843	2.901	3.150	3.083	3.066
N3a	2.957	2.920	2.864	2.807	2.877	3.128	3.055	3.032
N3b	2.980	2.946	2.888	2.826	2.901	3.144	3.074	3.050
N3c	2.980	2.946	2.887	2.824	2.903	3.142	3.075	3.052
N4a	2.845	2.822	2.773	2.765	2.820	3.013	2.970	2.932
N4b	2.841	2.814	2.770	2.763	2.813	3.007	2.968	2.931
N4c	2.718	2.601	2.664	2.657	2.645	2.858	2.859	2.823
WL21	2.784	2.724	2.720	2.712	2.731	2.941	2.923	2.884
WL22	2.711	2.606	2.656	2.651	2.629	2.855	2.861	2.820
WL23	2.512	2.227	2.482	2.502	2.337	2.643	2.698	2.649
WL24	2.399	1.914	2.366	2.405	2.131	2.552	2.596	2.542
WL25	2.031	1.999	1.978	1.957	1.931	1.934	1.958	1.954
N5a	2.106	2.042	2.059	2.062	1.987	2.042	2.118	2.107
N5b	2.124	2.061	2.078	2.081	2.007	2.061	2.135	2.123
N5c	2.119	2.053	2.071	2.072	2.001	2.052	2.128	2.116
W27								
Abd Bore #8	2.894	2.848	2.822		2.774	2.856	2.924	2.943
CSIRO #1	2.857	2.809	2.768	2.748	2.713	2.763	2.832	2.852
Ag (old bore)	3.083	3.033	3.003	2.970	2.938	2.976	3.019	3.033
Ag (old well)	3.053	3.016	3.028	2.996	2.961	2.970	3.009	3.031
Lemnos St	2.685	2.645	2.612	2.578	2.556	2.613	2.627	2.634
GE1 Bold Park								
City Beach HS								
Tennis Ct #11								
Chandler Dr #10								
McLean Park #12								
McGillivray #85								
Henderson Pk								

Well	21-04-97	28-04-97	05-05-97	12-05-97	19-05-97	26-05-97	02-06-97	09-06-97
PL1	3.011	3.009	3.029	3.027	3.039	3.058	3.126	3.229
WL1	2.958	2.935	2.960	2.950	2.972	2.988	3.077	3.187
WL2	2.940	2.896	2.922	2.916	2.942	2.958	3.079	3.172
WL3	2.923	2.850	2.883	2.871	2.914	2.923	3.095	3.160
N1a	2.924	2.822	2.862	2.852	2.907	2.905	3.118	3.159
N1b	2.918	2.825	2.863	2.860	2.903	2.907	3.115	3.158
N1c	2.892	2.815	2.850	2.853	2.877	2.895	3.100	3.145
N2a	2.474	2.431	2.461	2.435	2.438	2.489	2.650	2.731
N2b	2.506	2.455	2.489	2.463	2.469	2.523	2.691	2.765
N2c	2.511	2.461	2.496	2.474	2.471	2.529	2.689	2.762
WL4	2.404	2.378	2.401	2.374	2.378	2.422	2.537	2.619
WL5	2.281	2.271	2.285	2.274	2.266	2.297	2.356	2.433
WL6	2.808	2.745	2.773	2.722	2.741	2.836	3.114	3.123
WL7	2.805	2.719	2.753	2.735	2.754	2.801	3.095	3.109
WL8	2.780	2.700	2.733	2.700	2.729	2.786	3.102	3.113
WL9	2.695	2.668	2.673	2.663	2.653	2.708	2.890	2.926
WL10	2.662	2.591	2.631	2.601	2.616	2.677	2.898	2.964
WL11	2.626	2.562	2.601	2.571	2.581	2.640	2.837	2.914
WL12	2.559	2.514	2.546	2.523	2.519	2.576	2.731	2.824
PL2	2.855	2.765	2.795	2.773	2.806	2.848	3.100	3.136
WL13	2.880	2.848	2.820	2.778	2.832	2.871	3.109	3.154
WL14	2.909	2.820	2.841	2.814	2.858	2.894	3.133	3.174
WL15	2.929	2.835	2.853	2.830	2.877	2.907	3.133	3.181
WL16	2.964	2.859	2.875	2.855	2.903	2.930	3.160	3.203
WL17	3.004	2.884	2.899	2.886	2.937	2.958	3.200	3.233
W26A								
WL18	3.128	3.091	3.107	3.093	3.114	3.135	3.281	3.363
WL19	3.099	3.030	3.043	3.028	3.066	3.081	3.266	3.337
WL20	3.089	2.991	3.004	2.982	3.036	3.049	3.269	3.317
N3a	3.065	2.949	2.964	2.943	2.993	3.002	3.272	3.290
N3b	3.081	2.967	2.981	2.962	3.018	3.028	3.278	3.302
N3c	3.078	2.968	2.982	2.961	3.016	3.030	3.277	3.301
N4a	2.923	2.812	2.798	2.772	2.834	2.853	3.086	3.121
N4b	2.921	2.812	2.801	2.776	2.832	2.853	3.084	3.121
N4c	2.805	2.743	2.743	2.718	2.745	2.772	2.958	3.012
WL21	2.869	2.776	2.768	2.744	2.788	2.814	3.025	3.074
WL22	2.799	2.729	2.728	2.701	2.730	2.760	2.950	3.015
WL23	2.612	2.592	2.603	2.574	2.574	2.616	2.758	2.850
WL24	2.498	2.492	2.512	2.485	2.473	2.521	2.692	2.771
WL25	1.949	1.949	1.956	1.952	1.935	1.942	1.979	2.020
N5a	2.086	2.100	2.114	2.111	2.081	2.100	2.125	2.203
N5b	2.104	2.114	2.131	2.129	2.100	2.119	2.142	2.219
N5c	2.097	2.106	2.126	2.124	2.093	2.112	2.137	2.213
W27								
Abd Bore #8	2.941	2.935	2.956	2.951	2.966	2.984	3.057	3.152
CSIRO #1	2.845	2.873	2.874	2.880	2.850	2.844	2.892	2.932
Ag (old bore)	3.042	3.050	3.065	3.073	3.056	3.048	3.093	3.129
Ag (old well)	3.051	3.064	3.070	3.086	3.070	3.063	3.092	3.130
Lemnos St	2.619	2.614	2.624	2.632	2.608	2.637	2.734	2.797
GE1 Bold Park						1.182	1.204	1.231
City Beach HS								
Tennis Ct #11								
Chandler Dr #10								
McLean Park #12								
McGillivray #85								
Henderson Pk								

Well	16-06-97	23-06-97	30-06-97	07-07-97	14-07-97	21-07-97	28-07-97	04-08-97
PL1	3.279	3.285	3.278	3.297	3.335	3.364	3.385	3.400
WL1	3.224	3.213	3.197	3.221	3.264	3.287	3.302	3.317
WL2	3.187	3.172	3.152	3.192	3.233	3.243	3.260	3.276
WL3	3.147	3.129	3.103	3.159	3.201	3.191	3.210	3.230
N1a	3.120	3.099	3.070	3.140	3.185	3.156	3.177	3.199
N1b	3.125	3.105	3.077	3.143	3.188	3.163	3.185	3.207
N1c	3.083	3.095	3.068	3.135	3.180	3.113	3.180	3.204
N2a	2.712	2.695	2.668	2.729	2.783	2.771	2.791	2.805
N2b	2.739	2.725	2.698	2.764	2.816	2.800	2.820	2.837
N2c	2.739	2.727	2.704	2.766	2.816	2.784	2.822	2.837
WL4	2.618	2.613	2.598	2.639	2.687	2.691	2.707	2.718
WL5	2.454	2.464	2.466	2.485	2.527	2.547	2.561	2.574
WL6	3.107	3.033	3.002	3.092	3.134	3.093	3.121	3.146
WL7	3.051	3.012	2.970	3.069	3.118	3.075	3.099	3.128
WL8	3.045	2.999	2.954	3.069	3.117	3.066	3.091	3.121
WL9	3.008	2.972	2.938	2.983	3.037	3.032	3.027	3.032
WL10	2.918	2.893	2.857	2.938	2.988	2.961	2.981	2.998
WL11	2.873	2.856	2.822	2.896	2.946	2.925	2.943	2.957
WL12	5.497	2.791	2.763	2.822	2.869	2.862	2.879	2.889
PL2	3.095	3.057	3.017	3.103	3.151	3.116	3.139	3.162
WL13	3.123	3.085	3.046	3.116	3.170	3.156	3.161	3.180
WL14	3.148	3.109	3.069	3.142	3.189	3.162	3.183	3.199
WL15	3.167	3.127	3.087	3.149	3.197	3.175	3.194	3.209
WL16	3.193	3.151	3.110	3.169	3.216	3.195	3.214	3.231
WL17	3.228	3.180	3.136	3.193	3.239	3.215	3.235	3.255
W26A							3.277	3.318
WL18	3.389	3.366	3.343	3.379	3.419	3.429	3.446	3.461
WL19	3.346	3.308	3.274	3.326	3.366	3.360	3.377	3.398
WL20	3.311	3.268	3.227	3.295	3.334	3.309	3.332	3.359
N3a	3.274	3.229	3.184	3.266	3.305	3.274	3.302	3.341
N3b	3.288	3.243	3.200	3.278	3.318	3.279	3.307	3.345
N3c	3.286	3.245	3.201	3.277	3.316	3.274	3.306	3.344
N4a	3.107	3.068	3.020	3.068	3.118	3.093	3.113	3.133
N4b	3.103	3.068	3.020	3.068	3.117	3.090	3.109	3.129
N4c	2.992	2.982	2.947	2.992	3.037	3.017	3.036	3.056
WL21	3.058	3.032	2.986	3.032	3.081	3.058	3.076	3.094
WL22	2.994	2.981	2.944	2.984	3.034	3.019	3.034	3.051
WL23	2.808	2.842	2.818	2.855	2.903	2.899	2.913	2.930
WL24	2.710	2.762	2.748	2.789	2.837	2.829	2.845	2.865
WL25	2.047	2.070	2.090	2.109	2.136	2.155	2.171	2.188
N5a	2.215	2.264	2.283	2.301	2.335	2.356	2.368	2.384
N5b	2.231	2.280	2.300	2.317	2.351	2.372	2.386	2.400
N5c	2.226	2.272	2.295	2.312	2.346	2.366	2.380	2.395
W27								
Abd Bore #8	3.197	3.200	3.193	3.215	3.256	3.281	3.299	3.318
CSIRO #1	2.978	3.011	3.038	3.061	3.085	3.105	3.122	3.141
Ag (old bore)	3.164	3.197	3.221	3.250	3.277	3.289	3.313	3.331
Ag (old well)	3.166	3.197	3.224	3.249	3.273	3.291	3.310	3.314
Lemnos St	2.818	2.808	2.800	2.831	2.864	2.867	2.887	2.908
GE1 Bold Park	1.255	1.268	1.280	1.288	1.302	1.308	1.314	1.325
City Beach HS		2.142	2.236	2.241	2.262	2.286	2.295	2.302
Tennis Ct #11	3.613	3.644	3.662	3.691	3.715	3.723	3.762	3.794
Chandler Dr #10	3.595	3.625	3.644	3.668	3.689		3.745	3.782
McLean Park #12		3.635	3.659	3.683	3.712	3.727	3.769	3.799
McGillivray #85		2.242	2.260	2.276	2.314	2.311	2.308	2.337
Henderson Pk				6.568	6.595	6.600	6.615	6.629

Well	11-08-97	18-08-97	25-08-97	01-09-97	08-09-97	15-09-97	22-09-97	29-09-97
PL1	3.441	3.511	3.524	3.536	3.590	3.722	3.710	3.695
WL1	3.371	3.435	3.433	3.444	3.525	3.645	3.612	3.591
WL2	3.331	3.390	3.382	3.392	3.493	3.602	3.560	3.535
WL3	3.290	3.338	3.320	3.334	3.463	3.546	3.498	3.468
N1a	3.268	3.304	3.275	3.294	3.460	3.506	3.454	3.420
N1b	3.273	3.311	3.285	3.303	3.462	3.515	3.464	3.432
N1c	3.266	3.306	3.265	3.301	3.454	3.510	3.455	3.435
N2a	2.864	2.912	2.906	2.926	3.025	3.119	3.092	3.064
N2b	2.895	2.940	2.930	2.953	3.058	3.144	3.117	3.089
N2c	2.895	2.937	2.930	2.953	3.055	3.142	3.114	3.089
WL4	2.773	2.815	2.819	2.836	2.914	3.013	2.998	2.976
WL5	2.606	2.647	2.666	2.680	2.722	2.817	2.829	2.821
WL6	3.210	3.249	3.222	3.240	3.467	3.447	3.411	3.374
WL7	3.197	3.227	3.195	3.243	3.420	3.442	3.384	3.345
WL8	3.196	3.225	3.187	3.240	3.424	3.436	3.378	3.338
WL9	3.115	3.164	3.157	3.156	3.294	3.395	3.367	3.308
WL10	3.067	3.114	3.089	3.110	3.257	3.334	3.281	3.244
WL11	3.023	3.072	3.053	3.072	3.203	3.295	3.244	3.207
WL12	2.948	3.003	2.992	3.008	3.111	3.230	3.183	3.147
PL2	3.228	3.269	3.239	3.254	3.437	3.477	3.423	3.385
WL13	3.251	3.309	3.282	3.280	3.448	3.510	3.451	3.413
WL14	3.268	3.314	3.286	3.300	3.471	3.530	3.472	3.435
WL15	3.277	3.326	3.300	3.311	3.467	3.545	3.487	3.450
WL16	3.296	3.343	3.320	3.331	3.485	3.562	3.509	3.472
WL17	3.318	3.360	3.338	3.349	3.510	3.577	3.530	3.493
W26A	3.362	3.393	3.370	3.380	3.539	3.598	3.554	3.525
WL18	3.516	3.577	3.571	3.579	3.680	3.797	3.757	3.733
WL19	3.454	3.506	3.492	3.498	3.612	3.721	3.675	3.645
WL20	3.415	3.454	3.436	3.444	3.575	3.661	3.619	3.588
N3a	3.387	3.420	3.398	3.409	3.552	3.620	3.578	3.545
N3b	3.391	3.425	3.404	3.416	3.557	3.629	3.589	3.557
N3c	3.389	3.424	3.400	3.415	3.556	3.629	3.586	3.557
N4a	3.196	3.238	3.217	3.240	3.395	3.463	3.420	3.386
N4b	3.192	3.234	3.212	3.235	3.388	3.458	3.414	3.381
N4c	3.111	3.156	3.143	3.165	3.296	3.377	3.339	3.312
WL21	3.154	3.202	3.184	3.201	3.348	3.431	3.385	3.351
WL22	3.109	3.159	3.146	3.160	3.299	3.390	3.344	3.310
WL23	2.980	3.036	3.029	3.040	3.161	3.263	3.220	3.189
WL24	2.914	2.963	2.958	2.970	3.113	3.187	3.147	3.118
WL25	2.208	2.231	2.251	2.267	2.307	2.346	2.369	2.383
N5a	2.404	2.438	2.462	2.478	2.510	2.584	2.617	2.625
N5b	2.421	2.453	2.477	2.494	2.525	2.600	2.631	2.640
N5c	2.415	2.449	2.471	2.489	2.520	2.592	2.624	2.633
W27								
Abd Bore #8	3.361	3.421	3.432	3.447	3.511	3.622	3.609	3.597
CSIRO #1	3.211	3.192	3.227	3.257	3.294	3.349	3.399	3.427
Ag (old bore)	3.347	3.374	3.403	3.437	3.481	3.533	3.571	3.589
Ag (old well)	3.336	3.318	3.379	3.406	3.446	3.486	3.529	3.556
Lemnos St	2.933	2.973	2.973	2.993	3.069	3.114	3.108	3.105
GE1 Bold Park	1.335	1.348	1.350	1.346	1.360	1.376	1.376	1.379
City Beach HS	2.310	2.331	2.347	2.372	2.391	2.402	2.417	2.426
Tennis Ct #11	3.827	3.867	3.895	3.924	3.987	4.059	4.087	4.092
Chandler Dr #10	3.810	3.862	3.887	3.915	3.963	4.067	4.089	
McLean Park #12	3.829	3.887	3.916	3.939	3.980	4.084	4.111	4.120
McGillivray #85	2.370	2.397	2.424	2.456	2.503	2.561	2.567	2.571
Henderson Pk	6.663	6.727	6.744	6.753	6.811	6.922	6.933	6.910

Well	06-10-97	12-10-97	19-10-97	26-10-97	02-11-97	09-11-97	16-11-97	23-11-97
PL1	3.673	3.672	3.638	3.573	3.520	3.469	3.422	3.398
WL1	3.569	3.570	3.538	3.477	3.425	3.384	3.339	3.315
WL2	3.509	3.516	3.482	3.424	3.375	3.337	3.291	3.268
WL3	3.440	3.453	3.415	3.360	3.311	3.271	3.228	3.208
N1a	3.391	3.412	3.371	3.317	3.267	3.225	3.183	3.167
N1b	3.402	3.420	3.380	3.326	3.277	3.235	3.194	3.175
N1c	3.406	3.423	3.385	3.330	3.280	3.237	3.195	3.173
N2a	3.040	3.051	3.023	2.983	2.949	2.909	2.854	2.815
N2b	3.065	3.076	3.047	3.006	2.963	2.921	2.870	2.833
N2c	3.066	3.075	3.047	3.006	2.962	2.922	2.873	2.836
WL4	2.957	2.960	2.940	2.903	2.873	2.839	2.790	2.751
WL5	2.811	2.811	2.798	2.767	2.733	2.705	2.661	2.629
WL6	3.340	3.360	3.323	3.273	3.222	3.180	3.139	3.098
WL7	3.309	3.336	3.293	3.241	3.187	3.135	3.090	3.063
WL8	3.301	3.329	3.284	3.231	3.173	3.124	3.076	3.047
WL9	3.278	3.280	3.249	3.199	3.144	3.096	3.050	3.003
WL10	3.211	3.228	3.191	3.147	3.094	3.049	3.004	2.962
WL11	3.177	3.189	3.157	3.113	3.062	3.018	2.975	2.930
WL12	3.118	3.128	3.097	3.055	3.008	2.967	2.919	2.877
PL2	3.352	3.373	3.334	3.282	3.233	3.185	3.140	3.111
WL13	3.382	3.400	3.361	3.306	3.260	3.211	3.171	3.138
WL14	3.404	3.419	3.381	3.324	3.280	3.230	3.185	3.155
WL15	3.420	3.433	3.397	3.339	3.294	3.245	3.200	3.164
WL16	3.443	3.454	3.416	3.358	3.316	3.262	3.221	3.182
WL17	3.461	3.476	3.438	3.378	3.328	3.274	3.228	3.198
W26A	3.493	3.510	3.467	3.412	3.359	3.301	3.251	3.219
WL18	3.712	3.711	3.681	3.634	3.598	3.546	3.499	3.471
WL19	3.620	3.624	3.593	3.546	3.511	3.456	3.413	3.382
WL20	3.560	3.569	3.535	3.485	3.444	3.387	3.327	3.311
N3a	3.520	3.529	3.495	3.444	3.395	3.339	3.286	3.265
N3b	3.529	3.539	3.505	3.454	3.406	3.349	3.298	3.276
N3c	3.529	3.539	3.505	3.453	3.405	3.348	3.296	3.275
N4a	3.352	3.368	3.327	3.268	3.206	3.157	3.093	3.059
N4b	3.349	3.362	3.322	3.262	3.201	3.152	3.088	3.057
N4c	3.283	3.292	3.257	3.191	3.126	3.086	3.023	2.994
WL21	3.319	3.330	3.293	3.232	3.171	3.125	3.060	3.028
WL22	3.280	3.289	3.254	3.190	3.129	3.090	3.024	2.990
WL23	3.164	3.167	3.135	3.069	2.999	2.974	2.909	2.880
WL24	3.094	3.098	3.068	2.992	2.932	2.905	2.842	2.814
WL25	2.389	2.390	2.382	2.354	2.324	2.297	2.261	2.239
N5a	2.627	2.623	2.607	2.559	2.518	2.487	2.438	2.410
N5b	2.642	2.636	2.622	2.573	2.533	2.502	2.453	2.426
N5c	2.636	2.632	2.617	2.568	2.526	2.495	2.447	2.420
W27								
Abd Bore #8	3.578	3.577	3.544	3.487	3.434	3.389	3.344	3.321
CSIRO #1	3.433	3.436	3.417	3.368	3.349	3.324	3.293	3.282
Ag (old bore)	3.600	3.614	3.565	3.575	3.556	3.544	3.499	3.490
Ag (old well)	3.574	3.564	3.534		3.546	3.536	3.494	3.482
Lemnos St	3.094	3.096	3.089	3.065	3.043	3.018	2.981	2.965
GE1 Bold Park	1.379	1.376	1.374	1.353	1.335	1.308	1.283	1.263
City Beach HS	2.409	2.422	2.424	2.410	2.394	2.367	2.337	2.317
Tennis Ct #11	4.091	4.108	4.092	4.053	4.001	3.972	3.922	3.901
Chandler Dr #10		4.101	4.077	4.033		3.932	3.885	3.863
McLean Park #12	4.116	4.129	4.104	4.050	3.985	3.935	3.883	3.840
McGillivray #85	2.569	2.550	2.507	2.474	2.342	2.355	2.255	2.272
Henderson Pk		6.889	6.834	6.779	6.763	6.729	6.674	6.673

Well	30-11-97	08-12-97	14-12-97	21-12-97	28-12-97	04-01-98
PL1	3.358	3.309	3.262	3.214	3.191	3.149
WL1	3.276	3.229	3.173	3.128	3.100	3.054
WL2	3.230	3.185	3.132	3.083	3.052	3.003
WL3	3.174	3.129	3.077	3.029	2.996	2.947
N1a	3.136	3.094	3.040	2.994	2.958	2.909
N1b	3.142	3.098	3.045	2.997	2.961	2.915
N1c	3.135	3.092	3.035	2.987	2.952	2.905
N2a	2.777	2.728	2.667	2.629	2.580	2.533
N2b	2.797	2.746	2.685	2.640	2.595	2.550
N2c	2.802	2.753	2.693	2.647	2.603	2.558
WL4	2.720	2.680	2.624	2.584	2.538	2.494
WL5	2.603	2.564	2.523	2.487	2.449	2.408
WL6	3.068	3.027	2.965	2.904	2.860	2.810
WL7	3.022	2.972	2.905	2.848	2.804	2.760
WL8	3.006	2.955	2.885	2.827	2.781	2.740
WL9	2.973	2.932	2.858	2.783	2.738	2.692
WL10	2.927	2.878	2.803	2.742	2.698	2.655
WL11	2.896	2.848	2.775	2.716	2.674	2.630
WL12	2.841	2.798	2.728	2.670	2.629	2.587
PL2	3.075	3.027	2.955	2.900	2.860	2.815
WL13	3.106	3.061	2.985	2.925	2.884	2.838
WL14	3.126	3.075	3.002	2.944	2.904	2.858
WL15	3.137	3.088	3.016	2.961	2.920	2.872
WL16	3.148	3.103	3.035	2.981	2.939	2.891
WL17	3.159	3.115	3.051	2.999	2.959	2.911
W26A	3.187	3.135	3.071	3.016	2.985	2.932
WL18	3.438	3.391	3.324	3.296	3.228	3.184
WL19	3.349	3.302	3.228	3.176	3.120	3.077
WL20	3.272	3.224	3.154	3.094	3.048	3.001
N3a	3.223	3.174	3.105	3.040	2.997	2.951
N3b	3.233	3.183	3.114	3.051	3.008	2.960
N3c	3.232	3.184	3.115	3.052	3.008	2.961
N4a	3.016	2.937	2.855	2.808	2.783	2.747
N4b	3.010	2.934	2.853	2.805	2.781	2.746
N4c	2.953	2.895	2.820	2.753	2.727	2.697
WL21	2.987	2.915	2.838	2.785	2.758	2.723
WL22	2.954	2.890	2.817	2.757	2.727	2.696
WL23	2.838	2.791	2.734	2.663	2.634	2.618
WL24	2.768	2.721	2.666	2.601	2.580	2.573
WL25	2.206	2.183	2.158	2.126	2.095	2.067
N5a	2.381	2.346	2.306	2.265	2.239	2.205
N5b	2.397	2.362	2.321	2.282	2.255	2.222
N5c	2.390	2.353	2.313	2.275	2.248	2.215
W27						2.817
Abd Bore #8	3.279	3.232	3.187	3.141	3.107	3.069
CSIRO #1	3.267	3.216				
Ag (old bore)	3.479	3.449	3.418	3.389	3.358	3.326
Ag (old well)	3.464	3.432	3.410	3.387	3.362	3.335
Lemnos St	2.938	2.903	2.876	2.843	2.814	2.792
GE1 Bold Park	1.247	1.228	1.206	1.184	1.161	1.144
City Beach HS	2.299	2.274	2.253	2.222	2.196	2.174
Tennis Ct #11	3.866	3.826	3.776	3.731	3.691	3.652
Chandler Dr #10	3.825	3.781	3.715	3.675	3.642	3.597
McLean Park #12	3.806	3.782	3.717	3.679	3.626	3.589
McGillivray #85	2.242	2.156	2.137	2.082		1.984
Henderson Pk	6.647	6.626	6.582	6.530	6.508	6.471

CHAPTER
8

APPENDICES

Appendix 8.1 Thermal Balances

The thermal balances have a similar form as the mass balances, with the exception that they are balanced daily and by balance period. Thermal balances were completed for balance periods 20 to 50 inclusive (periods for which floating pan E was measured).

Balance	Start	End	Days	Balance	Start	End	Days
1996/97							
20	December 22	January 03	12	36	July 10	July 22	12
21	January 03	January 15	12	37	July 22	August 03	12
22	January 15	January 27	12	38	August 03	August 19	16
23	January 27	February 08	12	39	August 19	August 31	12
24	February 08	February 20	12	40	August 31	September 12	12
25	February 20	March 04	12	41	September 12	September 24	12
26	March 04	March 16	12	42	September 24	October 06	12
27	March 16	March 28	12	43	October 06	October 18	12
28	March 28	April 09	12	44	October 18	October 30	12
29	April 09	April 21	12	45	October 30	November 11	12
30	April 21	May 03	12	46	November 11	November 23	12
31	May 03	May 15	12	47	November 23	December 05	12
32	May 15	May 27	12	48	December 05	December 17	12
33	May 27	June 16	20	49	December 17	December 25	8
34	June 16	June 28	12	1997/98			
35	June 28	July 10	12	50	December 25	January 03	9

There is one sheet for each balance period. As in the mass balances a 'balance day' starts and ends at 08:00hr each morning.

Notes to Accompany Thermal Balances

Each balance sheet includes evaporation by floating Class A pan (Pan E) and in the last column evaporation (E) computed using the thermal balance ignoring the sediment heat flux (Qse). These two figures (as balance period totals and daily averages) appear at the bottom of each balance sheet. The remainder of the balance components are calculated using floating pan E. A value for the sediment heat flux (as a daily average) was computed by setting E equal to Pan E. The sediment heat flux is also expressed as equivalent daily evaporation. This is the error in daily evaporation (in mm) if the thermal balance was used to determine evaporation without taking Qse into account.

Five components (Qrn, Qsd, Qtu, Qdc and Qrc) appear twice expressed as megajoules and watts m^{-2}. This was for computational convenience. For these components:
Heat (Mj day^{-1})11.574/lake surface area yields flux in W m^{-2}.

Qe, Qh and Qw are not directly measured but are determined as functions of the floating pan evaporation as follows:

$Qe = \rho E_{pan}L$

$Qh = RQe$

$Qw = \rho cE_{pan}(T_e - T_b)$

Note: resultant for Qe and Qw must be multiplied by 11.574 to yield flux in W m^{-2}

Formula for c:	0.00418Mj kg^{-1} ˚C or 4.180Mj m^{-3}	(at 20˚C)
Formula for L:	2.45378Mj kg^{-1}	(at 20˚C)
Formula for ρ:	998.24kg m^{-3}	(at 20˚C)

Balance Sheet Key

Component	Units	Details
Day & Time		Date and time of the end of each 24 hour balance 'day'
Stage	m	Lake stage (metres above Australian Height Datum)
Area	m^2	Lake area from lake stage, refer Appendix 3.8
Volume	m^3	Lake volume from lake stage, refer Appendix 3.8
Pan E	mm	Daily evaporation as measured by floating Class A pan in East Lake
R		Bowen Ratio (daily average), dimensionless
T_o	°C	Temperature of evaporated water taken to be mean surface water T
T_m	°C	Mean mid level temperature of water column
Qrn	Mj	Heat in rain falling directly on the lake
Qsd	Mj	Heat in storm water
Qtu	Mj	Heat in top up water
Qdc	Mj	Heat in groundwater discharged to the lake
Qrc	Mj	Heat in lake water recharged to the aquifer
Qa	W m^{-2}	Incoming long wave radiation
Qar	W m^{-2}	Reflected long wave radiation
Qbs	W m^{-2}	Long wave radiation emitted from the water
Qs	W m^{-2}	Incoming short wave radiation
Qsr	W m^{-2}	Reflected short wave radiation
Qrn	W m^{-2}	Heat in rain falling directly on the lake
Qsd	W m^{-2}	Heat in storm water
Qtu	W m^{-2}	Heat in top up water
Qdc	W m^{-2}	Heat in groundwater discharged to the lake
Qrc	W m^{-2}	Heat in lake water recharged to the aquifer
Qse	W m^{-2}	Heat conducted into and out of the lake sediments
Qx	W m^{-2}	Change in heat energy stored in the lake (T_m at final lake volume)
Qe	W m^{-2}	Energy used for evaporation
Qh	W m^{-2}	Energy conducted from the water as sensible heat
Qw	W m^{-2}	Energy advected from the water body via evaporated water
ρ	kg m^{-3}	Density of evaporated water
L	Mj kg^{-1}	Latent heat of vaporisation of water
c	Mj kg^{-1} °C	Specific heat of water
E	mm	Evaporation by thermal balance ignoring Qse

Appendix 8.2 Solar Instrument Specifications

Middleton Instruments CN9 Short Wave Pyranometer

Also referred to as an 'pyrano-albedometer'. Sensitivity 10 μV W^{-1} m^{-2}. Output was amplified 100x using a Carter-Scott (nil offset) 'Net Radiometer Amplifier'. Multi point calibration from 0 to 20.07 mV peak for 1.997 volts amplifier output.

Eppley Model PIR Pyrgeometer

Also referred to as a precision infrared radiometer.

Sensitivity	4 μV W^{-1} m^{-2}
Linearity	± 1% from 0 to 700 Wm^{-2}
Calibration	blackbody reference

The pyrgeometer output was amplified 200x using an identical Carter-Scott amplifier. Top point of multi point calibration was 10.14 mV in for 2.04 volts amplifier output.

Instruments were set up, calibrated and maintained by Peter Mountford, WA Department of the Environment, Perth.

Middleton Instruments and Carter-Scott voltage amplifiers designed and manufactured by:

Carter-Scott Design
16 Wilson Avenue
Brunswick, Victoria
3056
www.carterscott.com.au

Model PIR Pyrgeometer designed and manufactured by:

The Eppley Laboratory Inc.
12 Sheffield Avenue
PO Box 419
Newport, Rhode Island USA
02840
www.eppleylab.com

Balance Period No: 20

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
22/12/96	8:00	3.305	47355	13352	9.0		26.0	27.4																								
23/12/96	8:00	3.342	49807	15152	6.1	0.15	24.8	26.0	0	0	0	0	74132	318	9.6	433	394	21.9	0	0	0	0	17.2		9.7	172.0	24.9	7.3	997.134	2443	4.180	6.6
24/12/96	8:00	3.316	48161	13877	8.3	0.16	25.1	26.3	0	0	0	0	98026	310	9.3	435	393	21.9	0	0	0	0	23.6		-16.3	235.1	37.5	10.1	997.050	2442	4.180	6.7
25/12/96	8:00	3.293	46526	12789	7.0	0.18	23.5	24.7	0	0	0	0	80302	301	9.0	426	396	22.0	0	0	0	0	20.0		-38.9	197.3	36.0	7.9	997.447	2446	4.180	7.4
26/12/96	8:00	3.274	45237	11917	5.8	0.13	23.9	25.0	0	0	0	0	64829	310	9.3	428	389	21.8	0	0	0	0	16.6		-9.9	164.8	21.9	6.7	997.358	2445	4.180	7.0
Balance 20A																																
27/12/96	8:00	3.257	44150	11158	5.8	0.11	25.4	26.6	0	0	0	0	56285	322	9.7	437	389	21.8	0	0	0	0	14.8		6.6	164.5	17.8	7.2	996.973	2441	4.180	6.8
28/12/96	8:00	3.240	42963	10417	7.9	0.13	25.9	27.1	0	0	194397	0	45674	328	9.8	440	389	21.8	0	0	52.4	0	12.3		-6.8	223.1	28.5	9.9	996.838	2440	4.179	8.8
29/12/96	8:00	3.268	44850	11647	7.4	0.11	25.1	26.2	0	0	115318	0	72290	326	9.8	435	384	21.6	0	0	29.8	0	18.7		11.4	208.7	23.3	9.0	997.054	2442	4.180	7.4
30/12/96	8:00	3.275	45302	11963	5.8	0.15	25.0	26.0	0	0	0	0	80456	324	9.7	435	389	21.8	0	0	0	0	20.6		3.3	164.6	24.1	7.0	997.084	2442	4.180	6.6
Balance 20B																																
31/12/96	8:00	3.250	43688	10850	6.5	0.07	26.1	27.2	0	0	0	0	91320	333	10.0	441	386	21.7	0	0	0	0	24.2		-5.9	182.0	13.2	8.1	996.791	2439	4.179	7.2
1/1/97	8:00	3.229	42117	9949	7.4	-0.06	28.5	29.6	0	0	191371	0	70126	387	11.6	455	370	21.2	0	0	52.6	0	19.3		11.0	207.8	-11.8	10.2	996.125	2434	4.179	10.4
2/1/97	8:00	3.252	43822	10938	7.4	-0.07	29.9	30.9	0	0	0	0	113774	412	12.4	464	333	20.2	0	0	0	0	30.0		35.7	207.4	-14.6	10.7	995.691	2430	4.179	6.6
3/1/97	8:00	3.230	42194	9991	7.1	0.03	31.1	32.3	0	0	0	0	84354	407	12.2	472	312	19.6	0	0	0	0	23.1		-3.6	198.3	5.3	10.6	995.326	2427	4.179	6.5
Balance 20C																																
Totals			ΔS	-3361	82.7																											88.2

Daily average 6.9

Daily average 7.3

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -14.6

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.46

Notes

Qrn, Qsd & Qto are total energy flux to lake in Megajoules. Flux(11.574)/lake surface area yields flux in W m^{-2}

Qe, Qh & Qw are not directly measured, but are determined as functions of the floating pan evaporation as follows:

$Qe=\rho E_{pan}L$ where ρ is density of evaporated water in kg m^{-3}

E_{pan} is daily evaporation from floating pan in metres

$Qh=RQe$ L is latent heat of vapourisation of water in Megajoules kg^{-1}

c is specific heat of water in Megajoules kg^{-1} °C

$Qw=\rho cE_{pan}(T_e-T_b)$ T_e is temperature of the evaporated water equals surface water temperature T_0

T_b is arbitrary base temperature of 0°C

Note: resultant for Qe and Qw must be multiplied by 11.574 to yield flux in W m^{-2}

	T °C	
Formula for c:	20	0.00418 Megajoules kg^{-1}°C or 4.180 Mj m^{-3}
Formula for L:	20	2.45378 Megajoules kg^{-1} or 2453.78 Mj m^{-3}
Formula for ρ:	20	998.24kg m^{-3}

Qx taken as average mid level T (at final vol) - equivalent value for previous day

Balance Period No: 21

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
3/1/97 8:00	3.230	42194	9991	7.1	0.03	31.1	32.3																								
4/1/97 8:00	3.204	40187	8921	8.3	0.13	30.7	31.9	0	0	249189	0	104887	383.0	11.5	469.0	352.2	20.7	0	0	71.8	0	30.2		-27.7	233.5	31.0	12.3	995.474	2429	4.179	9.1
5/1/97 8:00	3.243	43192	10546	7.5	0.11	26.4	27.4	0	0	266154	0	114736	340.1	10.2	443.1	373.4	21.3	0	0	71.3	0	30.7		-18.4	211.3	23.4	9.6	996.708	2439	4.179	9.1
6/1/97 8:00	3.284	45897	12373	6.0	0.08	24.9	25.8	0	0	0	0	112562	329.3	9.9	434.2	382.7	21.6	0	0	0	0	28.4		13.3	170.5	13.8	7.3	997.103	2442	4.180	6.4
7/1/97 8:00	3.255	44021	11069	6.3	-0.02	26.2	27.2	0	0	0	0	123781	349.0	10.5	441.7	378.7	21.5	0	0	0	0	32.5		-6.2	176.1	-2.8	7.9	996.762	2439	4.179	7.8
Balance 21A																															
8/1/97 8:00	3.228	42039	9907	7.0	0.00	28.1	29.1	0	0	0	0	103853	360.8	10.8	453.2	375.0	21.4	0	0	0	0	28.6		1.2	196.2	-0.5	9.5	996.233	2435	4.179	7.5
9/1/97 8:00	3.201	39984	8800	6.6	0.05	29.7	30.7	0	0	0	0	106517	379.2	11.4	462.6	368.5	21.2	0	0	0	0	30.8		-5.3	184.1	8.7	9.4	995.779	2431	4.179	7.3
10/1/97 8:00	3.178	38466	7898	5.6	0.16	30.2	31.5	0	0	0	0	88910	391.6	11.7	466.2	356.5	20.8	0	0	0	0	26.8		-13.6	157.7	24.6	8.2	995.601	2430	4.179	7.0
11/1/97 8:00	3.153	36768	6958	6.7	0.17	30.3	31.6	0	0	325950	0	90144	379.4	11.4	466.9	366.8	21.1	0	0	102.6	0	28.4		-23.9	186.9	31.6	9.8	995.573	2429	4.179	10.0
Balance 21B																															
12/1/97 8:00	3.214	40912	9326	8.1	0.12	28.4	29.5	0	0	294876	0	129028	391.1	11.7	455.0	352.2	20.7	0	0	83.4	0	36.5		35.6	228.3	27.6	11.1	996.148	2434	4.179	8.1
13/1/97 8:00	3.258	44214	11202	7.1	0.13	25.6	26.8	0	0	0	0	134540	341.6	10.2	438.4	355.9	20.8	0	0	0	0	35.2		3.1	199.7	25.4	8.8	996.916	2441	4.180	5.7
14/1/97 8:00	3.229	42117	9949	6.2	0.09	26.3	27.6	0	0	0	0	115930	332.7	10.0	442.7	377.8	21.4	0	0	0	0	31.9		-13.0	173.1	16.3	7.8	996.723	2439	4.179	6.8
15/1/97 8:00	3.198	39783	8681	5.4	0.10	27.1	28.4	0	0	0	0	126352	344.0	10.3	446.9	378.2	21.5	0	0	0	0	36.8		-15.8	152.5	14.9	7.1	996.525	2437	4.179	6.9
Balance 21C																															
Totals		ΔS	-1310	80.8																											91.8

Daily average 6.7

Daily average 7.7

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -29.4

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.92

Balance Period No: 22 **East Lake**

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m²	m³	mm				m joules	m joules	m joules	m joules	m joules																			mm
15/1/97 8:00	3.198	39783	8681	5.4	0.10	27.1	28.4																								
16/1/97 8:00	3.168	37787	7517	5.8	0.06	27.9	29.2	0	0	0	0	117683	352.1	10.6	452.0	372.6	21.3	0	0	0	0	36.0		-18.4	164.0	9.5	7.9	996.292	2435	4.179	7.2
17/1/97 8:00	3.140	35818	6486	5.5	0.01	28.7	29.9	0	0	5264	0	106561	366.6	11.0	456.9	365.6	21.1	0	0	1.7	0	34.4		-18.9	155.1	2.3	7.6	996.059	2433	4.179	7.7
18/1/97 8:00	3.114	33734	5582	6.8	0.06	28.8	29.9	0	0	236490	0	93911	390.0	11.7	457.5	342.4	20.4	0	0	81.1	0	32.2		-22.3	190.2	12.0	9.4	996.031	2433	4.179	10.0
19/1/97 8:00	3.159	37177	7180	8.0	0.16	26.1	27.1	0	0	233310	0	100128	360.9	10.8	441.2	334.5	20.2	0	0	72.6	0	31.2		13.4	226.0	36.0	10.1	996.792	2439	4.179	7.4
Balance 22A																															
20/1/97 8:00	3.193	39451	8483	9.4	0.12	24.4	25.4	862	0	0	0	112636	345.0	10.4	431.3	332.9	20.2	0.25	0	0	0	33.0		10.7	264.5	32.5	11.0	997.233	2443	4.180	5.2
21/1/97 8:00	3.164	37516	7366	4.7	0.13	22.7	23.7	0	0	0	0	94083	312.5	9.4	421.8	332.9	20.2	0	0	0	0	29.0		-38.3	132.6	17.2	5.1	997.634	2447	4.180	6.1
22/1/97 8:00	3.134	35344	6272	5.6	0.01	23.2	24.3	0	0	0	0	91473	323.5	9.7	424.4	376.1	21.4	0	0	0	0	30.0		-16.9	159.1	1.0	6.3	997.523	2446	4.180	7.8
23/1/97 8:00	3.108	33246	5381	7.4	0.07	25.4	26.5	0	0	0	0	71503	331.3	9.9	437.3	370.9	21.2	0	0	0	0	24.9		-1.0	208.6	14.8	9.1	996.972	2441	4.180	6.7
Balance 22B																															
24/1/97 8:00	3.080	30711	4484	10.4	0.02	26.3	27.4	0	0	101199	0	68273	340.5	10.2	442.8	368.8	21.2	0	0	38.1	0	25.7		-13.9	293.4	7.2	13.2	996.723	2439	4.179	8.7
25/1/97 8:00	3.094	32057	4923	7.4	-0.01	27.3	28.3	0	0	232460	0	62665	366.0	11.0	448.5	359.1	20.9	0	0	83.9	0	22.6		16.4	208.1	-1.1	9.7	996.460	2437	4.179	9.9
26/1/97 8:00	3.134	35344	6272	4.0	0.15	23.6	24.6	0	0	223893	0	131388	331.5	9.9	427.1	296.9	19.2	0	0	73.3	0	43.0		1.0	111.9	16.6	4.5	997.419	2445	4.180	6.0
27/1/97 8:00	3.172	38059	7669	5.2	0.08	23.2	24.2	0	0	258	0	107543	314.8	9.4	424.4	371.9	21.3	0	0	0.08	0	32.7		25.0	147.3	11.8	5.8	997.523	2446	4.180	5.5
Balance 22C																															
Totals		ΔS	-1012	80.3																											88.1

Daily average 6.7

Daily average 7.3

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -20.4

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.65

Balance Period No: 23

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
27/1/97	8:00	3.172	38059	7669	5.2	0.08	23.2	24.2																								
28/1/97	8:00	3.141	35893	6522	6.0	0.04	25.1	26.1	0	0	0	0	102066	332.3	10.0	435.2	369.2	21.2	0	0	0	0	32.9		-6.6	170.5	6.1	7.3	997.060	2442	4.180	6.9
29/1/97	8:00	3.111	33489	5481	7.1	-0.03	27.3	28.4	0	0	0	0	95442	381.5	11.4	448.6	330.4	20.1	0	0	0	0	33.0		-4.3	199.3	-5.5	9.3	996.449	2436	4.179	7.1
30/1/97	8:00	3.083	31008	4576	5.5	0.14	26.2	27.3	0	0	0	0	83936	360.2	10.8	442.2	291.6	19.0	0	0	0	0	31.3		-29.9	155.5	21.3	7.0	996.754	2439	4.179	5.3
31/1/97	8:00	3.053	27801	3692	6.8	0.08	25.9	27.0	0	0	0	0	78213	339.1	10.2	440.2	360.0	20.9	0	0	0	0	32.6		-21.5	190.8	15.3	8.5	996.842	2440	4.179	6.8
Balance 23A																																
1/2/97	8:00	3.038	25951	3289	5.1	0.03	26.6	27.7	0	0	198805	0	31716	350.0	10.5	444.5	357.3	20.9	0	0	88.7	0	14.1		-4.0	143.7	5.0	6.6	996.646	2438	4.179	10.2
2/2/97	8:00	3.081	30810	4515	6.9	-0.09	27.9	28.5	0	0	287050	0	108925	396.3	11.9	451.8	345.5	20.5	0	0	107.8	0	40.9		32.4	193.3	-17.0	9.2	996.303	2435	4.179	10.8
3/2/97	8:00	3.143	36045	6594	3.4	-0.04	28.1	28.6	0	0	0	0	140006	429.8	12.9	453.2	265.8	18.3	0	0	0	0	45.0		50.9	96.6	-4.0	4.7	996.224	2435	4.179	4.1
4/2/97	8:00	3.107	33165	5347	3.8	0.15	27.6	28.4	0	0	0	0	136475	429.5	12.9	450.4	213.4	16.4	0	0	0	0	47.6		-31.7	105.5	15.4	5.0	996.368	2436	4.179	4.4
Balance 23B																																
5/2/97	8:00	3.072	29929	4241	7.1	0.10	24.9	25.8	0	0	0	0	95432	347.4	10.4	434.3	333.1	20.2	0	0	0	0	36.9		-44.5	199.9	19.5	8.5	997.108	2442	4.180	6.9
6/2/97	8:00	3.042	26423	3394	5.8	0.13	25.3	26.2	0	0	7408	0	75178	335.5	10.1	436.4	353.5	20.8	0	0	3.2	0	32.9		-13.5	164.5	21.0	7.1	997.009	2441	4.180	6.2
7/2/97	8:00	3.021	23729	2866	5.8	0.07	27.2	28.1	0	0	0	0	55254	368.5	11.1	447.6	338.2	20.3	0	0	0	0	27.0		1.2	164.2	12.0	7.6	996.497	2437	4.179	6.3
8/2/97	8:00	2.994	19195	2287	6.2	0.10	25.4	26.2	0	0	302669	0	49212	356.7	10.7	437.3	303.1	19.4	0	0	182.5	0	29.7		-13.2	173.3	18.0	7.5	996.978	2441	4.180	11.1
Balance 23C																																
Totals			ΔS	-5382	69.6																											86.0

Daily average 5.8

Daily average 7.2

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: -42.4

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): -1.37

Balance Period No: 24 **East Lake**

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
8/2/97 8:00	2.994	19195	2287	6.2	0.10	25.4	26.2																								
9/2/97 8:00	3.090	31692	4796	5.3	-0.02	24.6	25.5	0	0	326644	0	89761	341.7	10.3	432.8	350.5	20.7	0	0	119.3	0	32.8		35.3	150.0	-2.4	6.3	997.172	2443	4.180	9.6
10/2/97 8:00	3.151	36630	6884	4.8	0.04	24.1	24.9	0	0	33076	0	156725	337.6	10.1	429.4	347.1	20.6	0	0	10.5	0	49.5		40.3	135.4	5.2	5.6	997.313	2444	4.180	4.8
11/2/97 8:00	3.120	34218	5785	6.7	0.04	26.1	27.2	0	0	0	0	139064	342.3	10.3	441.6	345.8	20.5	0	0	0	0	47.0		-4.7	187.8	7.2	8.4	996.777	2439	4.179	5.7
12/2/97 8:00	3.083	31008	4576	5.7	0.09	27.2	28.2	0	0	0	0	118832	342.6	10.3	447.7	343.9	20.5	0	0	0	0	44.4		-20.4	161.2	14.9	7.5	996.498	2437	4.179	5.7
Balance 24A																															
13/2/97 8:00	3.049	27302	3582	5.2	0.14	27.4	28.4	0	0	0	0	110402	346.0	10.4	449.0	343.8	20.5	0	0	0	0	46.8		-21.2	146.5	21.1	6.9	996.437	2436	4.179	5.5
14/2/97 8:00	3.022	23869	2890	6.3	0.12	26.5	27.5	0	0	36959	0	67527	342.6	10.3	443.9	339.4	20.4	0	0	17.9	0	32.7		-19.2	176.0	21.3	8.0	996.680	2438	4.179	6.4
15/2/97 8:00	3.014	22660	2704	5.2	0.09	24.1	25.0	0	0	519411	0	56798	324.5	9.7	430.1	331.8	20.2	0	0	265.3	0	29.0		-16.7	147.1	13.8	6.1	997.291	2444	4.180	14.0
16/2/97 8:00	3.158	37109	7143	4.5	0.12	23.8	24.6	0	0	275242	0	162129	334.3	10.0	428.0	341.2	20.4	0	0	85.8	0	50.6		84.7	126.6	15.6	5.2	997.375	2445	4.180	5.1
Balance 24B																															
17/2/97 8:00	3.228	42039	9907	6.2	0.09	24.7	25.4	0	0	0	0	18266	356.9	10.7	433.3	321.3	19.9	0	0	0	0	5.0		59.9	173.5	15.9	7.3	997.141	2443	4.180	4.7
18/2/97 8:00	3.182	38726	8053	4.6	0.11	24.9	25.9	0	0	0	0	180829	337.1	10.1	434.3	315.5	19.7	0	0	0	0	54.0		-28.8	129.3	13.9	5.5	997.099	2442	4.180	5.0
19/2/97 8:00	3.140	35818	6486	6.5	0.09	26.6	27.6	0	0	0	0	153288	365.8	11.0	444.1	323.1	19.9	0	0	0	0	49.5		-18.4	181.9	16.7	8.3	996.654	2438	4.179	5.7
20/2/97 8:00	3.100	32578	5117	2.9	0.16	26.7	27.7	773	0	0	0	148587	381.7	11.5	444.9	267.4	18.3	0.27	0	0	0	52.8		-31.0	81.8	13.5	3.7	996.615	2438	4.179	4.5
Balance 24C																															
Totals		ΔS	2830	63.8																											76.7
		Daily average		5.3																								Daily average			6.4

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: -34.3

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): -1.07

Balance Period No: 25 **East Lake**

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
20/2/97 8:00	3.100	32578	5117	2.9	0.16	26.7	27.7																								
21/2/97 8:00	3.069	29623	4152	4.7	0.12	24.3	25.1	424	1121	65262	0	87859	360.5	10.8	431.0	197.4	15.8	0.17	0.44	25.5	0	34.3		-40.3	132.1	16.5	5.5	997.241	2444	4.180	4.0
22/2/97 8:00	3.051	27555	3637	3.9	0.08	25.6	26.4	0	15	238716	0	127784	350.8	10.5	438.4	307.8	19.5	0	0.01	100.3	0	53.7		-1.7	108.7	8.9	4.8	996.917	2441	4.180	7.5
23/2/97 8:00	3.110	33408	5447	2.7	-0.03	25.5	26.3	0	118	150518	0	95164	374.0	11.2	438.0	314.3	19.7	0	0.04	52.1	0	33.0		38.8	76.4	-2.6	3.3	996.938	2441	4.180	7.0
24/2/97 8:00	3.128	34863	6062	2.5	-0.06	22.6	23.2	2938	2752	0	0	106579	391.0	11.7	420.6	133.7	12.4	0.98	0.91	0	0	35.4		-12.5	69.5	-4.3	2.7	997.672	2448	4.181	2.1
Balance 25A																															
25/2/97 8:00	3.092	31878	4859	2.3	-0.10	27.0	27.7	0	430	433	0	130158	435.0	13.1	446.5	191.1	15.5	0	0.16	0.16	0	47.3		9.5	64.5	-6.3	3.0	996.539	2437	4.179	3.5
26/2/97 8:00	3.060	28623	3890	1.3	-0.09	29.3	30.2	0	33	0	0	117218	442.7	13.3	460.4	190.7	15.5	0	0.01	0	0	47.4		-6.1	35.1	-3.0	1.8	995.878	2432	4.179	3.8
27/2/97 8:00	3.025	24290	2962	4.7	0.00	31.2	31.8	0	0	0	0	106047	422.9	12.7	472.2	271.8	18.5	0	0	0	0	50.5		-10.9	131.2	0.1	7.1	995.302	2427	4.179	5.1
28/2/97 8:00	2.983	17777	2083	5.2	0.12	30.3	29.9	0	0	111655	0	95525	361.8	10.9	467.1	302.5	19.3	0	0	72.7	0	62.2		-17.8	146.0	17.7	7.6	995.578	2429	4.179	5.9
Balance 25B																															
1/3/97 8:00	3.040	26186	3341	6.9	0.05	26.0	25.1	0	0	416585	0	0	330.3	9.9	441.3	302.3	19.3	0	0	184.1	0	0.0		-15.0	193.7	9.0	8.6	996.807	2440	4.179	11.7
2/3/97 8:00	3.129	34943	6097	2.5	0.12	25.9	24.4	0	0	417901	0	196539	342.7	10.3	440.2	301.0	19.3	0	0	138.4	0	65.1		51.2	70.5	8.3	3.1	996.837	2440	4.179	6.0
3/3/97 8:00	3.191	39319	8404	6.0	0.03	27.3	25.5	0	0	493565	0	239163	354.7	10.6	448.3	304.9	19.4	0	0	145.3	0	70.4		58.1	170.0	4.8	8.0	996.467	2437	4.179	6.5
4/3/97 8:00	3.255	44021	11069	6.4	0.06	25.8	24.1	0	0	0	0	274340	325.7	9.8	439.2	316.0	19.7	0	0	0	0	72.1		28.9	179.1	11.6	7.9	996.878	2440	4.180	2.3
Balance 25C																															
Totals		ΔS	5952	49.0																											65.6

Daily average 4.1

Daily average 5.5

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -41.6

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -1.38

Balance Period No: 26

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
4/3/97	8:00	3.255	44021	11069	6.4	0.06	25.8	24.1																								
5/3/97	8:00	3.201	39984	8800	4.7	0.11	26.3	24.7	0	0	0	0	212324	319.7	9.6	442.0	316.8	19.7	0	0	0	0	61.5		-30.0	132.1	14.5	5.9	996.745	2439	4.179	4.1
6/3/97	8:00	3.155	36905	7032	5.1	0.12	27.6	26.3	0	0	0	0	171529	323.3	9.7	450.2	312.0	19.6	0	0	0	0	53.8		-20.5	143.6	16.8	6.8	996.378	2436	4.179	3.7
7/3/97	8:00	3.110	33408	5447	6.3	0.14	25.4	24.7	498	0	0	0	140594	347.3	10.4	437.3	293.3	19.1	0.17	0	0	0	48.7		-47.6	176.3	25.1	7.7	996.974	2441	4.180	5.2
8/3/97	8:00	3.068	29517	4122	3.8	0.10	23.9	23.5	0	0	0	0	117794	328.5	9.9	428.7	286.8	18.9	0	0	0	0	46.2		-35.9	106.0	10.7	4.3	997.343	2444	4.180	4.6
Balance 26A																																
9/3/97	8:00	3.038	25951	3289	5.8	0.07	25.9	25.3	0	0	0	0	70027	342.0	10.3	440.0	296.8	19.2	0	0	0	0	31.2		-3.7	164.4	11.5	7.3	996.847	2440	4.179	4.5
10/3/97	8:00	3.070	29727	4182	4.4	0.12	26.7	25.9	0	0	167029	0	97010	351.5	10.5	445.1	293.3	19.1	0	0	65.0	0	37.8		21.1	123.2	14.5	5.6	996.623	2438	4.179	5.4
11/3/97	8:00	3.037	25834	3263	5.6	0.16	25.8	25.2	0	0	8160	0	89106	327.8	9.8	439.9	263.9	18.2	0	0	3.7	0	39.9		-22.2	158.6	25.4	7.0	996.860	2440	4.179	3.2
12/3/97	8:00	3.001	20280	2425	4.7	0.11	23.7	23.2	0	0	0	0	69903	303.7	9.1	427.6	300.3	19.3	0	0	0	0	39.9		-19.7	132.5	15.1	5.4	997.404	2445	4.180	3.9
Balance 26B																																
13/3/97	8:00	2.960	15365	1703	4.7	0.06	23.4	22.9	0	0	0	0	62281	306.3	9.2	425.6	301.4	19.3	0	0	0	0	46.9		-11.5	132.5	8.0	5.3	997.483	2446	4.180	3.8
14/3/97	8:00	2.927	12908	1240	3.3	0.08	23.3	22.8	0	0	0	0	40512	316.3	9.5	425.2	256.6	18.0	0	0	0	0	36.3		-16.6	94.3	7.2	3.8	997.497	2446	4.180	3.2
15/3/97	8:00	2.896	10945	869	6.7	-0.01	24.9	24.2	0	0	0	0	30071	345.0	10.4	434.2	281.9	18.8	0	0	0	0	31.8		-13.1	188.1	-2.6	8.0	997.112	2442	4.180	5.0
16/3/97	8:00	2.867	8651	582	5.8	0.03	25.3	24.6	0	0	0	0	24112	371.3	11.1	437.1	233.8	17.2	0	0	0	0	32.3		-13.1	163.4	4.2	7.1	996.986	2441	4.180	4.0
Balance 26C																																
Totals			ΔS	-10487	60.9																											50.5
			Daily average		5.1																									Daily average		4.2

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: 27.6

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): 0.86

Balance Period No: 27

East Lake

Day & Time	Stage m AHD	Area m^2	Volume m^3	Pan E mm	R	T_0 °C	T_m °C	Qrn m joules	Qsd m joules	Qtu m joules	Qdc m joules	Qrc m joules	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E mm
16/3/97 8:00	2.867	8651	582	5.8	0.03	25.3	24.6																								
17/3/97 8:00	3.072	29929	4241	4.0	0.14	23.5	22.8	12599	35456	409231	0	125837	354.5	10.6	426.0	199.3	15.8	4.9	13.7	158.3	0	48.7		76.4	112.9	16.1	4.5	997.455	2446	4.180	4.6
18/3/97 8:00	3.028	24697	3036	3.9	0.22	25.4	24.9	0	319	1835	0	119196	381.7	11.5	437.2	265.2	18.3	0	0.15	0.86	0	55.9		-8.5	108.7	23.8	4.7	996.968	2441	4.180	3.7
19/3/97 8:00	2.990	18657	2211	4.8	0.26	25.4	25.1	0	0	0	0	65936	424.5	12.7	437.6	270.4	18.4	0	0	0	0	40.9		-4.1	135.1	34.6	5.9	996.959	2441	4.180	5.2
20/3/97 8:00	2.955	14894	1627	3.9	0.19	24.8	24.3	0	0	0	0	46019	416.2	12.5	433.6	280.5	18.7	0	0	0	0	35.8		-15.3	108.8	20.8	4.6	997.134	2443	4.180	6.1
Balance 27A																															
21/3/97 8:00	2.915	12173	1089	3.3	0.19	25.5	25.0	0	0	0	0	52704	412.0	12.4	438.0	278.2	18.6	0	0	0	0	50.1		-20.6	94.0	17.6	4.1	996.944	2441	4.180	5.5
22/3/97 8:00	3.088	31498	4733	6.0	0.05	24.7	24.1	0	0	429565	0	125029	403.3	12.1	433.5	274.9	18.5	0	0	157.8	0	45.9		67.2	170.5	7.8	7.2	997.147	2443	4.180	8.4
23/3/97 8:00	3.133	35264	6237	3.5	0.04	23.8	23.4	0	0	352990	0	248423	386.7	11.6	427.9	265.7	18.3	0	0	115.9	0	81.5		25.2	100.1	3.8	4.1	997.376	2445	4.180	6.7
24/3/97 8:00	3.191	39319	8404	4.5	0.07	23.9	23.5	0	0	201936	0	0	354.8	10.6	428.3	267.7	18.3	0	0	59.4	0	0.0		42.2	126.6	8.7	5.2	997.359	2445	4.180	5.8
Balance 27B																															
25/3/97 8:00	3.140	35818	6486	2.8	0.19	25.1	24.6	0	0	779	0	187607	394.8	11.8	435.5	265.4	18.3	0	0	0.25	0	60.6		-26.7	79.3	15.2	3.4	997.041	2442	4.180	4.6
26/3/97 8:00	3.089	31597	4764	5.0	0.16	25.0	24.7	0	0	0	0	160468	403.6	12.1	435.1	253.6	17.9	0	0	0	0	58.8		-35.6	141.1	23.1	6.0	997.067	2442	4.180	5.0
27/3/97 8:00	3.043	26544	3421	3.4	0.12	22.1	21.9	0	0	0	0	113680	380.5	11.4	418.2	150.3	13.4	0	0	0	0	49.6		-43.9	97.3	11.5	3.7	997.780	2449	4.181	2.5
28/3/97 8:00	3.045	26794	3474	3.9	-0.01	21.5	21.4	0	0	109281	0	99526	369.4	11.1	414.9	231.3	17.1	0	0	47.2	0	43.0		-2.4	109.2	-1.5	4.0	997.913	2450	4.181	5.7
Balance 27C																															
Totals		ΔS	2892	49.1																											63.7
		Daily Average		4.1																									Daily average		5.3

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -40.3

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -1.22

Balance Period No: 28 **East Lake**

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
28/3/97 8:00	3.045	26794	3474	3.9	-0.01	21.5	21.4																								
29/3/97 8:00	3.092	31878	4859	2.6	0.09	19.2	19.0	39188	129873	52918	0	102435	404.2	12.1	402.0	111.2	10.9	14.2	47.2	19.2	0	37.2		5.9	72.9	6.4	2.4	998.394	2456	4.182	4.0
30/3/97 8:00	3.329	49013	14509	2.6	0.25	17.9	17.5	136584	290737	477241	0	127760	371.3	11.1	394.6	17.6	2.3	32.3	68.7	112.7	0	30.2		110.4	74.3	18.2	2.3	998.646	2459	4.183	1.5
31/3/97 8:00	3.292	46458	12742	2.5	0.14	22.4	21.9	0	642	0	0	126544	366.8	11.0	419.8	234.5	17.2	0	0.16	0	0	31.5		40.6	70.8	9.8	2.7	997.706	2448	4.181	2.4
1/4/97 8:00	3.256	44085	11113	3.9	0.21	24.0	23.6	0	0	0	0	119820	372.5	11.2	429.2	243.8	17.6	0	0	0	0	31.5		-2.7	108.9	23.2	4.5	997.316	2444	4.180	3.7
Balance 28A																															
2/4/97 8:00	3.225	41803	9781	3.0	0.13	21.5	21.3	0	0	12637	0	124888	372.0	11.2	414.7	133.8	12.4	0	0	3.5	0	34.6		-47.2	85.6	11.2	3.1	997.915	2450	4.181	2.5
3/4/97 8:00	3.223	41644	9697	3.9	0.05	21.1	20.9	0	0	105509	0	103812	372.9	11.2	412.2	236.3	17.3	0	0	29.3	0	28.9		-5.7	109.3	5.1	3.9	998.007	2451	4.181	5.7
4/4/97 8:00	3.220	41400	9573	3.1	-0.05	22.7	22.4	2125	3563	123780	0	147308	379.4	11.4	421.6	202.2	16.0	0.59	1.00	34.6	0	41.2		15.5	87.6	-4.0	3.4	997.632	2447	4.180	4.0
5/4/97 8:00	3.215	40988	9367	2.8	0.11	22.1	21.7	307	776	108436	0	129400	363.9	10.9	417.7	121.4	11.6	0.09	0.22	30.6	0	36.5		-10.5	79.5	8.9	3.0	997.789	2449	4.181	1.5
Balance 28B																															
6/4/97 8:00	3.197	39716	8641	1.8	0.11	23.1	22.7	17655	51455	0	0	127206	394.6	11.8	423.5	170.0	14.5	5.1	15.0	0	0	37.1		-1.6	52.2	5.9	2.1	997.552	2447	4.180	3.0
7/4/97 8:00	3.170	37923	7593	4.2	0.04	23.5	23.1	637	838	0	0	83918	399.6	12.0	425.7	145.2	13.1	0.19	0.26	0	0	25.6		-15.2	117.5	4.4	4.7	997.461	2446	4.180	2.8
8/4/97 8:00	3.168	37787	7517	1.3	0.20	24.0	23.6	22202	76990	0	0	96726	388.9	11.7	429.0	128.8	12.1	6.8	23.6	0	0	29.6		3.6	36.0	7.3	1.5	997.320	2444	4.180	1.8
9/4/97 8:00	3.143	36045	6594	4.7	0.15	26.6	26.0	0	0	0	0	78546	376.2	11.3	443.9	230.6	17.1	0.0	0.0	0	0	25.2		3.3	132.0	19.9	6.0	996.662	2438	4.179	3.1
Balance 28C																															
Totals		ΔS	3120	36.3																											36.0

Daily average 3.0 Daily average 3.0

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 0.8

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 0.025

Balance Period No: 29

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m²	m³	mm				m joules	m joules	m joules	m joules	m joules																			mm
9/4/97 8:00	3.143	36045	6594	4.7	0.15	26.6	26.0																								
10/4/97 8:00	3.197	39716	8641	2.8	0.13	25.8	25.3	0	0	319095		158561	396.3	11.9	439.2	207.8	16.2	0	0	93.0	0	46.2		35.7	79.3	10.5	3.5	996.875	2440	4.180	4.5
11/4/97 8:00	3.176	38334	7821	1.7	0.21	24.6	24.1	12338	24202	0		118477	391.2	11.7	432.4	102.6	10.3	3.7	7.3	0	0	35.8		-28.3	47.7	9.8	2.0	997.174	2443	4.180	1.2
12/4/97 8:00	3.208	40465	9082	1.9	0.28	23.7	23.5	1540	531	240743		141803	382.0	11.5	427.4	188.7	15.4	0.44	0.15	68.9	0	40.6		17.4	52.7	14.6	2.1	997.394	2445	4.180	3.4
13/4/97 8:00	3.173	38128	7707	3.2	0.22	23.1	22.9	450	0	0		118565	379.1	11.4	424.0	221.9	16.8	0.14	0	0	0	36.0		-31.7	91.1	19.8	3.6	997.537	2446	4.180	4.1
Balance 29A																															
14/4/97 8:00	3.143	36045	6594	4.2	0.12	22.7	22.5	0	0	0		86213	375.2	11.3	421.4	216.9	16.6	0	0	0	0	27.7		-24.7	117.9	14.3	4.6	997.642	2447	4.180	4.3
15/4/97 8:00	3.130	35025	6132	2.8	0.03	23.8	23.5	0	0	51808		89667	388.0	11.6	427.7	199.3	15.8	0	0	17.1	0	29.6		0.1	79.5	2.1	3.2	997.377	2445	4.180	4.0
16/4/97 8:00	3.102	32749	5183	3.3	0.17	25.0	24.7	0	0	0		82778	371.0	11.1	434.9	215.8	16.5	0	0	0	0	29.3		-9.7	94.1	16.2	4.0	997.069	2442	4.180	3.0
17/4/97 8:00	3.151	36630	6884	1.8	0.19	24.4	24.1	0	0	256294		115520	347.5	10.4	431.5	217.2	16.6	0	0	81.0	0	36.5		29.4	50.0	9.5	2.1	997.219	2443	4.180	3.5
Balance 29B																															
18/4/97 8:00	3.135	35425	6308	3.0	0.18	24.7	24.2	0	0	68256		125863	392.6	11.8	433.1	212.2	16.4	0	0	22.3	0	41.1		-10.2	85.3	15.4	3.6	997.146	2443	4.180	3.9
19/4/97 8:00	3.177	38400	7860	2.1	0.22	24.3	24.0	0	76	273471		151056	386.8	11.6	430.6	205.5	16.1	0	0.02	82.4	0	45.5		29.0	58.8	12.9	2.4	997.257	2444	4.180	4.0
20/4/97 8:00	3.155	36905	7032	2.6	0.26	24.0	23.6	0	342	54816		133446	396.5	11.9	428.9	207.8	16.2	0	0.11	17.2	0	41.9		-19.7	73.6	19.3	3.0	997.327	2444	4.180	3.9
21/4/97 8:00	3.147	36349	6738	3.4	0.27	22.8	22.5	26450	56487	0		110243	407.0	12.2	421.9	140.0	12.8	8.4	18.0	0	0	35.1		-16.2	94.7	25.1	3.7	997.620	2447	4.180	2.9
Balance 29C																															
Totals		ΔS	144	32.8																											42.6
		Daily average		2.7																								Daily average			3.5

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -28.3

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.82

Balance Period No: 30

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
21/4/97 8:00	3.147	36349	6738	3.4	0.27	22.8	22.5																								
22/4/97 8:00	3.120	34218	5785	1.7	0.33	21.4	21.2	0	0	0	0	76782	368.0	11.0	414.5	151.9	13.5	0	0	0	0	26.0		-28.2	47.2	15.7	1.7	997.926	2450	4.181	2.1
23/4/97 8:00	3.103	32834	5215	2.3	0.29	20.7	20.3	0	0	0	0	40506	349.6	10.5	410.0	190.1	15.4	0	0	0	0	14.3		-17.6	65.0	18.6	2.3	998.098	2452	4.181	2.9
24/4/97 8:00	3.070	29727	4182	1.9	0.22	20.8	20.4	0	0	0	0	80503	371.7	11.2	410.6	205.7	16.1	0	0	0	0	31.3		-17.0	53.2	11.8	1.9	998.075	2452	4.181	3.5
25/4/97 8:00	3.095	32145	4955	2.9	0.22	22.0	21.6	0	0	156511	0	83523	383.7	11.5	417.5	207.1	16.2	0	0	56.4	0	30.1		22.3	82.6	18.1	3.1	997.802	2449	4.181	4.2
Balance 30A																															
26/4/97 8:00	3.068	29517	4122	2.3	0.03	23.5	22.9	0	0	0	0	74922	403.0	12.1	426.2	182.0	15.1	0	0	0	0	29.4		-6.7	64.8	2.0	2.6	997.441	2445	4.180	3.6
27/4/97 8:00	3.045	26794	3474	2.3	0.12	23.1	22.6	419	0	0	0	57216	405.0	12.2	424.0	97.2	9.9	0.18	0	0	0	24.7		-12.8	64.6	7.6	2.6	997.535	2446	4.180	1.4
28/4/97 8:00	3.024	24150	2938	1.7	0.12	20.3	19.8	0	0	0	0	42042	393.9	11.8	408.1	112.1	11.0	0	0	0	0	20.1		-25.0	47.3	5.5	1.6	998.169	2453	4.182	2.4
29/4/97 8:00	3.105	33001	5281	4.0	0.02	19.6	19.1	0	0	244187	0	29210	388.8	11.7	404.2	121.5	11.6	0	0	85.6	0	10.2		31.4	112.4	2.8	3.8	998.308	2455	4.182	4.2
Balance 30B																															
30/4/97 8:00	3.083	31008	4576	2.0	0.15	19.2	18.7	4908	10405	23262	0	83551	413.8	12.4	401.8	88.5	9.2	1.8	3.9	8.7	0	31.2		-14.8	56.8	8.6	1.9	998.396	2456	4.182	2.3
1/5/97 8:00	3.073	30028	4271	1.2	0.20	19.5	19.0	12369	31650	0	0	63526	415.1	12.5	403.2	76.0	8.2	4.8	12.2	0	0	24.5		-2.9	34.8	7.0	1.2	998.345	2455	4.182	1.8
2/5/97 8:00	3.049	27302	3582	1.9	0.32	20.2	20.0	0	9	0	0	51330	388.9	11.7	407.7	164.6	14.2	0	0.0	0	0	21.8		-3.4	53.2	17.1	1.8	998.185	2453	4.182	2.6
3/5/97 8:00	3.046	26918	3501	2.6	0.21	20.1	19.8	9698	25397	0	0	42762	384.4	11.5	406.7	152.3	13.5	4.2	10.9	0	0	18.4		-2.7	72.5	14.9	2.5	998.219	2454	4.182	3.0
Balance 30C																															
Totals		ΔS	-3237	26.6																											34.0

Daily average 2.2

Daily average 2.8

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -21.1

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.61

Balance Period No: 31

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
3/5/97	8:00	3.046	26918	3501	2.6	0.21	20.1	19.8																								
4/5/97	8:00	3.025	24290	2962	1.7	0.28	19.5	19.3	0	7187	0	0	46354	351.7	10.6	403.9	161.3	14.0	0	3.4	0	0	22.1		-10.4	47.3	13.2	1.6	998.328	2455	4.182	2.0
5/5/97	8:00	3.006	21204	2528	2.9	0.34	17.9	17.7	0	0	0	0	26375	331.5	9.9	395.1	188.9	15.4	0	0	0	0	14.4		-11.6	83.0	27.9	2.5	998.636	2459	4.183	2.5
6/5/97	8:00	2.980	17434	2031	1.7	0.09	17.5	17.2	0	0	0	0	32348	375.2	11.3	392.8	167.8	14.4	0	0	0	0	21.5		-5.3	47.4	4.2	1.4	998.716	2460	4.183	3.4
7/5/97	8:00	2.968	16172	1829	2.9	0.25	16.1	15.8	0	0	0	0	9787	357.8	10.7	385.3	195.6	15.7	0	0	0	0	7.0		-10.4	83.2	20.9	2.3	998.953	2463	4.185	4.0
Balance 31A																																
8/5/97	8:00	3.080	30711	4484	4.6	0.14	16.9	16.6	0	0	325023	0	69522	361.3	10.8	389.4	191.9	15.5	0	0	122.5	0	26.2		31.0	130.6	17.9	3.8	998.823	2461	4.184	6.1
9/5/97	8:00	3.048	27174	3555	3.4	0.09	16.0	15.8	0	0	0	0	55298	359.2	10.8	384.8	187.5	15.3	0	0	0	0	23.6		-17.4	98.0	8.8	2.7	998.966	2463	4.185	4.1
10/5/97	8:00	3.019	23441	2819	2.1	-0.10	15.2	14.9	0	0	0	0	42906	358.3	10.8	380.2	164.4	14.2	0	0	0	0	21.2		-13.5	59.5	-5.7	1.5	999.101	2465	4.185	4.1
11/5/97	8:00	2.996	19487	2325	2.1	-0.10	15.6	15.2	0	0	0	0	28765	368.3	11.0	382.1	118.0	11.4	0	0	0	0	17.1		1.0	59.4	-5.7	1.6	999.043	2464	4.185	2.4
Balance 31B																																
12/5/97	8:00	2.975	16910	1945	0.8	0.07	14.8	14.5	921	1739	0	0	23975	406.5	12.2	378.4	46.5	5.4	0.63	1.2	0	0	16.4		-7.2	22.3	1.5	0.6	999.152	2466	4.186	1.6
13/5/97	8:00	2.972	16596	1894	0.7	-0.04	16.0	15.6	2520	9624	0	0	13217	399.6	12.0	384.6	58.1	6.5	1.8	6.7	0	0	9.2		5.9	20.7	-0.8	0.6	998.968	2463	4.185	1.7
14/5/97	8:00	3.084	31107	4607	2.5	0.17	20.1	19.7	0	0	323038	0	77019	396.3	11.9	406.7	143.1	13.0	0	0	120.2	0	28.7		54.9	71.0	12.2	2.4	998.219	2454	4.182	4.2
15/5/97	8:00	3.050	27428	3609	2.2	0.14	20.7	20.4	0	0	0	0	77354	398.9	12.0	410.4	152.3	13.5	0	0	0	0	32.6		-11.4	62.0	8.7	2.2	998.078	2452	4.181	2.8
Balance 31C																																
Totals			ΔS	108	27.6																											39.0

Daily average 2.3

Daily average 3.2

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -30.4

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.95

Balance Period No: 32 East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
15/5/97	8:00	3.050	27428	3609	2.2	0.14	20.7	20.4																								
16/5/97	8:00	3.108	33246	5381	1.7	0.24	19.8	19.4	0	0	268870	0	100429	381.1	11.4	404.9	78.3	8.3	0	0	93.6	0	35.0		21.9	47.3	11.5	1.6	998.286	2454	4.182	2.0
17/5/97	8:00	3.095	32145	4955	1.9	0.14	21.6	21.1	0	0	60107	0	90146	363.0	10.9	415.4	165.7	14.3	0	0	21.6	0	32.5		5.4	53.1	7.5	2.0	997.883	2450	4.181	2.2
18/5/97	8:00	3.072	29929	4241	1.1	0.04	21.2	20.8	6807	8565	0	0	72822	435.6	13.1	413.0	67.5	7.4	2.6	3.3	0	0	28.2		-14.8	32.1	1.2	1.2	997.975	2451	4.181	2.0
19/5/97	8:00	3.059	28507	3861	1.7	0.32	18.9	18.7	7982	23662	0	0	58434	391.8	11.8	400.1	82.3	8.7	3.2	9.6	0	0	23.7		-19.9	48.8	15.4	1.6	998.461	2456	4.182	1.6
Balance 32A																																
20/5/97	8:00	3.038	25951	3289	0.9	0.17	19.0	18.9	0	0	0	0	43495	375.1	11.3	400.8	131.3	12.3	0	0	0	0	19.4		-6.7	26.6	4.5	0.9	998.434	2456	4.182	2.0
21/5/97	8:00	3.118	34057	5717	2.3	0.34	19.1	19.1	0	0	333954	0	109011	362.2	10.9	401.2	168.9	14.4	0	0	113.5	0	37.0		39.4	65.1	22.2	2.1	998.422	2456	4.182	3.6
22/5/97	8:00	3.088	31498	4733	2.9	0.27	17.5	17.5	0	0	0	0	65687	357.8	10.7	392.8	143.0	13.0	0	0	0	0	24.1		-27.7	83.0	22.0	2.5	998.711	2460	4.183	2.4
23/5/97	8:00	3.065	29194	4034	3.1	-0.25	17.9	17.7	20981	61663	0	0	45033	358.0	10.7	394.7	126.3	12.0	8.3	24.4	0	0	17.9		-9.3	88.9	-22.1	2.7	998.645	2459	4.183	4.1
Balance 32B																																
24/5/97	8:00	3.081	30810	4515	1.3	0.14	17.2	17.1	9233	29957	0	0	74627	370.0	11.1	391.2	84.3	8.8	3.5	11.3	0	0	28.0		3.1	37.1	5.2	1.1	998.762	2460	4.184	0.8
25/5/97	8:00	3.073	30028	4271	1.5	-0.14	17.2	17.0	10991	25648	0	0	44347	374.8	11.2	390.9	91.1	9.4	4.2	9.9	0	0	17.1		-4.2	42.6	-6.0	1.2	998.772	2460	4.184	2.2
26/5/97	8:00	3.052	27679	3665	1.6	0.06	17.0	17.0	301	0	0	0	36116	363.7	10.9	390.1	134.9	12.5	0.13	0	0	0	15.1		-8.1	44.4	2.7	1.3	998.798	2461	4.184	2.5
27/5/97	8:00	3.033	25349	3161	1.8	-0.05	17.3	17.2	759	1173	0	0	31192	355.5	10.7	391.2	121.5	11.6	0.35	0.54	0	0	14.2		-5.4	50.1	-2.5	1.5	998.760	2460	4.184	2.0
Balance 32C																																
Totals			ΔS	-448	21.8																											27.4

Daily average 1.8

Daily average 2.3

Balance Duration: 12 days

Daily average sediment term Qse ($W m^{-2} d^{-1}$) required to balance pan and thermal evaporation: -14.8

All Q terms expressed in watts per square meter ($W m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm d^{-1}$): -0.47

Balance Period No: 33

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
27/5/97	8:00	3.033	25349	3161	1.8	-0.05	17.3	17.2																								
28/5/97	8:00	3.128	34863	6062	1.4	0.26	18.5	18.5	31518	94037	199407	0	84348	355.0	10.6	397.9	124.6	11.8	10.5	31.2	66.2	0	28.0		52.4	39.8	10.4	1.3	998.536	2457	4.183	2.4
29/5/97	8:00	3.169	37855	7555	3.0	0.39	18.8	18.8	0	0	243940	0	92924	306.5	9.2	399.8	135.6	12.5	0	0	74.6	0	28.4		25.2	85.9	33.1	2.8	998.470	2457	4.182	1.0
30/5/97	8:00	3.157	37041	7105	2.2	0.19	18.2	18.1	0	0	57453	0	75599	341.6	10.2	396.2	152.4	13.5	0	0	18.0	0	23.6		-13.0	62.2	11.9	1.9	998.596	2458	4.183	2.3
31/5/97	8:00	3.220	41400	9573	3.5	0.02	15.4	15.2	66287	164438	0	0	72680	365.8	11.0	381.3	52.8	6.0	18.5	46.0	0	0	20.3		1.8	99.8	1.6	2.6	999.068	2465	4.185	2.1
Balance 33A																																
1/6/97	8:00	3.240	42963	10417	0.7	0.03	16.4	16.3	39736	64269	0	0	51707	362.7	10.9	386.8	104.7	10.4	10.7	17.3	0	0	13.9		21.4	20.2	0.5	0.6	998.900	2462	4.184	1.7
2/6/97	8:00	3.305	47355	13352	1.7	0.14	16.7	16.6	82009	144715	0	0	41542	361.1	10.8	388.1	72.1	7.8	20.0	35.4	0	0	10.2		34.8	49.6	6.9	1.4	998.860	2462	4.184	1.1
3/6/97	8:00	3.294	46594	12835	3.1	-0.01	16.6	16.5	8262	70774	0	0	108930	343.6	10.3	387.5	72.8	7.9	2.1	17.6	0	0	27.1		-6.4	88.7	-0.7	2.5	998.881	2462	4.184	0.3
4/6/97	8:00	3.292	46458	12742	0.2	-0.07	15.5	15.3	28625	43240	0	0	72836	325.0	9.8	381.6	82.5	8.7	7.1	10.8	0	0	18.1		-16.2	5.1	-0.3	0.1	999.060	2465	4.185	0.9
Balance 33B																																
5/6/97	8:00	3.282	45762	12281	1.9	-0.05	15.2	15.1	7739	22852	0	8505	63073	353.1	10.6	380.1	110.0	10.8	2.0	5.8	0	2.2	16.0		-7.9	55.3	-2.6	1.4	999.102	2465	4.185	2.3
6/6/97	8:00	3.271	45041	11782	0.0	-0.03	16.0	16.0	6815	13579	0	7581	59572	357.8	10.7	384.2	95.8	9.8	1.8	3.5	0	1.9	15.3		6.4	0.4	0.0	0.0	998.979	2463	4.185	1.2
7/6/97	8:00	3.257	44150	11158	0.2	0.10	16.6	16.7	3416	2966	0	6565	53848	368.0	11.0	387.5	80.9	8.6	0.9	0.8	0	1.7	14.1		1.7	5.0	0.5	0.1	998.878	2462	4.184	0.9
8/6/97	8:00	3.265	44659	11513	2.0	0.08	18.0	18.1	28386	49876	0	7143	63694	363.4	10.9	395.3	132.3	12.3	7.4	12.9	0	1.9	16.5		22.2	56.1	4.3	1.7	998.623	2458	4.183	1.9
Balance 33C																																
9/6/97	8:00	3.292	46458	12742	0.9	0.11	16.5	16.5	38852	94671	0	447	43697	346.6	10.4	387.5	43.0	5.0	9.7	23.6	0	0.1	10.9		-6.7	25.5	2.9	0.7	998.883	2462	4.184	0.5
10/6/97	8:00	3.277	45432	12053	2.6	0.28	16.0	16.3	0	0	0	409	39486	325.7	9.8	384.6	130.3	12.2	0	0	0	0.1	10.1		-9.8	74.3	21.1	2.0	998.968	2463	4.185	1.3
11/6/97	8:00	3.278	45498	12099	0.5	0.22	16.3	16.3	17487	33106	0	549	52991	363.8	10.9	386.0	109.8	10.8	4.4	8.4	0	0.1	13.5		0.7	13.2	2.9	0.4	998.924	2463	4.184	1.8
12/6/97	8:00	3.280	45629	12190	0.3	0.37	16.1	16.4	17230	32711	0	441	42649	350.5	10.5	385.0	99.8	10.1	4.4	8.3	0	0.1	10.8		1.0	8.5	3.1	0.2	998.958	2463	4.185	1.1
Balance 33D																																
13/6/97	8:00	3.268	44850	11647	1.4	0.22	17.0	17.3	0	399	0	7984	43606	361.1	10.8	389.7	129.2	12.1	0	0.10	0	2.1	11.3		5.7	40.9	9.0	1.2	998.808	2461	4.184	1.8
14/6/97	8:00	3.286	46035	12465	1.8	0.20	17.2	17.4	0	0	142655	11976	65814	366.8	11.0	390.8	80.4	8.5	0	0	35.9	3.0	16.5		10.7	50.4	10.3	1.5	998.774	2460	4.184	1.4
15/6/97	8:00	3.309	47651	13542	2.4	0.35	16.3	16.7	0	0	178210	13949	73466	326.8	9.8	386.1	150.7	13.4	0	0	43.3	3.4	17.8		1.3	68.3	24.1	1.9	998.925	2463	4.184	2.4
16/6/97	8:00	3.290	46315	12650	1.9	0.13	15.5	15.8	0	0	0	12587	62919	307.8	9.2	382.1	150.6	13.4	0	0	0	3.1	15.7		-20.1	53.5	7.0	1.4	999.045	2464	4.185	1.9
Balance 33E																																
Totals			ΔS	9489	31.7																											30.4
			Daily average		1.6																									Daily average		1.5

Balance Duration: 20 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 2.2

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 0.067

Balance Period No: 34 **East Lake**

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
16/6/97	8:00	3.290	46315	12650	1.9	0.13	15.5	15.8																								
17/6/97	8:00	3.273	45172	11872	1.8	0.11	15.9	16.2	0	0	0	0	49543	357.9	10.7	383.9	145.1	13.1	0	0	0	0	12.7		-2.9	50.5	5.3	1.4	998.991	2463	4.185	2.6
18/6/97	8:00	3.258	44214	11202	2.9	-0.09	16.3	16.6	0	0	0	0	39297	368.6	11.1	386.0	144.4	13.1	0	0	0	0	10.3		-2.3	83.1	-7.4	2.3	998.928	2463	4.184	3.5
19/6/97	8:00	3.246	43409	10676	1.3	-0.04	16.1	16.4	3562	3016	0	0	41033	392.2	11.8	385.1	92.9	9.5	0.9	0.8	0	0	10.9		-8.8	37.0	-1.4	1.0	998.953	2463	4.185	2.8
20/6/97	8:00	3.235	42577	10203	1.9	-0.10	15.3	15.5	4820	4657	0	0	36999	384.5	11.5	380.5	42.5	5.0	1.3	1.3	0	0	10.1		-15.2	54.5	-5.5	1.4	999.091	2465	4.185	1.4
Balance 34A																																
21/6/97	8:00	3.225	41803	9781	1.0	-0.02	15.8	16.2	5288	6578	0	0	37735	371.8	11.2	383.4	115.0	11.2	1.5	1.8	0	0	10.4		3.2	27.8	-0.6	0.7	999.006	2464	4.185	2.5
22/6/97	8:00	3.211	40683	9204	1.0	0.23	16.4	16.8	0	0	0	0	38270	329.5	9.9	386.7	133.2	12.4	0	0	0	0	10.9		1.4	29.4	6.6	0.8	998.905	2462	4.184	1.2
23/6/97	8:00	3.205	40254	8961	1.4	0.18	16.8	17.2	5493	7199	0	0	27417	382.3	11.5	388.9	112.8	11.0	1.6	2.1	0	0	7.9		1.0	39.2	7.0	1.1	998.835	2461	4.184	2.3
24/6/97	8:00	3.192	39385	8443	0.8	0.32	16.8	17.3	0	0	0	0	35197	360.3	10.8	388.7	116.5	11.3	0	0	0	0	10.3		-5.8	23.7	7.5	0.7	998.842	2461	4.184	1.6
Balance 34B																																
25/6/97	8:00	3.182	38726	8053	1.3	0.13	15.8	16.1	454	98	0	5087	27383	382.9	11.5	383.2	92.1	9.5	0.14	0.03	0	1.5	8.2		-17.5	38.4	5.1	1.0	999.012	2464	4.185	2.5
26/6/97	8:00	3.171	37991	7631	1.1	0.18	16.7	17.1	0	0	0	5557	31766	364.4	10.9	388.2	144.4	13.1	0	0	0	1.7	9.7		4.2	32.6	5.9	0.9	998.858	2462	4.184	2.4
27/6/97	8:00	3.162	37381	7292	1.1	0.22	16.5	16.9	0	0	0	4352	24540	347.8	10.4	387.1	142.0	12.9	0	0	0	1.3	7.6		-7.0	32.7	7.3	0.9	998.895	2462	4.184	2.2
28/6/97	8:00	3.155	36905	7032	1.7	0.15	16.6	17.0	0	0	8098	4308	24430	334.3	10.0	387.9	117.4	11.4	0	0	2.5	1.4	7.7		-2.8	47.5	7.1	1.3	998.865	2462	4.184	1.2
Balance 34C																																
Totals			ΔS	-5618	17.4																											26.3

Daily average 1.5

Daily average 2.2

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -23.6

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.74

Balance Period No: 35

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qsd	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
28/6/97	8:00	3.155	36905	7032	1.7	0.15	16.6	17.0																								
29/6/97	8:00	3.145	36197	6666	0.7	0.22	16.4	16.7	0	0	0	6529	29226	378.9	11.4	386.7	86.8	9.1	0	0	0	2.1	9.3		-7.4	20.8	4.5	0.6	998.903	2462	4.184	1.7
30/6/97	8:00	3.136	35507	6343	1.8	0.34	16.2	16.8	0	0	0	4988	22370	346.4	10.4	385.6	139.0	12.8	0	0	0	1.6	7.3		-4.2	50.5	17.2	1.4	998.942	2463	4.184	1.9
1/7/97	8:00	3.127	34783	6027	2.1	0.30	13.7	14.2	0	0	0	4680	17759	347.6	10.4	372.4	154.1	13.6	0	0	0	1.6	5.9		-26.0	59.6	17.7	1.4	999.317	2469	4.187	3.4
2/7/97	8:00	3.116	33896	5649	2.5	-0.06	12.9	13.1	0	0	0	5624	19762	355.3	10.7	368.2	154.4	13.6	0	0	0	1.9	6.7		-13.0	71.5	-4.6	1.6	999.419	2471	4.188	4.6
Balance 35A																																
3/7/97	8:00	3.128	34863	6062	2.6	-0.15	11.7	11.7	11316	31422	0	0	21005	373.7	11.2	362.2	95.9	9.8	3.8	10.4	0	0	7.0		-7.1	73.7	-11.2	1.5	999.556	2473	4.190	4.1
4/7/97	8:00	3.123	34463	5888	2.1	0.11	12.9	13.0	0	410	0	0	6416	340.1	10.2	368.3	91.1	9.4	0	0.14	0	0	2.2		9.1	59.6	6.4	1.3	999.416	2471	4.188	1.0
5/7/97	8:00	3.116	33896	5649	1.6	-0.23	15.4	15.6	643	882	0	0	14824	376.3	11.3	381.3	122.4	11.7	0.22	0.30	0	0	5.1		17.8	44.2	-10.2	1.2	999.066	2465	4.185	3.2
6/7/97	8:00	3.160	37244	7217	1.5	0.13	15.7	15.9	38168	89797	0	0	30915	381.5	11.4	382.9	68.5	7.5	11.9	27.9	0	0	9.6		23.1	43.9	5.5	1.2	999.021	2464	4.185	1.7
Balance 35B																																
7/7/97	8:00	3.186	38986	8208	2.4	0.08	15.2	15.5	18350	54976	0	91	16165	357.2	10.7	380.4	93.0	9.6	5.4	16.3	0	0	4.8		9.1	68.6	5.5	1.8	999.095	2465	4.185	1.8
8/7/97	8:00	3.181	38661	8014	0.5	0.51	13.0	13.5	3228	3273	0	113	17530	326.3	9.8	368.6	121.2	11.6	1.0	1.0	0	0	5.2		-22.5	15.4	7.8	0.3	999.410	2470	4.188	1.8
9/7/97	8:00	3.215	40988	9367	1.2	0.44	12.5	13.0	19347	52780	0	124	18597	327.5	9.8	366.1	146.2	13.2	5.5	14.9	0	0	5.3		8.2	34.3	14.9	0.7	999.469	2472	4.189	2.2
10/7/97	8:00	3.207	40394	9041	2.2	0.45	12.4	13.1	0	0	0	86	12985	299.9	9.0	365.8	150.3	13.4	0	0	0	0	3.7		-1.9	62.6	28.0	1.3	999.477	2472	4.189	1.4
Balance 35C																																
Totals			ΔS	2009	21.2																											28.6
			Daily average		1.8																								Daily average			2.4

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: -20.4

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): -0.62

Balance Period No: 36

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
10/7/97	8:00	3.207	40394	9041	2.2	0.45	12.4	13.1																								
11/7/97	8:00	3.199	39850	8721	1.0	0.52	12.0	12.7	0	0	0	2094	16177	320.0	9.6	363.6	157.8	13.8	0	0	0	0.6	4.7		-7.4	29.8	15.4	0.6	999.526	2473	4.189	2.1
12/7/97	8:00	3.190	39251	8365	2.5	0.41	11.5	12.1	0	0	0	1936	14236	321.8	9.7	361.0	161.3	14.0	0	0	0	0.6	4.2		-9.8	71.6	29.0	1.4	999.582	2474	4.190	2.6
13/7/97	8:00	3.199	39850	8721	0.5	-0.28	11.4	11.4	14962	25123	0	2622	18182	365.6	11.0	360.4	58.6	6.6	4.3	7.3	0	0.8	5.3		-3.9	15.5	-4.3	0.3	999.593	2474	4.190	2.7
14/7/97	8:00	3.240	42963	10417	0.6	0.35	12.6	12.8	35369	82002	0	1793	13991	333.3	10.0	367.0	25.2	3.1	9.5	22.1	0	0.5	3.8		29.8	16.2	5.7	0.3	999.448	2471	4.188	-0.6
Balance 36A																																
15/7/97	8:00	3.231	42271	10033	2.0	0.45	12.3	12.9	0	0	0	750	16595	302.0	9.1	365.4	155.8	13.7	0	0	0	0.2	4.5		-2.1	56.7	25.6	1.2	999.485	2472	4.189	1.6
16/7/97	8:00	3.224	41724	9739	2.5	0.23	12.0	12.4	0	0	0	473	10088	289.6	8.7	363.5	159.8	13.9	0	0	0	0.1	2.8		-7.6	71.6	16.8	1.5	999.526	2473	4.189	1.9
17/7/97	8:00	3.216	41066	9408	1.7	0.35	11.8	12.3	0	0	0	655	13841	314.5	9.4	362.7	164.8	14.2	0	0	0	0.2	3.9		-4.0	47.7	16.5	1.0	999.545	2473	4.189	2.4
18/7/97	8:00	3.209	40536	9122	1.9	0.35	11.9	12.4	0	0	0	523	11120	315.8	9.5	363.3	165.8	14.3	0	0	0	0.1	3.2		-1.5	53.7	18.7	1.1	999.533	2473	4.189	2.4
Balance 36B																																
19/7/97	8:00	3.200	39917	8760	1.5	0.33	12.2	12.6	0	0	0	1447	16975	326.7	9.8	364.7	162.1	14.1	0	0	0	0.4	4.9		-0.8	41.8	14.0	0.9	999.502	2472	4.189	2.5
20/7/97	8:00	3.196	39649	8601	1.0	0.30	12.7	13.0	0	0	0	564	6787	328.5	9.9	367.1	166.0	14.3	0	0	0	0.2	2.0		2.0	29.8	9.1	0.6	999.446	2471	4.188	2.6
21/7/97	8:00	3.188	39117	8286	1.8	0.32	13.0	13.3	0	0	0	1170	14463	318.6	9.6	368.8	169.7	14.5	0	0	0	0.3	4.3		0.3	50.7	16.1	1.1	999.406	2470	4.188	2.4
22/7/97	8:00	3.183	38791	8091	2.1	0.17	12.6	13.1	0	0	0	545	6594	297.0	8.9	367.0	172.8	14.6	0	0	0	0.2	2.0		-4.8	59.6	10.0	1.3	999.448	2471	4.188	2.4
Balance 36C																																
Totals			ΔS	-950	19.0																											25.0
			Daily average		1.6																								Daily average			2.1

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -18.0

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.50

Balance Period No: 37 **East Lake**

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
22/7/97	8:00	3.183	38791	8091	2.1	0.17	12.6	13.1																								
23/7/97	8:00	3.177	38400	7860	2.8	0.08	13.4	13.7	0	0	0	768	7733	340.1	10.2	370.8	170.9	14.5	0	0	0	0.2	2.3		3.9	80.4	6.3	1.8	999.354	2469	4.187	3.5
24/7/97	8:00	3.189	39183	8325	2.6	-0.01	14.4	14.5	17874	27643	0	1505	15977	368.5	11.1	375.8	130.1	12.2	5.3	8.2	0	0.4	4.7		12.9	73.5	-0.4	1.8	999.222	2467	4.186	3.3
25/7/97	8:00	3.210	40608	9163	2.2	0.09	14.1	14.2	20142	43289	0	938	9791	347.2	10.4	374.6	71.0	7.7	5.7	12.3	0	0.3	2.8		6.5	62.8	5.7	1.5	999.257	2468	4.187	1.1
26/7/97	8:00	3.207	40394	9041	1.4	0.14	14.9	15.1	3487	3185	0	1177	13063	342.3	10.3	378.7	119.5	11.5	1.0	0.9	0	0.3	3.7		8.5	39.7	5.6	1.0	999.141	2466	4.186	1.5
Balance 37A																																
27/7/97	8:00	3.216	41066	9408	1.1	-0.03	15.4	15.5	14973	29979	0	4647	26606	320.3	9.6	381.3	117.5	11.4	4.2	8.4	0	1.3	7.5		8.0	31.3	-1.0	0.8	999.069	2465	4.185	1.2
28/7/97	8:00	3.211	40683	9204	2.2	0.34	16.0	16.3	0	144	0	1523	9200	287.0	8.6	384.5	126.8	12.0	0	0	0	0.4	2.6		7.2	62.4	21.0	1.7	998.973	2463	4.185	0.0
29/7/97	8:00	3.207	40394	9041	2.2	0.24	16.8	17.0	1983	3686	0	2109	13257	321.3	9.6	388.7	160.0	14.0	0.6	1.1	0	0.6	3.8		5.3	61.7	14.8	1.8	998.841	2461	4.184	1.7
30/7/97	8:00	3.200	39917	8760	1.8	0.27	17.4	17.6	0	0	0	2734	17756	296.7	8.9	392.0	154.0	13.6	0	0	0	0.8	5.1		2.4	50.4	13.7	1.5	998.737	2460	4.183	0.8
Balance 37B																																
31/7/97	8:00	3.195	39583	8562	1.6	0.23	17.3	17.5	0	0	0	2746	12391	309.8	9.3	391.3	144.8	13.1	0	0	0	0.8	3.6		-3.6	44.5	10.2	1.3	998.761	2460	4.184	1.2
1/8/97	8:00	3.190	39251	8365	2.3	0.24	17.9	18.1	0	0	0	2160	10093	292.0	8.8	394.6	169.5	14.5	0	0	0	0.6	3.0		3.7	65.2	15.6	2.0	998.648	2459	4.183	1.0
2/8/97	8:00	3.183	38791	8091	2.9	0.37	17.2	17.5	0	0	0	3231	14632	294.1	8.8	391.1	176.8	14.8	0	0	0	1.0	4.4		-9.6	83.1	30.7	2.4	998.770	2460	4.184	1.6
3/8/97	8:00	3.179	38531	7937	0.7	0.29	16.5	16.8	0	0	0	2544	11037	317.7	9.5	387.4	166.8	14.3	0	0	0	0.8	3.3		-9.6	20.8	6.0	0.6	998.885	2462	4.184	2.1
Balance 37C																																
Totals			ΔS	-154	23.7																											19.0

Daily average 2.0

Daily average 1.6

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 13.5

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 0.39

Qa and Qar data in red are estimates using method of Koberg 1964

Balance Period No: 38

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
3/8/97 8:00	3.179	38531	7937	0.7	0.29	16.5	16.8																								
4/8/97 8:00	3.233	42424	10118	1.3	-0.01	15.1	15.0	55102	65291	0	0	0	328.1	9.8	379.9	52.5	6.0	15.0	17.8	0	0.0	0.0		5.3	36.1	-0.4	0.9	999.108	2465	4.185	0.4
5/8/97 8:00	3.248	43550	10763	2.8	0.07	17.3	17.4	17595	68788	0	13646	49982	316.0	9.5	391.2	144.2	13.1	4.7	18.3	0	3.6	13.3		34.9	80.3	5.6	2.4	998.762	2460	4.184	0.8
6/8/97 8:00	3.249	43619	10806	1.9	0.13	15.8	15.9	5439	14940	0	4704	15729	327.1	9.8	383.4	111.0	10.9	1.4	4.0	0	1.2	4.2		-17.6	53.4	6.8	1.4	999.005	2464	4.185	1.6
7/8/97 8:00	3.248	43550	10763	2.0	0.19	16.7	16.8	3838	9301	0	3371	11972	323.1	9.7	388.2	141.8	12.9	1.0	2.5	0	0.9	3.2		11.3	57.5	10.8	1.6	998.856	2462	4.184	1.3
Balance 38A																															
8/8/97 8:00	3.245	43337	10632	1.4	0.35	17.7	17.8	4430	8036	6522	11292	34983	322.5	9.7	393.4	120.2	11.5	1.2	2.1	1.7	3.0	9.3		9.8	39.1	13.6	1.2	998.690	2459	4.183	0.4
9/8/97 8:00	3.250	43688	10850	2.4	0.16	16.8	16.9	12835	30921	0	13470	39534	313.8	9.4	388.9	110.8	10.9	3.4	8.2	0	3.6	10.5		-8.7	67.3	11.0	1.9	998.836	2461	4.184	0.8
10/8/97 8:00	3.316	48161	13877	1.5	0.42	14.6	14.7	46671	120912	0	13625	34934	271.7	8.2	377.0	68.8	7.5	11.2	29.1	0	3.3	8.4		2.7	42.0	17.6	1.0	999.190	2467	4.186	-0.5
11/8/97 8:00	3.310	47725	13590	1.9	0.47	14.7	14.9	0	1573	0	7186	18618	255.1	7.7	377.6	174.9	14.7	0	0.4	0	1.7	4.5		-0.3	53.5	25.3	1.3	999.174	2466	4.186	0.7
Balance 38B																															
12/8/97 8:00	3.303	47214	13257	1.5	0.39	14.5	14.8	0	0	0	17582	29747	255.0	7.6	376.8	188.6	15.4	0	0	0	4.3	7.3		-4.3	41.7	16.1	1.0	999.196	2467	4.186	1.1
13/8/97 8:00	3.298	46866	13022	2.3	0.32	15.1	15.5	0	0	0	8458	14991	264.8	7.9	379.6	196.3	15.7	0	0	0	2.1	3.7		7.4	65.4	21.1	1.7	999.119	2465	4.186	1.3
14/8/97 8:00	3.293	46526	12789	3.1	0.04	16.1	16.2	0	0	0	5794	10722	330.2	9.9	385.0	198.5	15.8	0	0	0	1.4	2.7		6.9	89.1	3.4	2.4	998.956	2463	4.185	3.6
15/8/97 8:00	3.343	49866	15201	3.3	0.05	17.5	17.4	56065	121208	0	4395	8777	334.2	10.0	392.6	140.1	12.8	13.0	28.1	0	1.0	2.0		42.3	93.8	4.5	2.8	998.714	2460	4.183	1.8
Balance 38C																															
16/8/97 8:00	3.347	50104	15401	2.1	0.30	16.9	17.3	14140	28514	0	11060	35775	267.5	8.0	389.4	155.4	13.7	3.3	6.6	0	2.6	8.3		-0.1	59.3	17.9	1.7	998.820	2461	4.184	0.4
17/8/97 8:00	3.340	49688	15052	2.2	0.36	16.3	16.8	0	1661	0	7964	25059	241.4	7.2	386.2	188.3	15.4	0	0.4	0	1.9	5.8		-10.6	62.4	22.7	1.7	998.922	2462	4.184	0.7
18/8/97 8:00	3.335	49387	14804	2.7	0.39	15.7	16.2	0	0	0	3426	10399	230.3	6.9	383.0	200.6	15.9	0	0	0	0.8	2.4		-11.2	77.3	30.4	2.1	999.020	2464	4.185	0.9
19/8/97 8:00	3.330	49075	14558	2.5	0.29	15.2	15.7	0	0	0	3697	10866	263.9	7.9	380.5	164.4	14.2	0	0	0	0.9	2.6		-9.8	71.4	20.9	1.8	999.093	2465	4.185	0.9
Balance 38D																															
Totals		ΔS	6621	34.7																											16.3
		Daily average		2.2																								Daily average			1.0

Balance Duration: 16 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 41.2

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 1.15

Qa and Qar terms in red are estimates using method of Koberg 1964

Balance Period No: 39

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
19/8/97 8:00	3.330	49075	14558	2.5	0.29	15.2	15.7																								
20/8/97 8:00	3.325	48760	14314	1.8	0.34	15.7	16.2	0	0	0	17857	25321	261.6	7.8	383.2	175.9	14.8	0	0	0	4.2	6.0		5.2	50.5	17.3	1.4	999.014	2464	4.185	0.6
21/8/97 8:00	3.320	48436	14071	3.0	0.32	16.2	16.7	0	0	0	10919	15892	262.2	7.9	385.6	211.5	16.4	0	0	0	2.6	3.8		3.6	86.1	27.5	2.4	998.940	2463	4.184	1.5
22/8/97 8:00	3.316	48161	13877	2.1	0.28	16.8	17.2	0	0	0	10578	15914	267.9	8.0	388.9	179.3	14.9	0	0	0	2.5	3.8		5.9	59.4	16.6	1.7	998.836	2461	4.184	0.8
23/8/97 8:00	3.311	47799	13638	2.1	0.33	17.0	17.4	0	0	0	15810	24045	244.5	7.3	389.6	187.2	15.3	0	0	0	3.8	5.8		0.3	59.3	19.6	1.7	998.813	2461	4.184	0.4
Balance 39A																															
24/8/97 8:00	3.306	47427	13399	2.4	0.33	16.6	17.0	0	0	0	8595	14158	230.9	6.9	387.7	199.6	15.9	0	0	0	2.1	3.5		-8.4	68.3	22.5	1.9	998.876	2462	4.184	0.7
25/8/97 8:00	3.301	47075	13163	2.4	0.17	16.5	16.9	0	0	0	8458	13861	237.2	7.1	387.3	202.9	16.0	0	0	0	2.1	3.4		-3.6	68.3	11.3	1.9	998.888	2462	4.184	0.9
26/8/97 8:00	3.295	46662	12882	4.3	-0.01	16.8	17.1	0	0	0	5570	9225	283.1	8.5	388.7	207.3	16.2	0	0	0	1.4	2.3		-0.5	121.7	-1.1	3.5	998.841	2461	4.184	2.6
27/8/97 8:00	3.294	46594	12835	2.8	-0.14	16.1	16.2	1336	0	0	0	0	326.0	9.8	385.1	131.3	12.3	0.3	0	0	0.0	0.0		-12.2	79.6	-11.1	2.2	998.954	2463	4.185	2.5
Balance 39B																															
28/8/97 8:00	3.314	48019	13781	1.5	0.18	18.1	18.3	21599	44658	0	17801	30450	325.8	9.8	395.5	178.3	14.9	5.2	10.8	0	4.3	7.3		38.9	42.8	7.7	1.3	998.616	2458	4.183	1.7
29/8/97 8:00	3.326	48823	14362	1.8	0.42	16.4	16.7	14494	30037	0	8340	12997	294.6	8.8	386.5	153.5	13.6	3.4	7.1	0	2.0	3.1		-16.9	52.0	22.0	1.4	998.913	2462	4.184	1.6
30/8/97 8:00	3.321	48503	14119	2.3	0.35	15.9	16.4	0	0	0	12555	19172	257.0	7.7	383.9	162.9	14.1	0	0	0	3.0	4.6		-7.2	65.4	22.9	1.8	998.991	2463	4.185	0.5
31/8/97 8:00	3.318	48300	13974	2.4	0.30	17.1	17.6	0	0	0	2780	4558	240.2	7.2	390.2	214.6	16.5	0	0	0	0.7	1.1		15.5	68.2	20.8	2.0	998.796	2461	4.184	0.7
Balance 39C																															
Totals		ΔS	-584	28.9																											14.6
		Daily average		2.4																									Daily average		1.2

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 42.3

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 1.19

Balance Period No: 40

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
31/8/97	8:00	3.318	48300	13974	2.4	0.30	17.1	17.6																								
1/9/97	8:00	3.312	47873	13685	3.2	0.33	17.5	18.0	0	0	0	12464	20104	249.0	7.5	392.3	230.0	17.1	0	0	0	3.0	4.9		2.4	91.9	30.4	2.7	998.725	2460	4.183	1.5
2/9/97	8:00	3.343	49866	15201	1.3	0.17	14.6	14.6	35809	56118	0	0	0	295.3	8.9	376.9	66.5	7.3	8.3	13.0	0	0.0	0.0		-32.5	38.1	6.5	0.9	999.193	2467	4.186	0.7
3/9/97	8:00	3.355	50567	15804	2.0	0.32	14.9	15.2	16138	21919	0	7255	9922	276.5	8.3	378.5	169.8	14.5	3.7	5.0	0	1.7	2.3		14.3	56.4	17.8	1.4	999.148	2466	4.186	1.0
4/9/97	8:00	3.350	50280	15552	2.0	0.34	16.3	16.9	497	122	0	14789	22435	249.7	7.5	386.1	200.6	15.9	0.1	0	0	3.4	5.2		22.5	56.3	18.9	1.6	998.925	2463	4.184	0.4
Balance 40A																																
5/9/97	8:00	3.345	49985	15301	2.3	0.05	16.7	17.0	0	0	0	298	10382	301.8	9.1	388.0	164.3	14.2	0	0	0	0.1	2.4		-0.7	65.3	3.2	1.9	998.862	2462	4.184	1.7
6/9/97	8:00	3.463	56474	21608	2.1	0.14	17.3	17.4	120746	240062	0	1897	67863	316.9	9.5	391.3	131.0	12.3	24.7	49.2	0	0.4	13.9		71.0	60.1	8.6	1.8	998.757	2460	4.184	0.7
7/9/97	8:00	3.456	56163	21213	3.0	0.19	16.7	16.9	2426	654	0	641	22279	294.8	8.8	388.2	159.5	13.9	0.5	0.1	0	0.1	4.6		-13.3	84.9	16.0	2.4	998.856	2462	4.184	1.5
8/9/97	8:00	3.526	59481	25261	3.0	0.29	18.0	18.3	80863	134849	0	1072	40199	308.1	9.2	395.1	189.8	15.4	15.7	26.2	0	0.2	7.8		66.1	83.9	24.3	2.6	998.630	2459	4.183	1.2
Balance 40B																																
9/9/97	8:00	3.551	60631	26761	3.3	0.26	18.6	18.9	44992	55089	0	6593	13155	311.9	9.4	398.3	176.2	14.8	8.6	10.5	0	1.3	2.5		26.9	93.1	23.9	2.9	998.523	2457	4.183	1.5
10/9/97	8:00	3.575	62269	28233	2.6	0.40	17.1	17.8	35527	77191	0	46604	87754	264.9	7.9	390.4	163.7	14.1	6.6	14.3	0	8.7	16.3		-12.3	72.7	28.9	2.1	998.788	2461	4.184	1.0
11/9/97	8:00	3.570	61779	27923	2.3	0.30	16.9	17.7	2018	1539	0	17353	32432	265.9	8.0	389.3	192.2	15.5	0.4	0.3	0	3.3	6.1		-4.1	64.5	19.5	1.9	998.821	2461	4.184	1.2
12/9/97	8:00	3.567	61539	27738	2.7	0.28	18.7	19.0	4174	4638	0	12503	25171	276.0	8.3	398.8	242.2	17.5	0.8	0.9	0	2.4	4.7		28.7	75.5	21.4	2.4	998.501	2457	4.183	1.7
Balance 40C																																
Totals			ΔS	13764	29.6																											14.3

Daily average 2.5

Daily average 1.2

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 46.3

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 1.27

Balance Period No: 41

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
12/9/97 8:00	3.567	61539	27738	2.7	0.28	18.7	19.0																								
13/9/97 8:00	3.561	61155	27370	3.1	0.29	19.3	19.7	0	0	0	16676	31093	254.9	7.6	402.2	238.0	17.4	0	0	0	3.2	5.9		11.4	88.8	25.5	2.9	998.382	2455	4.182	1.4
14/9/97 8:00	3.557	60947	27126	2.5	0.31	18.6	19.1	0	0	0	8622	15636	297.4	8.9	398.6	180.6	15.0	0	0	0	1.6	3.0		-14.0	71.1	22.0	2.3	998.508	2457	4.183	1.8
15/9/97 8:00	3.552	60684	26822	3.1	0.24	18.9	19.5	0	0	0	10801	19913	280.3	8.4	400.4	172.1	14.6	0	0	0	2.1	3.8		3.9	88.8	21.2	2.9	998.447	2456	4.182	0.6
16/9/97 8:00	3.547	60416	26519	3.1	0.10	20.1	20.5	0	0	0	10801	20986	296.5	8.9	406.7	244.5	17.6	0	0	0	2.1	4.0		19.4	88.7	8.6	3.0	998.216	2454	4.182	2.7
Balance 41A																															
17/9/97 8:00	3.542	60156	26218	2.6	0.27	21.2	21.6	0	0	0	2073	15306	289.7	8.7	413.1	250.1	17.8	0	0	0	0.4	2.9		19.0	73.8	20.0	2.7	997.971	2451	4.181	2.1
18/9/97 8:00	3.537	59935	25917	3.0	0.29	21.9	22.3	772	1367	0	2174	16571	298.3	8.9	416.7	242.8	17.5	0.15	0.26	0	0.4	3.2		11.1	85.3	24.7	3.2	997.830	2449	4.181	2.2
19/9/97 8:00	3.533	59766	25678	2.9	0.30	22.4	22.9	380	0	0	1008	7886	305.9	9.2	419.9	227.1	17.0	0.07	0	0	0.2	1.5		9.3	82.6	24.6	3.2	997.698	2448	4.181	2.0
20/9/97 8:00	3.527	59522	25320	3.0	0.29	22.2	22.7	0	0	0	2562	19921	319.8	9.6	418.6	197.0	15.8	0	0	0	0.5	3.9		-7.8	85.5	24.6	3.2	997.754	2449	4.181	2.1
Balance 41B																															
21/9/97 8:00	3.520	59236	24904	2.5	0.25	22.2	22.7	0	0	0	4991	31088	295.1	8.9	418.8	232.3	17.2	0	0	0	1.0	6.1		-6.7	70.8	17.6	2.7	997.747	2448	4.181	2.3
22/9/97 8:00	3.517	59115	24727	3.2	0.28	22.1	22.6	0	77	0	0	0	284.4	8.5	417.8	229.5	17.0	0	0.02	0	0.0	0.0		-4.0	91.4	25.4	3.4	997.786	2449	4.181	2.0
23/9/97 8:00	3.510	58809	24314	3.4	0.31	22.4	22.9	0	169	0	3963	24926	283.3	8.5	419.8	270.8	18.4	0	0.03	0	0.8	4.9		0.8	97.3	30.2	3.7	997.704	2448	4.181	2.7
24/9/97 8:00	3.506	58581	24079	4.0	0.20	22.9	23.4	1846	651	0	654	4207	302.7	9.1	422.4	269.9	18.4	0.36	0.13	0	0.1	0.8		7.5	114.3	22.6	4.5	997.600	2447	4.180	3.3
Balance 41C																															
Totals		ΔS	-3659	36.7																											25.2

Daily average 3.1

Daily average 2.1

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 35.1

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 0.96

Balance Period No: 42

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
24/9/97	8:00	3.506	58581	24079	4.0	0.20	22.9	23.4																								
25/9/97	8:00	3.499	58174	23671	4.3	0.33	21.9	22.6	0	121	0	9133	24682	276.0	8.3	416.8	262.4	18.2	0	0.02	0	1.8	4.9		-20.4	121.0	39.4	4.5	997.828	2449	4.181	2.9
26/9/97	8:00	3.495	57969	23438	3.4	0.30	20.7	21.1	2287	796	0	5252	13267	320.8	9.6	409.9	199.0	15.8	0.46	0.16	0	1.0	2.6		-31.6	96.9	29.0	3.4	998.096	2452	4.181	3.0
27/9/97	8:00	3.490	57724	23149	2.8	0.33	20.7	21.2	0	36	0	7250	18387	281.5	8.4	410.3	240.5	17.4	0	0.01	0	1.5	3.7		-1.7	79.8	26.2	2.8	998.081	2452	4.181	2.2
28/9/97	8:00	3.485	57486	22861	3.3	0.30	20.9	21.5	0	0	0	5480	14096	283.1	8.5	411.4	248.8	17.7	0	0	0	1.1	2.8		2.4	94.5	28.7	3.4	998.036	2452	4.181	2.4
Balance 42A																																
29/9/97	8:00	3.479	57207	22517	3.7	0.24	21.7	22.1	0	0	0	18096	34261	294.4	8.8	415.7	251.8	17.8	0	0	0	3.7	6.9		7.7	103.3	25.1	3.8	997.872	2450	4.181	2.6
30/9/97	8:00	3.475	57025	22289	3.1	0.26	22.9	23.4	0	0	0	6568	13167	306.7	9.2	422.3	285.0	18.9	0	0	0	1.3	2.7		21.7	88.4	23.2	3.5	997.599	2447	4.180	3.2
1/10/97	8:00	3.472	56890	22118	4.4	0.22	22.9	23.4	7463	10097	0	20241	40508	330.8	9.9	422.8	255.0	17.9	1.5	2.1	0	4.1	8.2		-3.1	125.0	27.1	4.9	997.583	2447	4.180	3.9
2/10/97	8:00	3.467	56663	21834	3.1	0.31	20.6	21.2	0	0	0	14209	25823	290.8	8.7	409.9	171.2	14.5	0	0	0	2.9	5.3		-44.0	88.6	27.3	3.1	998.099	2452	4.181	1.8
Balance 42B																																
3/10/97	8:00	3.460	56337	21438	3.9	0.28	20.4	21.1	0	0	0	15791	29608	279.9	8.4	408.3	285.9	18.9	0	0	0	3.2	6.1		-6.7	109.4	30.7	3.8	998.156	2453	4.182	3.6
4/10/97	8:00	3.455	56120	21157	4.0	0.23	21.6	22.2	0	0	0	5145	10110	287.9	8.6	415.1	298.4	19.2	0	0	0	1.1	2.1		14.9	112.2	25.6	4.1	997.892	2450	4.181	3.6
5/10/97	8:00	3.447	55778	20710	4.8	0.17	22.4	22.8	0	0	0	15880	32172	284.7	8.5	419.8	296.9	19.2	0	0	0	3.3	6.7		6.2	135.6	23.3	5.2	997.710	2448	4.181	3.6
6/10/97	8:00	3.442	55566	20431	5.6	0.04	21.2	21.8	0	0	0	0	0	306.4	9.2	413.2	287.3	18.9	0	0	0	0.0	0.0		-23.0	159.4	6.8	5.8	997.970	2451	4.181	5.7
Balance 42C																																
Totals			ΔS	-3648	46.4																											38.5
			Daily average		3.9																								Daily average			3.2

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: 24.0

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): 0.66

Balance Period No: 43

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
6/10/97	8:00	3.442	55566	20431	5.6	0.04	21.2	21.8																								
7/10/97	8:00	3.436	55308	20099	4.6	0.11	21.6	22.0	0	0	0	11749	21129	323.5	9.7	415.3	248.2	17.7	0	0	0	2.5	4.4		-1.1	129.9	13.9	4.8	997.885	2450	4.181	4.0
8/10/97	8:00	3.437	55351	20154	4.1	0.22	23.4	23.7	14757	24374	0	26210	50777	351.0	10.5	425.1	283.0	18.8	3.1	5.1	0	5.5	10.6		30.7	114.6	25.3	4.6	997.484	2446	4.180	4.3
9/10/97	8:00	3.469	56754	21947	4.7	0.24	22.1	22.3	54962	94655	0	0	0	328.8	9.9	418.2	207.4	16.2	11.2	19.3	0	0.0	0.0		-0.3	132.9	31.9	5.0	997.773	2449	4.181	3.4
10/10/97	8:00	3.483	57393	22746	4.9	0.20	19.6	19.8	30937	54525	0	36001	58228	309.2	9.3	403.8	249.7	17.8	6.2	11.0	0	7.3	11.7		-37.8	138.2	27.1	4.6	998.326	2455	4.182	5.1
Balance 43A																																
11/10/97	8:00	3.478	57161	22460	4.2	0.17	19.7	20.2	0	0	0	2632	6624	281.3	8.4	404.5	252.2	17.8	0	0	0	0.5	1.3		4.9	118.3	20.5	4.0	998.297	2454	4.182	2.8
12/10/97	8:00	3.470	56800	22004	3.9	0.25	21.5	22.0	0	0	0	13215	36225	297.7	8.9	414.3	301.7	19.3	0	0	0	2.7	7.4		28.4	109.2	27.0	4.0	997.924	2450	4.181	3.4
13/10/97	8:00	3.465	56571	21721	3.8	0.26	23.2	23.7	0	0	0	3920	11560	290.8	8.7	424.4	291.3	19.0	0	0	0	0.8	2.4		27.3	106.0	27.6	4.2	997.514	2446	4.180	2.7
14/10/97	8:00	3.458	56249	21326	3.4	0.27	22.7	23.3	0	0	0	11255	32698	311.8	9.4	421.5	264.9	18.2	0	0	0	2.3	6.7		-12.0	97.3	25.8	3.8	997.635	2447	4.180	3.7
Balance 43B																																
15/10/97	8:00	3.451	55948	20933	4.9	0.25	23.3	23.9	0	0	0	5365	18895	289.5	8.7	424.9	314.3	19.7	0	0	0	1.1	3.9		5.6	138.4	34.9	5.5	997.495	2446	4.180	3.9
16/10/97	8:00	3.443	55608	20487	4.2	0.26	22.8	23.5	0	0	0	9685	33506	276.3	8.3	422.1	305.8	19.4	0	0	0	2.0	7.0		-14.2	117.9	30.8	4.6	997.614	2447	4.180	3.8
17/10/97	8:00	3.435	55265	20043	5.0	0.24	21.9	22.7	0	0	0	7548	25206	282.0	8.5	417.1	290.5	19.0	0	0	0	1.6	5.3		-20.9	141.6	33.9	5.3	997.815	2449	4.181	4.0
18/10/97	8:00	3.425	54793	19493	5.0	0.14	20.8	21.5	0	0	0	12504	39583	280.1	8.4	410.8	299.0	19.3	0	0	0	2.6	8.4		-27.9	141.8	20.0	5.0	998.063	2452	4.181	4.9
Balance 43C																																
Totals			ΔS	-938	52.5																											45.9

Daily average 4.4

Daily average 3.8

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: 19.5

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): 0.55

Balance Period No: 44 East Lake

Day & Time	Stage m AHD	Area m^2	Volume m^3	Pan E mm	R	T_0 °C	T_m °C	Qrn m joules	Qsd m joules	Qtu m joules	Qdc m joules	Qrc m joules	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E mm
18/10/97 8:00	3.425	54793	19493	5.0	0.14	20.8	21.5																								
19/10/97 8:00	3.419	54510	19165	5.1	0.11	21.7	22.1	0	0	0	0	6455	275.6	8.3	415.7	334.6	20.2	0	0	0	0	1.4		5.6	144.6	15.8	5.4	997.872	2450	4.181	4.9
20/10/97 8:00	3.410	54055	18677	6.8	0.02	21.9	22.3	0	0	0	0	15948	310.8	9.3	416.9	331.0	20.1	0	0	0	0	3.4		-3.2	191.8	3.5	7.2	997.822	2449	4.181	6.5
21/10/97 8:00	3.402	53580	18246	4.7	-0.03	22.6	22.8	0	0	0	0	24164	358.8	10.8	420.6	266.8	18.3	0	0	0	0	5.2		2.5	132.7	-4.1	5.1	997.668	2448	4.181	5.9
22/10/97 8:00	3.393	52839	17767	6.0	0.09	25.6	26.0	0	0	0	0	24294	339.9	10.2	438.0	312.3	19.6	0	0	0	0	5.3		47.1	170.4	15.4	7.5	996.926	2441	4.180	4.1
Balance 44A																															
23/10/97 8:00	3.383	52166	17242	4.3	0.11	26.1	26.4	369	1001	0	16397	57469	360.0	10.8	440.8	254.6	17.9	0.08	0.22	0	3.6	12.8		-0.3	120.2	13.4	5.4	996.799	2439	4.179	4.2
24/10/97 8:00	3.373	51591	16723	5.2	0.23	25.9	26.4	0	0	0	12787	44825	343.0	10.3	439.9	263.1	18.2	0	0	0	2.9	10.1		-8.1	146.8	34.2	6.5	996.843	2440	4.179	3.8
25/10/97 8:00	3.364	51073	16261	3.3	0.28	22.8	23.3	0	0	0	15005	46399	322.5	9.7	422.2	187.3	15.3	0	0	0	3.4	10.5		-55.2	94.3	26.7	3.7	997.609	2447	4.180	3.0
26/10/97 8:00	3.357	50679	15905	4.6	0.28	23.4	24.0	0	0	0	6342	20190	309.4	9.3	425.5	339.4	20.4	0	0	0	1.4	4.6		5.3	129.6	35.9	5.2	997.472	2446	4.180	5.0
Balance 44B																															
27/10/97 8:00	3.349	50221	15502	4.8	0.26	24.2	24.6	0	356	0	7231	26053	312.6	9.4	429.8	334.6	20.2	0	0.08	0	1.7	6.0		3.9	135.3	35.0	5.6	997.286	2444	4.180	4.9
28/10/97 8:00	3.343	49866	15201	5.0	0.23	25.0	25.3	4573	4581	0	7669	28367	333.2	10.0	434.6	307.2	19.5	1.1	1.1	0	1.8	6.6		5.1	142.2	32.6	6.1	997.076	2442	4.180	4.7
29/10/97 8:00	3.331	49138	14607	5.3	0.23	24.1	24.5	0	0	0	14506	51908	303.6	9.1	429.3	311.4	19.6	0	0	0	3.4	12.2		-21.1	150.1	34.5	6.2	997.313	2444	4.180	4.7
30/10/97 8:00	3.318	48300	13974	6.2	0.26	21.3	21.8	0	0	0	14594	46565	279.8	8.4	413.7	318.6	19.8	0	0	0	3.5	11.2		-46.5	174.2	44.4	6.3	997.958	2451	4.181	5.3
Balance 44C																															
Totals		ΔS	-5519	61.4																											57.0
		Daily average		5.1																									Daily average		4.7

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: 12.4

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): 0.36

Balance Period No: 45 **East Lake**

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
30/10/97	8:00	3.318	48300	13974	6.2	0.26	21.3	21.8																								
31/10/97	8:00	3.308	47575	13494	5.2	0.17	20.8	21.4	0	0	0	0	22722	283.9	8.5	410.9	347.5	20.6	0	0	0	0	5.5		-11.9	147.7	25.4	5.2	998.058	2452	4.181	5.8
1/11/97	8:00	3.297	46798	12975	4.9	0.22	21.9	22.4	0	0	0	0	29835	293.7	8.8	417.0	345.6	20.5	0	0	0	0	7.4		7.3	138.7	30.7	5.2	997.821	2449	4.181	5.0
2/11/97	8:00	3.290	46315	12650	5.2	0.16	23.5	24.0	0	0	0	0	9102	297.9	8.9	426.1	349.3	20.6	0	0	0	0	2.3		16.7	147.2	24.2	5.9	997.450	2446	4.180	5.1
3/11/97	8:00	3.283	45829	12327	5.6	0.06	24.8	25.4	0	0	0	0	7507	321.5	9.6	433.5	329.3	20.1	0	0	0	0	1.9		12.9	158.8	9.1	6.7	997.126	2442	4.180	5.6
Balance 45A																																
4/11/97	8:00	3.274	45237	11917	5.5	0.08	24.6	25.3	0	0	0	1105	18264	356.1	10.7	432.6	268.3	18.3	0	0	0	0.3	4.7		-7.9	155.8	12.9	6.6	997.166	2443	4.180	5.2
5/11/97	8:00	3.265	44659	11513	4.4	0.22	22.6	23.3	0	0	0	1448	22048	347.8	10.4	420.9	182.8	15.1	0	0	0	0.4	5.7		-31.7	123.8	26.9	4.8	997.662	2448	4.181	3.1
6/11/97	8:00	3.256	44085	11113	4.4	0.19	22.1	22.9	0	0	0	1441	21579	306.8	9.2	417.9	300.0	19.3	0	0	0	0.4	5.7		-11.1	123.9	24.0	4.7	997.788	2449	4.181	4.8
7/11/97	8:00	3.244	43265	10589	6.4	0.16	22.3	23.2	0	0	0	1721	26064	299.5	9.0	419.2	361.5	21.0	0	0	0	0.5	7.0		-5.0	179.9	28.4	6.8	997.735	2448	4.181	6.2
Balance 45B																																
8/11/97	8:00	3.235	42577	10203	5.4	0.18	22.2	23.0	0	0	0	0	15623	307.4	9.2	418.4	354.0	20.8	0	0	0	0	4.2		-7.4	153.4	28.1	5.8	997.763	2449	4.181	6.2
9/11/97	8:00	3.227	41961	9865	5.8	0.14	24.5	25.3	0	0	0	0	10189	324.4	9.7	431.5	353.9	20.8	0	0	0	0	2.8		20.2	164.7	22.8	6.9	997.214	2443	4.180	5.8
10/11/97	8:00	3.220	41400	9573	5.0	0.16	25.6	26.6	0	0	0	0	9767	341.3	10.2	438.4	326.1	20.0	0	0	0	0	2.7		9.7	141.0	23.0	6.2	996.912	2441	4.180	5.5
11/11/97	8:00	3.209	40536	9122	5.9	0.12	24.9	25.9	0	0	0	0	23750	340.6	10.2	434.4	324.3	20.0	0	0	0	0	6.8		-15.2	167.6	20.7	7.1	997.093	2442	4.180	6.3
Balance 45C																																
Totals			ΔS	-4852	63.8																											64.5
			Daily average		5.3																								Daily average			5.4

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -2.0

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.057

Balance Period No: 46 **East Lake**

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
11/11/97 8:00	3.209	40536	9122	5.9	0.12	24.9	25.9																								
12/11/97 8:00	3.197	39716	8641	6.6	0.07	23.3	24.3	0	0	0	0	22641	354.2	10.6	425.2	288.3	18.9	0	0	0	0	6.6		-26.3	185.5	12.4	7.4	997.490	2446	4.180	6.6
13/11/97 8:00	3.190	39251	8365	1.5	0.15	19.5	20.2	0	0	0	0	18956	366.8	11.0	403.3	138.0	12.7	0	0	0	0	5.6		-46.9	41.4	6.2	1.4	998.343	2455	4.182	3.6
14/11/97 8:00	3.184	38856	8130	2.5	0.19	20.4	21.2	0	0	0	0	12497	325.8	9.8	408.4	176.3	14.8	0	0	0	0	3.7		6.2	70.9	13.2	2.5	998.155	2453	4.182	1.7
15/11/97 8:00	3.173	38128	7707	5.3	0.17	22.3	23.3	0	0	0	0	21863	308.8	9.3	419.5	356.4	20.8	0	0	0	0	6.6		13.4	150.4	25.2	5.7	997.723	2448	4.181	5.7
Balance 46A																															
16/11/97 8:00	3.164	37516	7366	6.9	0.15	22.7	23.7	0	0	0	4693	13531	306.8	9.2	421.8	360.7	21.0	0	0	0	1.4	4.2		-3.0	194.5	30.1	7.5	997.638	2447	4.180	6.4
17/11/97 8:00	3.156	36973	7068	5.4	0.13	22.0	23.0	0	0	0	5562	15584	302.9	9.1	417.6	375.0	21.4	0	0	0	1.7	4.9		-12.1	153.4	20.1	5.8	997.803	2449	4.181	7.2
18/11/97 8:00	3.148	36420	6775	6.3	0.20	22.8	23.8	0	0	0	3650	10571	306.9	9.2	422.1	375.5	21.4	0	0	0	1.2	3.4		1.2	176.8	35.7	6.9	997.615	2447	4.180	6.4
19/11/97 8:00	3.139	35742	6450	6.7	0.18	24.1	25.1	0	0	0	4866	14845	309.2	9.3	429.5	379.4	21.5	0	0	0	1.6	4.8		4.7	188.3	34.2	7.8	997.309	2444	4.180	6.4
Balance 46B																															
20/11/97 8:00	3.130	35025	6132	5.4	0.19	24.9	26.0	0	0	0	989	14979	326.4	9.8	434.4	360.4	20.9	0	0	0	0.3	4.9		0.8	152.9	29.0	6.5	997.093	2442	4.180	6.2
21/11/97 8:00	3.123	34463	5888	6.0	0.13	23.1	23.9	0	0	0	267	3720	366.7	11.0	423.9	263.0	18.2	0	0	0	0.1	1.2		-22.4	170.9	21.6	6.7	997.544	2446	4.180	6.0
22/11/97 8:00	3.131	35108	6167	3.1	0.14	20.6	21.4	14390	39464	0	1978	24671	419.5	12.6	409.7	173.0	14.6	4.7	13.0	0	0.7	8.1		-15.8	88.3	12.7	3.1	998.104	2452	4.181	5.4
23/11/97 8:00	3.126	34703	5992	4.0	0.23	23.1	24.0	0	64	0	290	4061	435.7	13.1	423.5	292.6	19.1	0	0.02	0	0.1	1.4		18.5	112.0	25.5	4.4	997.555	2447	4.180	7.0
Balance 46C																															
Totals		ΔS	-3130	59.6																											68.7

Daily average 5.0

Daily average 5.7

Balance Duration: 12 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: -25.6

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): -0.75

Balance Period No: 47

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
23/11/97	8:00	3.126	34703	5992	4.0	0.23	23.1	24.0																								
24/11/97	8:00	3.120	34218	5785	5.5	0.24	24.4	25.4	0	0	0	0	1909	398.5	12.0	431.1	323.6	19.9	0	0	0	0	0.6		7.4	155.9	37.1	6.5	997.237	2443	4.180	6.9
25/11/97	8:00	3.114	33734	5582	2.5	0.14	22.4	23.2	0	0	0	0	12120	382.4	11.5	419.8	224.8	16.9	0	0	0	0	4.2		-21.8	70.8	10.0	2.7	997.706	2448	4.181	5.3
26/11/97	8:00	3.111	33489	5481	4.9	0.21	24.3	25.1	3311	2883	0	0	1112	443.9	13.3	430.5	239.6	17.4	1.1	1.0	0	0	0.4		13.2	136.9	28.8	5.7	997.255	2444	4.180	6.0
27/11/97	8:00	3.103	32834	5215	3.9	0.24	25.0	26.0	280	319	0	0	16683	434.3	13.0	434.7	302.2	19.3	0.10	0.11	0	0	5.9		0.8	108.6	25.9	4.6	997.084	2442	4.180	7.3
Balance 47A																																
28/11/97	8:00	3.095	32145	4955	4.8	0.18	25.4	26.5	0	0	0	0	13119	400.4	12.0	437.4	316.5	19.7	0	0	0	0	4.7		-2.1	135.1	24.1	5.9	996.958	2441	4.180	7.1
29/11/97	8:00	3.084	31107	4607	7.4	0.21	25.7	26.8	0	0	0	0	14534	378.0	11.3	439.0	370.4	21.2	0	0	0	0	5.4		-5.7	208.5	44.6	9.2	996.894	2440	4.180	7.8
30/11/97	8:00	3.075	30223	4332	6.9	0.22	25.3	26.3	0	0	0	0	8022	355.5	10.7	436.9	368.5	21.2	0	0	0	0	3.1		-9.3	193.9	42.4	8.4	996.985	2441	4.180	7.3
1/12/97	8:00	3.068	29517	4122	6.6	0.16	26.4	27.4	0	0	0	0	1823	348.3	10.4	443.1	367.6	21.2	0	0	0	0	0.7		2.2	184.9	30.3	8.4	996.705	2439	4.179	7.0
Balance 47B																																
2/12/97	8:00	3.057	28274	3804	5.8	0.15	26.2	27.1	0	0	0	0	18151	364.5	10.9	442.1	381.8	21.6	0	0	0	0	7.4		-8.3	164.4	24.6	7.4	996.760	2439	4.179	8.1
3/12/97	8:00	3.044	26665	3447	6.0	0.10	25.3	26.2	0	0	0	0	22478	359.6	10.8	437.0	342.0	20.4	0	0	0	0	9.8		-12.7	170.4	17.3	7.4	996.986	2441	4.180	7.3
4/12/97	8:00	3.035	25596	3212	5.2	0.16	24.3	25.1	0	0	0	0	11168	359.9	10.8	430.6	296.2	19.2	0	0	0	0	5.0		-11.4	147.1	23.2	6.1	997.257	2444	4.180	6.0
5/12/97	8:00	3.022	23869	2890	4.7	0.13	25.1	26.0	0	0	0	0	24090	361.1	10.8	435.7	337.6	20.3	0	0	0	0	11.7		0.0	132.2	16.6	5.7	997.042	2442	4.180	6.7
Balance 47C																																
Totals			ΔS	-3102	64.2																											82.7
			Daily average		5.3																									Daily average		6.9

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -53.0

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -1.54

Balance Period No: 48 **East Lake**

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
5/12/97	8:00	3.022	23869	2890	4.7	0.13	25.1	26.0																								
6/12/97	8:00	3.009	21783	2593	7.5	0.12	23.6	24.5	0	0	0	0	13398	327.7	9.8	427.0	369.8	21.2	0	0	0	0	7.1		-11.6	212.0	25.1	8.5	997.429	2445	4.180	7.4
7/12/97	8:00	2.997	19634	2345	7.4	0.11	23.8	24.7	0	0	0	0	10201	320.8	9.6	428.2	384.6	21.7	0	0	0	0	6.0		1.9	209.0	23.7	8.5	997.374	2445	4.180	7.3
8/12/97	8:00	2.988	18405	2174	7.2	0.13	24.7	25.6	0	0	0	0	3777	327.5	9.8	433.1	383.9	21.6	0	0	0	0	2.4		3.3	202.9	26.9	8.6	997.158	2443	4.180	7.3
9/12/97	8:00	2.976	17015	1962	6.3	0.11	25.9	26.7	0	0	0	0	11692	329.8	9.9	440.4	385.8	21.7	0	0	0	0	8.0		2.5	176.2	19.3	7.8	996.841	2440	4.179	7.2
Balance 48A																																
10/12/97	8:00	2.961	15459	1718	8.3	0.06	27.0	27.6	0	0	0	0	14587	352.7	10.6	446.7	380.6	21.5	0	0	0	0	10.9		-0.4	234.6	14.8	10.8	996.554	2437	4.179	7.8
11/12/97	8:00	2.949	14383	1539	7.0	0.10	28.3	28.7	0	0	0	0	10459	384.2	11.5	454.5	352.8	20.7	0	0	0	0	8.4		0.5	196.1	20.4	9.5	996.185	2434	4.179	7.4
12/12/97	8:00	2.936	13483	1358	6.4	0.21	28.9	29.2	0	0	0	0	13053	356.1	10.7	458.3	359.4	20.9	0	0	0	0	11.2		-6.3	178.4	38.3	8.9	996.007	2433	4.179	6.2
13/12/97	8:00	2.922	12589	1176	6.6	0.13	26.1	26.4	0	0	0	0	12290	329.6	9.9	442.1	382.6	21.6	0	0	0	0	11.3		-23.2	184.9	24.5	8.3	996.785	2439	4.179	7.5
Balance 48B																																
14/12/97	8:00	2.910	11878	1029	8.9	0.11	24.8	25.0	0	0	0	0	5029	321.7	9.7	434.3	387.3	21.7	0	0	0	0	4.9		-14.6	249.9	28.2	10.6	997.127	2442	4.180	7.7
15/12/97	8:00	2.897	11013	880	8.3	0.01	26.0	26.1	0	0	0	0	7132	336.1	10.1	441.3	377.2	21.4	0	0	0	0	7.5		-3.9	234.9	3.2	10.5	996.819	2440	4.179	7.9
16/12/97	8:00	2.885	10189	753	8.7	0.10	26.3	26.4	0	0	0	0	4776	371.3	11.1	442.9	367.9	21.2	0	0	0	0	5.4		-6.2	243.6	25.0	11.0	996.733	2439	4.179	8.2
17/12/97	8:00	2.871	9082	618	5.6	0.15	24.1	24.1	0	301	0	0	10090	347.7	10.4	430.0	320.3	19.8	0	0.38	0	0	12.9		-15.1	158.9	24.3	6.5	997.308	2444	4.180	6.2
Balance 48C																																
Totals			ΔS	-2272	88.1																											88.2
			Daily average		7.3																								Daily average			7.3

Balance Duration: 12 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -0.2

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation (mm d^{-1}): -0.004

Balance Period No: 49

East Lake

Day & Time	Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
	m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
17/12/97 8:00	2.871	9082	618	5.6	0.15	24.1	24.1																								
18/12/97 8:00	2.861	7926	533	5.8	0.21	25.9	25.8	0	0	0	0	4110	343.8	10.3	440.8	378.9	21.5	0	0	0	0	6.0		4.4	164.4	34.1	7.3	996.846	2440	4.179	6.8
19/12/97 8:00	2.850	7110	450	5.8	0.21	26.5	26.3	0	0	0	0	4675	347.5	10.4	444.8	372.1	21.3	0	0	0	0	7.6		-3.3	164.3	33.9	7.5	996.678	2438	4.179	6.8
20/12/97 8:00	2.836	6162	357	5.2	0.17	23.3	22.9	0	0	0	0	6065	330.6	9.9	425.4	313.8	19.7	0	0	0	0	11.4		-16.2	147.3	25.0	5.9	997.509	2446	4.180	5.7
Balance 49A																															
21/12/97 8:00	2.960	15365	1703	6.8	0.15	25.5	25.2	0	0	142979	0	17873	354.9	10.6	438.4	343.4	20.5	0	0	107.7	0	13.5		70.6	190.9	28.1	8.3	996.946	2441	4.180	7.5
22/12/97 8:00	2.976	17015	1962	5.0	0.13	27.2	26.8	0	0	55653	0	30005	338.7	10.2	448.1	388.4	21.8	0	0	37.9	0	20.4		14.6	140.7	18.8	6.6	996.483	2437	4.179	7.5
23/12/97 8:00	2.963	15656	1749	9.2	0.04	29.8	29.2	0	0	0	0	7289	374.3	11.2	464.0	377.5	21.4	0	0	0	0	5.4		8.0	257.1	10.5	13.2	995.726	2431	4.179	7.9
24/12/97 8:00	2.928	12972	1253	7.6	0.08	28.4	27.7	0	0	0	0	42534	376.1	11.3	455.8	376.8	21.4	0	0	0	0	37.9		-28.1	213.7	18.1	10.4	996.146	2434	4.179	8.0
25/12/97 8:00	2.908	11755	1006	8.4	0.13	26.4	25.7	0	0	0	0	14603	326.8	9.8	443.6	390.4	21.8	0	0	0	0	14.4		-22.9	237.7	32.0	10.8	996.702	2439	4.179	7.5
Balance 49B																															
Totals		ΔS	388	53.9																											57.6
		Daily average		6.7																								Daily average			7.2

Balance Duration: 8 days

Daily average sediment term Qse ($W\ m^{-2}\ d^{-1}$) required to balance pan and thermal evaporation: -15.3

All Q terms expressed in watts per square meter ($W\ m^{-2}$)

Bowen Ratio R dimensionless

Qse expressed as equivalent evaporation ($mm\ d^{-1}$): -0.46

Balance Period No: 50

East Lake

Day & Time		Stage	Area	Volume	Pan E	R	T_0 °C	T_m °C	Qrn	Qsd	Qtu	Qdc	Qrc	Qa	Qar	Qbs	Qs	Qsr	Qrn	Qsd	Qtu	Qdc	Qrc	Qse	Qx	Qe	Qh	Qw	ρ	L	c	E
		m AHD	m^2	m^3	mm				m joules	m joules	m joules	m joules	m joules																			mm
25/12/97	8:00	2.908	11755	1006	8.4	0.13	26.4	25.7																								
26/12/97	8:00	2.889	10470	794	6.7	0.05	27.9	27.1	0	0	0	0	14862	343.5	10.3	452.6	380.9	21.5	0	0	0	0	16.4		-7.2	187.4	9.7	9.0	996.296	2435	4.179	7.4
27/12/97	8:00	2.875	9430	655	7.9	0.08	30.1	29.1	0	0	0	0	6950	417.0	12.5	465.7	316.5	19.7	0	0	0	0	8.5		-1.5	222.0	18.4	11.5	995.641	2430	4.179	7.2
28/12/97	8:00	2.982	17661	2066	3.5	0.20	26.5	25.6	0	0	145174	0	15897	377.0	11.3	444.3	256.3	18.0	0	0	95.1	0	10.4		47.1	99.7	19.9	4.5	996.674	2438	4.179	5.6
29/12/97	8:00	2.989	18532	2192	5.2	0.15	26.7	25.8	0	0	66250	0	53094	335.3	10.1	444.9	388.4	21.8	0	0	41.4	0	33.2		2.8	146.7	21.6	6.7	996.634	2438	4.179	7.5
Balance 50A																																
30/12/97	8:00	2.962	15557	1734	6.9	0.17	28.4	27.4	0	0	0	0	38290	357.8	10.7	454.9	379.8	21.5	0	0	0	0	28.5		0.1	193.2	33.2	9.4	996.157	2434	4.179	6.5
31/12/97	8:00	2.937	13547	1372	3.9	0.22	29.5	28.5	0	0	0	0	35741	370.2	11.1	461.8	372.0	21.3	0	0	0	0	30.5		-8.1	108.1	23.7	5.5	995.835	2431	4.179	6.3
1/1/98	8:00	2.912	11997	1053	5.8	0.17	28.0	27.0	0	0	0	0	26984	337.3	10.1	452.9	388.8	21.8	0	0	0	0	26.0		-25.1	164.0	27.3	7.9	996.270	2435	4.179	7.0
2/1/98	8:00	2.892	10676	826	6.6	0.14	26.3	25.5	0	0	0	0	15957	339.0	10.2	443.1	375.7	21.4	0	0	0	0	17.3		-19.3	184.9	25.4	8.3	996.734	2439	4.179	7.3
3/1/98	8:00	2.875	9430	655	6.8	0.18	26.8	25.8	0	0	0	0	10889	329.8	9.9	445.9	385.3	21.7	0	0	0	0	13.4		-8.6	190.6	34.8	8.7	996.605	2438	4.179	6.7
Balance 50B																																
Totals			ΔS	-351	53.3																											61.5

Daily average 5.9

Daily average 6.8

Balance Duration: 9 days

Daily average sediment term Qse (W m^{-2} d^{-1}) required to balance pan and thermal evaporation: -30.6

All Q terms expressed in watts per square meter (W m^{-2})

Bowen Ratio R dimensionless

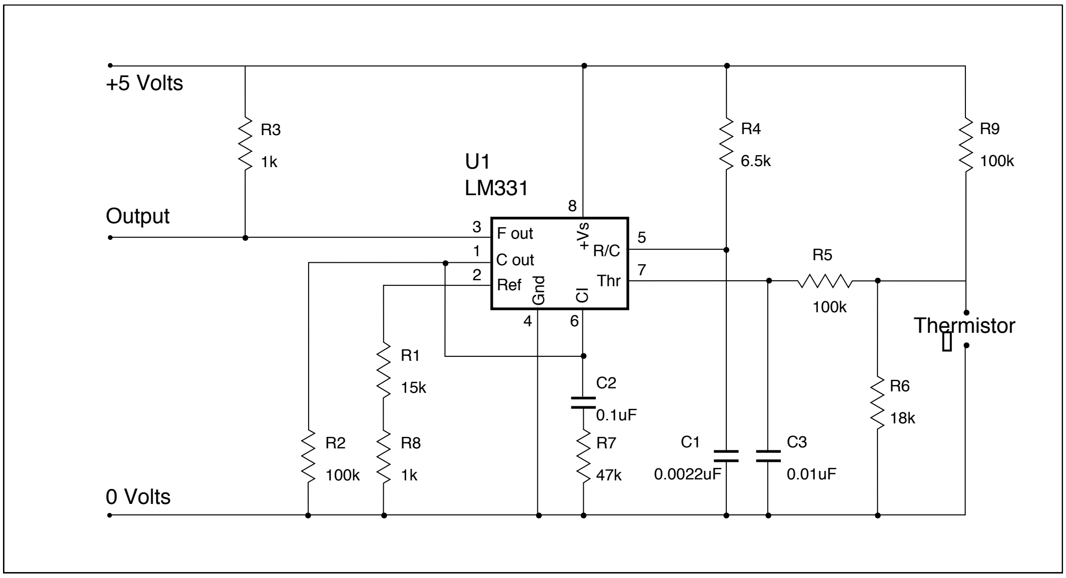
Qse expressed as equivalent evaporation (mm d^{-1}): -0.91

CHAPTER
9

APPENDICES

Appendix 9.1 Voltage to Frequency (V to F) Converter for Thermistor Loggers

Schematic diagram



Notes:

U1 is National Semiconductor precision voltage to frequency converter LM331

All resistors 1% tolerance

All capacitors temperature compensating type

CHAPTER
12

APPENDICES

Appendix 12.1 Isotopic Exchange Parameters Pan Data

These are the daily data sheets used for the experimental determination of pan limiting factors, relative humidity and δ_E. The data is arranged from Run 1 to Run 20.

Legend

Criteria	Units	Notes
Date		day, month and year
Time		start time
Day		day number for each run
Humidity (air)	percent	mean daily relative humidity 08:00hr to 08:00 hr at pan site
Humidity (norm)	percent	mean daily relative humidity normalised to lake surface temperature
Psychrometer (dry)	°C	dry bulb temperature
Psychrometer (wet)	°C	wet bulb temperature
RH	percent	Instantaneous sling psychrometer relative humidity
CV pan T	°C	Constant volume pan temperature (as check on logger data)
CV bath T	°C	Thermal regulation bath temperature (as check on lake logger data)
CV pan level	mm	Constant volume pan depth
Manometer	cm	Depth of water lost in reservoir (into CV pan in previous 24 hours)
Evaporation	mm	Evaporation from CV pan as calculated from reservoir level
Sample		Sample number, daily CV pan water sample
^2H	permil	deuterium, CV pan
^{18}O	permil	oxygen 18, CV pan
Standard pan T	°C	Temperature in pan evaporated to dryness
Standard bath T	°C	Thermal regulation bath temperature
Standard pan level	mm	Level of water remaining
V/Vo	ratio	Ratio water volume remaining to initial volume
Evaporation	mm	Evaporation from pan evaporated to dryness over previous 24 hours
Sample		Sample number, daily standard pan water sample
^2H	permil	deuterium, standard pan
^{18}O	permil	oxygen 18, standard pan
Wind	km	Wind run at 1m immediately above constant volume pan

The mean daily humidity data is based on wet and dry bulb logger data collected every ten minutes. Feed stock water was sampled immediately at the start of each pan run. These 'standard' samples represent the isotopic value of the groundwater obtained from CSIRO irrigation bore number two and are the isotopic values shown on 'Day 0' of each run. A total of 41 samples were collected between March 29, 1996 and December 31 1997 and analysed for deuterium. Mean feed stock deuterium -12.4‰. Standard deviation was 1.4‰ which is comparable to the 1.0‰ rated standard deviation of the mass spectrometer. Seven analyses for chloride over the same period averaged 262 mg l^{-1}.

Pan levels, evaporation and total wind run are summarised in Table 1.

Table 1

Run	CV Pan Mean level	CV Pan Mean vol	CV Pan Evap (mm)	CV Pan Evap (litres)	Std Pan Start depth	Std Pan Evap (litres)	Wind Run (km)
1	85.1	21.802	165.6	42.257	156	40.974	
2	84.2	21.576	83.8	21.384	75	19.860	
3	84.3	21.602	80.7	20.593	75	19.860	
4	84.3	21.602	77.5	19.776	75	19.860	
5	83.2	21.325	93.8	23.935	75	19.860	
6	82.3	21.099	139.6	35.623	120	31.590	
7	82.0	21.024	116.6	29.754	100	26.377	1125.1
8	81.8	20.974	122.7	31.310	100	26.377	1021.1
9	82.3	21.099	108	27.559	100	26.377	854.2
10	82.3	21.099	123.7	31.565	100	26.377	1320.8
11	81.3	20.848	124.8	31.846	100	26.377	1624.7
12	82.2	21.074	98.3	25.084	75	19.860	1488.4
13	82.4	21.125	88.4	22.558	75	19.860	1027.1
14	83.3	21.350	61.5	15.693	50	13.344	1245.7
15	83.5	21.401	62.8	16.025	50	13.344	982.3
16	83.2	21.325	67.3	17.173	50	13.344	1376.6
17	83.1	21.300	129.2	32.969	100	26.377	1766.4
18	81.7	20.949	195.3	49.836	150	39.410	2168.4
19	82.1	21.049	162.9	41.568	200	52.443	1893.6
20	81.6	20.924	234.7	59.890			2428.3
Total			2337.2	596.4	1826.0	481.9	20322.7

Appendix 12.2

These are the data sheets for the collection of atmospheric vapour for determination of δ_A.

Legend

Criteria	Units	Notes
Date		Date and run time information
Start		
End		
Time	minutes	Total time air was drawn through the Zundel trap(s)
Flow	litres $\min^{-1}$	Rate of air flow
Volume	m^3	Volume of air drawn through the trap(s)
Trap		Trap (there were four, designated A to D)
Weight wet	grams	Weight of the trap with collected condensate
Weight dry	grams	Weight of trap dry
Water	grams	Weight of water collected
Efficiency	Percent	Percentage of water caught in the first trap
Sample		Sample number
^2H	permil	Deuterium as δ_A
^{18}O	permil	Oxygen 18 as δ_A

Dry weights are noted for each run. Dry weights for several of the traps changed over time as several traps suffered breakages which were repaired by a glass blower. Runs concurrent with direct measurement of lake δ_E are noted.

Appendix 12.3

These are the data sheets for the collection of vapour from the surface of East Lake for direct determination of δ_E. Legend is similar to Appendix 12.2. Column headed CO_2 refers to experimental use of crushed dry ice packed around the tops of the Zundel traps to speed up cooling to operating temperature and provide a lower operating temperature. The freezer unit could accommodate three traps. Every δ_E sampling run was always accompanied by a concurrent δ_A sample. This meant that one of the two traps had to be run alone without a second trap in series as a check on extraction efficiency. The use of dry ice was therefore an insurance of complete extraction. In the event the dry ice proved too inconvenient and time consuming to make and use and the low night time ambient temperatures meant that the cooler operated more efficiently anyway with ethanol temperatures of -60˚C or better.

The column headed Nitrogen refers to the use of dry nitrogen to purge any moisture from the sampling line. This was done in two ways. Nitrogen was pumped back out to the floating sampler to remove any condensate in the sampling line. This also meant that when not in use the line was filled with dry gas. Secondly nitrogen was also occasionally used to purge the 6m or so of unheated connecting line between the service conduit and the freezer unit (remember the permanently installed sampling line was installed in the return water duct from the evaporation pans and was always within 1˚C of lake mid level temperature). This small length of connecting line was warmed with heat lamps but occasionally showed minor condensation which was extracted through the Zundel traps at the end of the sampling run. At the start of a run the line was cleared of nitrogen by operating the vacuum pump for at least a minute before connecting the flow through the Zundel traps. Calculated volume of the sampling line (6mm ID, length 60m) was 1.7 litres. During each δ_E sampling run manual measurements (every 15 or 30 minutes) of air and lake surface temperature were taken using glass laboratory thermometers and air relative humidity by sling psychrometer. Temperatures were also obtained from thermister string #6 located adjacent to the floating pick up. These are designated 'Ts 6', and from the thermal regulation bath around the evaporation pans which is roughly equivalent to centre of lake temperature. As a general rule we tried to always operate with a 10˚C difference between the lake (and hence sampling line) temperature and the air temperature. During late dawn sampling runs (E019, E020 and E021) this temperature differential was not maintained resulting in condensation and fractionation in the sampling line (refer thesis text). The temperature, humidity and other notes on wind and cloud conditions are included. Sampling runs were always done under dead calm conditions. A number were abandoned due to breezes developing. Only successful runs appear in Appendix 12.3.

Isotopic Exchange Parameters from Evaporation Pans Data

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^2H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^2H	^{18}O	Wind
Run 1																								
29/03/1996	1000	0			19.2	13.8	54	16.9		87.5	0.0	0.0	0001	-12.8	-3.37							-13.4		
29/03/1996	1140															20.2	21.0	156.0	1.000	0.0	0002	-12.0	-3.11	
29/03/1996	1200				23.9	15.8	43	19.9	22.0	88.0	0.9	0.6												
29/03/1996	1700				21.0	16.0	60	23.2	24.5	88.0	2.1	0.8	0003	-12.0	-2.80			155.0	0.994	1.0	0004	-13.2	-3.02	
30/03/1996	0900	1	69.0	55.1	19.2	13.5	54	16.5	17.5	88.0	5.0	3.4	0006	-10.4	-2.44	16.7		154.0	0.987	2.0	0007	-10.9	-2.65	
31/03/1996	0900	2	56.8	51.1	19.5	14.3	58	17.3	18.4	88.0	5.1	3.4	0008	-6.7	-1.63	17.5	18.4	150.0	0.962	4.0	0009	-9.7	-2.31	
01/04/1996	0900	3	39.9	42.7	20.5	14.4	52	17.5	18.4	87.5	6.6	4.4	0010	-4.0	-0.76	17.8	18.3	145.0	0.930	5.0	0011	-8.5	-1.70	
02/04/1996	0900	4	49.3	45.9	22.5	14.6	42	18.0	19.0	88.0	8.1	5.4	0012	-2.5	-0.04	18.4	19.0	140.0	0.898	5.0	0013	-7.1	-1.22	
03/04/1996	0800	5	57.9	53.4	19.0	16.0	74	20.0	20.6	88.5	5.9	4.0	0014	0.9	0.51	20.0	20.5	136.0	0.872	4.0	0015	-2.1	-0.83	
04/04/1996	0800	6	74.5	68.3	21.5	18.0	76	21.0	21.6	88.5	3.9	2.6	0017	4.0	0.73	21.1	21.5	134.0	0.860	2.0	0018	-0.1	-0.26	
05/04/1996	0900	7	67.5	62.7	18.5	13.3	54	18.5	19.6	88.5	4.2	2.8	0020	4.8	1.18	19.0	19.6	130.0	0.834	4.0	0021	-0.2	0.04	
06/04/1996	0900	8	60.1	50.1	16.8	12.0	55	15.5	16.5	88.5	5.7	3.8	0023	6.1	1.60	15.9	16.6	126.0	0.809	4.0	0024	2.4	0.06	
07/04/1996	0900	9	58.4	51.1	18.5	14.0	61	16.3	17.0	88.0	5.0	3.4	0026	7.5	1.69	16.5	17.0	123.0	0.790	3.0	0027	5.5	1.06	
08/04/1996	0900	10	61.3	53.7	21.0	14.0	46	17.4	18.2	88.0	4.3	2.9	0029	9.8	2.21	17.6	18.2	120.0	0.770	3.0	0030	6.2	1.39	
09/04/1996	0900	11	34.0	39.7	24.5	16.5	44	18.5	18.9	86.0	6.5	4.4	0032	12.3	2.81	18.8	19.0	115.0	0.738	5.0	0033	7.9	2.18	
10/04/1996	0800	12	61.2	62.4	21.8	19.0	76	20.1	20.5	86.0	3.2	2.2	0035	12.1	2.94	20.2	20.5	112.0	0.719	3.0	0036	9.9	2.37	
11/04/1996	0900	13	73.0	71.2	20.0	15.0	59	20.0	20.9	86.0	2.9	1.9	0038	13.8	3.16	20.2	20.8	110.0	0.707	2.0	0039	11.9	2.61	
12/04/1996	0730	14	60.3	58.3	18.0	14.5	69	16.8	17.2	86.0	6.1	4.1	0041	15.2	3.44	16.9	17.2	106.0	0.681	4.0	0042	13.3	3.02	
13/04/1996	0900	15	78.6	69.4	17.5	14.0	69	18.0	18.7	86.0	3.2	2.2	0044	14.7	3.66	18.4	18.8	105.0	0.675	1.0	0045	12.5	3.65	
14/04/1996	0900	16	73.8	56.0	19.0	14.5	61	17.4	17.9	86.0	4.6	3.1	0047	14.8	3.86	17.5	17.9	102.0	0.656	3.0	0048	15.9	4.13	
15/04/1996	0900	17	64.7	60.0	21.0	15.2	52	17.5	18.2	86.0	3.3	2.2	0050	16.1	4.11	17.8	18.2	99.0	0.636	3.0	0051	16.6	4.20	
16/04/1996	0900	18	53.4	52.0	21.0	15.5	56	17.7	18.4	85.0	5.3	3.6	0053	17.6	4.19	18.0	18.4	95.0	0.611	4.0	0054	19.5	4.65	
17/04/1996	0900	19	41.2	44.1	23.4	15.8	45	18.1	18.7	84.0	6.9	4.6	0056	19.3	4.43	18.4	18.8	91.0	0.585	4.0	0057	20.9	5.57	
18/04/1996	0900	20	42.8	44.7	26.0	17.5	43	19.5	19.8	84.0	6.6	4.4	0059	20.0	5.03	19.5	19.9	87.0	0.560	4.0	0060	24.2	5.97	
19/04/1996	0830	21	79.0	75.8	21.4	20.0	87	21.0	21.2	84.0	3.3	2.2	0063	20.0	4.97	21.1	20.3	85.0	0.547	2.0	0064	24.3	6.08	
20/04/1996	0900	22	72.5	70.3	19.0	14.0	58	16.5	16.8	84.0	3.7	2.5	0066	20.4	4.80	16.5	16.9	82.7	0.532	2.3	0067	24.7	6.04	
21/04/1996	0900	23	74.3	54.7	15.0	11.5	66	15.0	15.5	84.0	5.0	3.4	0070	20.5	4.81	15.0	15.6	80.1	0.516	2.6	0071	24.5	6.30	
22/04/1996	0900	24	73.3	53.5	16.0	12.5	67	16.1	16.6	84.0	4.4	3.0	0073	19.7	4.94	16.4	16.6	77.7	0.501	2.4	0074	26.5	6.59	
23/04/1996	0900	25	78.1	63.1	15.8	14.0	81	16.5	17.0	84.0	2.7	1.8	0077	19.8	4.69	16.6	17.0	76.0	0.490	1.7	0078	27.0	6.68	
24/04/1996	0900	26	69.1	57.6	17.5	14.2	69	17.8	18.4	84.0	4.1	2.8	0080	18.7	4.74	17.8	18.4	73.5	0.474	2.5	0081	28.1	6.48	
25/04/1996	0830	27	83.5	72.0	17.5	16.5	91	18.9	19.4	84.0	2.5	1.7	0084	19.3	4.74	19.1	19.5	72.2	0.466	1.3	0085	29.6	6.85	
26/04/1996	0800	28	82.1	70.4	17.0	15.5	86	18.5	19.1	84.0	2.3	1.5	0087	20.1	4.65	18.7	19.2	70.9	0.457	1.3	0088	29.1	6.86	
27/04/1996	0900	29	77.3	60.7	18.5	15.4	73	18.3	18.9	84.0	3.7	2.5	0091	20.2	4.69	18.5	18.9	68.5	0.442	2.4	0092	29.6	7.15	
28/04/1996	0830	30	66.2	60.1	18.2	14.5	69	17.6	18.5	85.0	4.1	2.8	0094	19.3	4.75	18.0	18.6	65.8	0.425	2.7	0095	30.1	7.22	
29/04/1996	0900	31	51.6	52.5	21.0	15.8	59	18.3	18.9	84.0	5.5	3.7	0098	21.5	4.91	18.5	19.0	62.1	0.401	3.7	0099	32.1	7.68	
30/04/1996	0900	32	60.3	50.8	20.2	14.4	51	17.6	18.5	84.0	5.4	3.6	0101	20.9	5.17	18.0	18.6	59.1	0.382	3.0	0102	35.5	8.32	
01/05/1996	0900	33	74.0	71.6	18.7	15.7	74	19.0	19.5	84.0	2.7	1.8	0105	20.0	4.91	19.1	19.6	57.5	0.372	1.6	0106	34.2	8.12	
02/05/1996	0800	34	71.8	59.0	11.9	11.8	98	16.9	17.6	84.0	3.9	2.6	0108	20.3	4.89	17.0	17.8	55.0	0.356	2.5	0109	35.9	8.33	

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
03/05/1996	0800	35	72.7	59.8	13.5	13.0	95	16.9	17.5	84.0	3.4	2.3	0112	21.1	5.06	16.8	17.6	52.8	0.342	2.2	0113	36.9	8.44	
04/05/1996	0830	36	76.1	67.2	19.4	17.6	82	18.7	19.1	84.0	3.1	2.1	0115	19.8	4.94	18.7	19.1	49.9	0.323	2.9	0116	36.9	8.37	
05/05/1996	0800	37	78.8	69.6	15.6	13.6	81	17.6	18.2	84.0	3.0	2.0	0119	20.1	4.77	17.5	18.2	48.5	0.314	1.4	0120	35.6	8.33	
06/05/1996	0830	38	67.3	55.5	19.5	15.2	61	17.1	17.5	84.0	4.6	3.1	0122	20.9	4.91	17.2	17.5	46.0	0.298	2.5	0123	38.1	8.78	
07/05/1996	0845	39	74.3	78.0	23.5	17.0	51	19.5	19.8	84.0	2.1	1.4	0126	20.3	4.87	19.5	19.8	44.5	0.289	1.5	0127	38.3	8.46	
08/05/1996	0900	40	53.8	65.3	19.8	18.1	87	18.5	18.7	84.0	5.0	3.4	0129	20.1	4.81	18.5	18.8	42.3	0.275	2.2	0130	38.3	8.44	
09/05/1996	0900	41	78.8	77.4	21.2	17.0	67	18.7	18.4	84.0	2.6	1.7	0133	20.4	4.57	18.4	18.6	41.5	0.270	0.8	0134	34.6	7.68	
10/05/1996	0730	42	71.2	69.6	14.9	14.3	95	16.2	16.5	84.0	3.5	2.4	0136	20.0	4.57	16.1	16.5	38.0	0.247	3.5	0137	34.3	7.45	
11/05/1996	0900	43	77.5	58.3	12.7	10.7	79	12.9	13.2	84.0	4.5	3.0	0140	19.4	4.55	12.6	13.2	35.5	0.231	2.5	0141	36.3	7.82	
12/05/1996	0745	44	73.0	52.9	4.6	4.4	95	11.1	11.7	84.0	3.6	2.4	0143	20.8	4.62	10.4	11.7	33.1	0.216	2.4	0144	39.3	8.30	
13/05/1996	0900	45	68.6	54.0	14.0	10.0	60	11.6	11.9	84.0	3.9	2.6	0147	20.8	4.72	11.1	11.8	30.9	0.202	2.2	0148	40.9	9.02	
14/05/1996	0900	46	52.2	48.6	16.0	11.4	58	13.5	14.0	84.0	2.6	1.7	0150	23.5	5.15	13.4	14.0	28.5	0.187	2.4	0151	44.8	9.84	
15/05/1996	0900	47	55.4	54.8	20.7	14.4	49	16.7	17.0	84.0	4.4	3.0	0154	22.7	5.33	16.9	17.1	26.1	0.171	2.4	0155	47.9	10.57	
16/05/1996	0700	48	74.1	72.2	14.3	13.5	90	16.3	16.6	84.0	3.7	2.5	0157	21.7	5.04	16.1	16.6	24.4	0.161	1.7	0158	46.2	10.06	
17/05/1996	0745	49	81.9	74.6	14.2	14.0	98	17.1	17.4	84.0	2.4	1.6	0161	21.0	5.05	17.0	17.5	23.0	0.152	1.4	0162	46.4	9.48	
18/05/1996	0900	50	68.0	49.5	13.0	9.8	67	14.1	14.7	84.0	4.4	3.0	0164	22.3	5.26	14.4	14.7	20.5	0.136	2.5	0165	49.9	10.56	
19/05/1996	0900	51	73.2	51.7	12.2	9.8	73	12.2	12.7	84.0	3.9	2.6	0168	23.4	5.32	12.4	12.8	18.0	0.120	2.5	0169	53.3	11.52	
20/05/1996	0900	52	71.5	54.9	14.8	10.8	61	11.6	12.1	84.0	3.4	2.3	0171	23.8	5.28	11.7	12.1	16.6	0.111	1.4	0172	57.7	12.02	
21/05/1996	0900	53	72.6	59.8	11.8	10.8	89	12.5	12.9	84.0	2.2	1.5	0175	24.1	5.39	12.6	13.1	14.3	0.096	2.3	0176	59.9	12.34	
22/05/1996	0900	54	78.1	61.3	13.4	12.4	89	12.9	13.3	84.0	2.5	1.7	0178	25.2	5.55	13.1	13.4	12.8	0.087	1.5	0179	60.8	12.53	
23/05/1996	0830	55	72.5	59.8	15.0	12.3	73	14.2	14.6	84.0	2.7	1.8	0182	26.0	5.59	14.3	14.8	11.8	0.080	1.0	0183	61.8	12.86	
24/05/1996	0715	56	68.5	61.5	14.6	12.0	74	15.2	15.6	84.0	2.2	1.5	0185	25.8	5.60	15.0	15.6	9.7	0.067	2.1	0186	58.5	12.28	
25/05/1996	0800	57	59.3	52.0	14.7	10.6	61	14.6	15.2	84.0	4.6	3.1	0189	24.1	5.64	14.5	15.3	7.0	0.050	2.7	0190	63.5	13.50	
26/05/1996	0845	58	60.8	54.1	17.6	11.1	44	15.0	15.4	84.0	4.3	2.9	0192	24.2	5.83	15.0	15.5	5.0	0.037	2.0	0193	66.4	14.69	
27/05/1996	0900	59	67.5	52.7	11.6	10.4	89	13.0	13.5	84.0	3.2	2.2	0196	24.7	5.95		13.6	2.7	0.022	2.3	0197	73.3	16.05	
28/05/1996	0900	60	78.1	66.5	12.8	12.0	92	14.2	14.7	84.0	2.8	1.9	0199	24.6	5.71		14.8	-1.0	0.006		0200	51.7	11.07	
End Run 1																								
Run 2																								
29/05/1996	0900	0	73.6	65.9	14.8	9.0	44	13.8	14.4	86.0	0.0	0.0	0203	-11.7	-2.54	13.0	14.4	75.5	1.000		0204	-13.2	-2.50	
30/05/1996	0830	1	66.8	49.8	10.9	8.5	72	14.2	14.7	85.0	3.0	2.0	0206	-9.2	-1.89	14.2	14.8	74.0	0.980	1.5	0207	-9.8	-1.55	
31/05/1996	0845	2	67.9	77.8	19.0	16.0	74	18.1	18.4	84.0	2.1	1.4	0210	-7.9	-1.52	18.0	18.4	72.5	0.961	1.5	0211	-6.9	-1.09	
01/06/1996	0900	3	65.7	66.0	16.5	15.5	90	16.6	16.7	84.0	3.5	2.4	0213	-6.1	-0.90	16.6	16.8	70.3	0.932	2.2	0214	-4.3	-0.36	
02/06/1996	0800	4	82.5	69.2	12.0	11.8	97	14.9	15.2	84.0	1.7	1.1	0217	-5.6	-0.69	14.9	15.3	68.8	0.912	1.5	0218	-2.4	-0.25	
03/06/1996	0845	5	67.1	73.7	14.8	13.6	89	15.3	15.4	84.0	1.4	0.9	0220	-4.5	-0.55	15.3	15.4	67.5	0.895	1.3	0221	-1.1	0.08	
04/06/1996	0845	6	76.0	60.3	12.5	9.0	64	12.6	13.2	84.0	3.5	2.4	0224	-2.7	-0.51	12.8	13.3	65.5	0.869	2.0	0225	-0.5	0.47	
05/06/1996	0900	7	75.8	58.8	11.0	10.2	88	11.7	12.2	84.0	3.3	2.2	0227	-2.0	0.18	11.8	12.4	64.0	0.849	1.5	0228	1.8	0.56	
06/06/1996	0900	8	77.1	60.1	9.8	9.2	94	11.4	11.7	84.0	2.8	1.9	0231	0.6	0.29	11.4	11.8	62.4	0.828	1.6	0232	4.7	1.21	
07/06/1996	0745	9	67.8	59.3	10.9	8.5	72	11.5	11.8	84.0	1.8	1.2	0234	3.0	0.74	11.4	11.8	60.9	0.809	1.5	0235	7.4	1.71	
08/06/1996	0815	10	55.8	57.4	12.2	10.0	78	11.8	12.0	84.0	3.0	2.0	0238	4.9	1.12	11.8	12.0	58.9	0.782	2.0	0239	6.7	2.18	
09/06/1996	0745	11	66.1	73.2	14.9	13.3	85	13.7	13.8	84.0	2.8	1.9	0241	2.6	1.06	13.8	13.9	57.8	0.768	1.1	0242	7.5	2.40	

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
10/06/1996	0900	12	87.0	88.2	15.6	15.1	95	15.4	15.5	84.0	1.5	1.0	0245	3.4	1.38	15.3	15.5	57.1	0.759	0.7	0246	10.2	2.38	
11/06/1996	0900	13	87.7	77.7	15.4	14.9	95	14.6	14.9	84.0	2.1	1.4	0248	4.3	1.23	14.6	14.9	56.1	0.746	1.0	0249	10.0	2.50	
12/06/1996	0900	14	85.5	75.1	15.8	14.9	90	15.1	15.2	84.0	1.5	1.0	0252	7.7	1.59	15.0	15.2	55.0	0.731	1.1	0253	12.9	2.57	
13/06/1996	0900	15	86.8	68.5	11.8	11.5	95	13.2	13.6	84.0	2.7	1.8	0255	8.6	1.53	13.1	13.5	53.5	0.712	1.5	0256	14.9	2.98	
14/06/1996	0750	16	84.6	68.1	8.5	8.2	94	12.2	12.4	84.0	0.9	0.6	0259	8.5	1.78	11.9	12.3	52.3	0.696	1.2	0260	13.8	3.15	
15/06/1996	0900	17	81.1	70.5	15.4	13.5	80	13.5	13.2	84.0	1.2	0.8	0262	8.3	1.64	13.0	13.2	51.2	0.681	1.1	0263	15.4	3.31	
16/06/1996	0830	18	66.8	74.6	16.7	12.9	64	12.4	12.2	83.0	1.1	0.7	0266	9.8	2.04	12.4	12.4	49.8	0.663	1.4	0267	14.9	3.30	
17/06/1996	0845	19	78.8	75.9	14.7	12.5	80	13.7	13.8	84.0	3.8	2.6	0269	7.0	2.03	13.8	13.9	48.6	0.647	1.2	0270	13.6	3.43	
18/06/1996	0900	20	70.4	75.5	16.5	14.2	78	13.4	13.3	84.0	2.2	1.5	0273	8.1	2.02	13.4	13.5	47.2	0.629	1.4	0274	16.2	3.33	
19/06/1996	0900	21	80.2	84.6	16.1	14.1	81	14.6	14.6	84.0	2.5	1.7	0276	8.0	1.89	14.6	14.6	45.9	0.612	1.3	0277	15.1	3.10	
20/06/1996	0915	22	77.5	79.9	16.2	14.8	85	14.2	14.3	84.0	1.6	1.1	0280	8.1	1.76	14.2	14.3	45.0	0.600	0.9	0281	14.9	3.04	
21/06/1996	0830	23	67.4	70.9	16.1	12.4	65	13.0	13.0	84.0	2.8	1.9	0283	7.7	1.64	12.9	13.0	43.2	0.577	1.8	0284	14.5	3.01	
22/06/1996	0830	24	87.9	76.4	11.3	10.8	94	12.2	12.4	84.0	3.3	2.2	0287	5.3	1.63	12.3	12.4	42.5	0.567	0.7	0288	13.3	2.66	
23/06/1996	0800	25	81.0	82.2	16.5	13.0	68	13.5	13.5	84.0	0.1	0.1	0290	6.0	1.59	13.5	13.6	42.0	0.561	0.5	0291	12.2	2.58	
24/06/1996	0900	26	88.0	79.6	11.4	10.8	94	12.8	13.1	84.0	0.4	0.3	0294	5.0	1.82	12.6	13.1	41.1	0.549	0.9	0295	13.1	2.73	
25/06/1996	0900	27	82.3	64.5	9.5	9.1	94	11.4	11.7	85.0	3.5	2.4	0297	7.6	2.11	11.4	11.7	39.8	0.532	1.3	0298	14.7	3.03	
26/06/1996	0845	28	69.6	69.2	15.5	11.0	58	12.6	13.0	84.0	0.1	0.1	0301	7.4	1.91	12.8	13.0	38.7	0.518	1.1	0302	15.5	3.37	
27/06/1996	0900	29	77.3	85.6	15.7	14.7	90	13.5	13.4	83.0	0.1	0.1	0304	9.1	2.06	13.5	13.4	37.9	0.507	0.8	0305	16.4	3.18	
28/06/1996	0730	30	65.4	76.1	16.9	12.9	64	12.9	12.8	84.0	2.8	1.9	0307A	9.0	1.97	12.9	12.9	36.5	0.489	1.4	0308	14.4	3.22	
29/06/1996	0830	31	70.1	73.0	15.8	13.2	76	14.2	14.4	84.0	2.8	1.9	0310	8.4	2.14	14.3	14.4	35.0	0.469	1.5	0311	16.1	3.57	
30/06/1996	0800	32	73.8	78.8	16.8	12.2	59	14.6	14.9	84.0	1.8	1.2	0314	8.5	2.03	14.9	14.9	33.9	0.455	1.1	0315	18.3	3.60	
01/07/1996	0900	33	69.1	67.9	14.4	12.2	77	13.2	13.4	84.0	3.9	2.6	0317	10.9	2.22	13.2	13.4	32.0	0.430	1.9	0318	21.1	4.03	
02/07/1996	0900	34	76.0	77.7	18.0	15.8	80	14.7	14.8	84.0	0.4	0.3	0321	10.7	2.52	14.9	14.9	31.1	0.418	0.9	0322	26.9	3.93	
03/07/1996	0830	35	75.6	80.3	15.3	12.5	73	14.7	15.0	84.0	3.2	2.2	0324	11.9	2.08	14.6	15.0	29.8	0.401	1.3	0325	20.8	3.62	
04/07/1996	0900	36	73.5	71.6	15.0	14.0	90	14.3	14.4	84.0	1.6	1.1	0328	12.2	2.19	14.4	14.5	28.5	0.384	1.3	0329	21.8	3.91	
05/07/1996	0730	37	87.5	80.2	13.1	12.0	89	14.6	14.9	84.0	1.7	1.1	0331	10.8	2.20	14.7	15.0	27.8	0.375	0.7	0332	21.3	3.76	
06/07/1996	0900	38	79.7	68.4	13.7	11.2	74	13.2	13.4	84.0	2.9	1.9	0335	11.7	2.30	13.2	13.5	26.6	0.359	1.2	0336	23.4	4.11	
07/07/1996	0915	39	56.1	57.2	16.4	11.5	55	13.1	13.4	83.0	0.3	0.2	0338	13.9	2.80	13.2	13.5	24.3	0.329	2.3	0339	29.3	5.03	
08/07/1996	0900	40	82.3	82.6	14.2	13.0	90	14.3	14.4	85.0	5.8	3.9	0342	13.2	2.52	14.4	14.5	23.5	0.318	0.8	0343	26.4	4.91	
09/07/1996	0830	41	79.3	64.0	11.8	9.9	78	13.6	13.6	85.0	1.9	1.3	0345	14.5	2.92	13.0	13.5	21.9	0.297	1.6	0346	26.4	5.48	
10/07/1996	0900	42	75.6	57.8	10.8	8.0	66	11.5	11.9	85.5	4.8	3.2	0349	12.7	2.88	11.4	12.0	20.1	0.274	1.8	0350	28.0	5.76	
11/07/1996	0930	43	68.4	51.7	11.5	8.2	64	10.9	11.1	85.5	3.4	2.3	0352	12.7	3.16	10.5	11.0	18.3	0.250	1.8	0353	32.7	6.97	
12/07/1996	0845	44	51.8	50.6	14.8	10.6	61	11.5	11.8	84.0	0.2	0.1	0356	14.0	3.29	11.6	11.8	16.5	0.227	1.8	0357	37.7	7.72	
13/07/1996	0800	45	82.0	84.8	11.3	11.0	96	12.3	12.5	83.0	0.3	0.2	0359	13.3	3.13	12.2	12.6	15.9	0.219	0.6	0360	35.5	7.33	
14/07/1996	0830	46	73.3	73.5	14.0	11.4	74	13.1	13.3	84.0	2.5	1.7	0363	14.6	3.29	13.2	13.4	14.7	0.203	1.2	0364	33.0	6.87	
15/07/1996	0730	47	73.5	77.9	13.5	12.2	87	12.5	12.6	85.0	3.8	2.6	0366	13.4	3.07	12.5	12.6	13.8	0.191	0.9	0367	-13.5	-2.24	
16/07/1996	0900	48	78.0	85.5	16.5	12.4	63	13.2	13.3	85.0	0.7	0.5	0370	10.8	2.73	13.0	13.4	13.0	0.181	0.8	0371	14.0	3.02	
17/07/1996	0900	49	66.7	74.2	15.8	10.4	50	13.4	13.7	87.0	7.0	4.7	0373	10.9	2.68	13.0	13.6	10.9	0.153	2.1	0374	17.4	3.26	
18/07/1996	0830	50	62.0	65.7	15.2	12.4	72	12.7	12.8	84.0	0.1	0.1	0377	13.6	2.66	12.7	12.9	8.1	0.116	2.8	0378	24.0	4.49	
19/07/1996	0745	51	69.0	74.3	15.4	13.2	79	13.2	13.2	83.5	0.3	0.2	0380	14.2	2.88	13.2	13.3	6.8	0.099	1.3	0381	29.3	4.80	
20/07/1996	0900	52	79.3	76.8	15.2	12.3	71	13.6	13.8	85.0	4.9	3.3	0384	13.6	2.80	13.7	13.9	5.8	0.086	1.0	0385	29.9	5.22	

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
21/07/1996	0745	53	79.1	81.8	15.2	14.2	90	13.7	13.8	84.0	0.2	0.1	0387	14.3	2.71	14.0	13.9	4.9	0.075	0.9	0388	31.5	4.50	
22/07/1996	0845	54	78.1	80.9	16.9	14.0	72	14.0	14.1	84.0	0.9	0.6	0391	14.3	2.60	14.0	14.2	4.0	0.063	0.9	0392	25.7	3.72	
23/07/1996	0845	55	73.8	67.8	12.8	11.5	84	13.6	13.6	85.0	6.0	4.0	0394	13.0	2.57	13.6	13.6	1.9	0.035	2.1	0395	25.2	5.27	
24/07/1996	0900	56	70.7	72.3	15.0	11.1	61	13.4	13.6	85.0	0.2	0.1	0398	14.1	2.81	N/S	13.6	0.3	0.022	1.6	0399	24.8	4.97	
End Run 2																								
Run 3																								
25/07/1996	0915	0	78.9	69.9	17.0	12.8	62	12.4	12.8	84.0	0.0	0.0		-10.7		12.4	12.7	75.5	1.000	0.0		-10.7		
26/07/1996	0715	1	63.3	68.8	13.3	12.1	87	13.7	14.1	84.0	0.3	0.2	0403	-10.2		13.9	14.1	74.2	0.983	1.3	0404	-10.0		
27/07/1996	0845	2	66.2	70.6	20.0	18.0	83	15.0	15.1	84.0	3.9	2.6	0406	-6.5		15.3	15.2	72.2	0.957	2.0	0407	-5.4		
28/07/1996	0730	3	67.3	69.2	15.1	11.9	69	13.9	14.0	84.0	2.8	1.9	0410	-5.9		13.7	14.1	70.4	0.933	1.8	0411	-3.3		
29/07/1996	0845	4	69.0	67.1	15.8	12.8	71	14.5	15.0	84.0	2.6	1.7	0413	-2.8		14.5	14.9	68.5	0.908	1.9	0414	-0.3		
30/07/1996	0930	5	81.3	87.1	16.8	14.0	74	15.8	16.2	84.0	4.3	2.9	0417	-2.0		15.7	16.2	67.0	0.889	1.5	0418	1.0		
31/07/1996	0830	6	60.4	57.4	12.8	9.8	69	12.6	13.0	84.0	2.5	1.7	0420	0.6		12.5	13.0	63.8	0.847	3.2	0421	4.2		
01/08/1996	0845	7	64.7	65.2	15.8	13.5	76	13.2	13.3	84.0	4.0	2.7	0424	2.3		13.2	13.3	61.4	0.815	2.4	0425	7.1		
02/08/1996	0715	8	69.0	71.9	15.0	12.2	71	14.0	14.1	84.0	1.3	0.9	0427	3.0		13.8	14.2	59.0	0.784	2.4	0428	8.5		
03/08/1996	0745	9	67.2	67.9	15.1	12.5	75	13.7	13.8	84.0	3.6	2.4	0431	4.7		13.6	13.9	57.0	0.757	2.0	0432	11.2		
04/08/1996	0830	10	76.5	71.1	11.3	11.0	95	13.9	14.2	85.0	6.0	4.0	0434	4.2		13.8	14.2	55.1	0.733	1.9	0435	11.5		
05/08/1996	0830	11	70.1	67.5	13.6	13.0	95	14.7	15.0	84.0	0.0	0.0	0438	6.7		14.6	15.0	53.6	0.713	1.5	0439	12.4		
06/08/1996	0830	12	83.3	61.7	8.5	7.0	82	11.5	12.2	85.5	4.6	3.1	0441	6.9		11.4	12.2	52.1	0.693	1.5	0442	13.9		
07/08/1996	0830	13	74.5	72.4	13.0	12.8	98	13.3	13.6	85.0	0.1	0.1	0445	8.8		13.4	13.6	51.1	0.680	1.0	0446	15.5		
08/08/1996	0830	14	79.3	62.9	11.6	9.8	78	13.2	13.7	84.0	0.7	0.5	0448	8.0		13.0	13.7	49.6	0.660	1.5	0449	16.8		
09/08/1996	0730	15	74.9	58.2	5.8	5.5	95	13.4	14.1	84.5	5.3	3.6	0452	9.0		12.9	14.0	47.5	0.633	2.1	0453	18.4		
10/08/1996	0815	16	60.2	54.2	14.4	11.4	70	13.6	14.2	84.0	0.3	0.2	0455	10.3		13.6	14.1	45.8	0.611	1.7	0456	21.4		
11/08/1996	0745	17	84.2	77.2	9.9	9.8	98	14.2	14.6	84.0	4.2	2.8	0459	11.3		13.9	14.6	44.5	0.594	1.3	0460	22.0		
12/08/1996	0830	18	69.6	57.5	13.1	11.7	84	14.6	15.1	84.0	0.8	0.5	0462	11.6		14.4	15.0	42.8	0.571	1.7	0463	24.4		
13/08/1996	0845	19	72.1	67.1	11.7	10.4	83	14.3	14.8	84.0	2.9	1.9	0466	12.3		14.1	14.8	40.6	0.543	2.2	0467	24.7		
14/08/1996	0830	20	75.3	50.1	8.9	6.5	70	12.1	12.7	85.0	7.0	4.7	0469	12.6		11.9	12.7	38.4	0.514	2.2	0470	28.6		
15/08/1996	0830	21	79.5	65.4	10.5	9.5	88	13.2	13.7	84.5	0.1	0.1	0473	13.4		13.0	13.7	36.9	0.494	1.5	0474	29.0		
16/08/1996	0730	22	80.6	65.8	10.4	10.1	96	13.9	14.4	84.0	1.4	0.9	0476	15.5		13.7	14.4	35.8	0.480	1.1	0477	28.7		
17/08/1996	0815	23	74.3	60.9	11.2	7.5	62	13.4	14.2	84.0	2.2	1.5	0480	15.1		13.4	14.0	33.9	0.455	1.9	0481	30.4		
18/08/1996	0830	24	51.5	43.1	11.0	7.2	56	12.6	13.6	84.0	6.2	4.2	0483	17.6		13.4	12.4	30.9	0.415	3.0	0484	35.1		
19/08/1996	0845	25	49.4	43.7	13.0	7.9	49	12.0	12.7	84.0	4.5	3.0	0487	21.0		11.9	12.7	27.7	0.373	3.2	0488	41.9		
20/08/1996	0715	26	57.8	60.9	14.9	14.1	92	13.8	14.0	84.0	5.1	3.4	0490	22.4		13.9	14.0	25.7	0.347	2.0	0491	46.0		
21/08/1996	0900	27	75.1	73.8	12.7	11.1	84	12.8	13.2	84.0	0.4	0.3	0494	20.4		12.9	13.2	24.6	0.333	1.1	0495	46.3		
22/08/1996	0845	28	75.8	64.6	12.5	10.6	79	13.4	14.0	84.0	2.0	1.3	0497	22.1		13.3	14.0	22.9	0.310	1.7	0498	44.4		
23/08/1996	0730	29	72.1	66.2	12.1	11.5	94	15.1	15.6	84.0	2.8	1.9	0501	20.4		14.8	15.5	21.2	0.288	1.7	0503	44.5		
24/08/1996	0900	30	82.5	75.7	15.7	12.5	70	15.6	16.2	84.0	2.3	1.5	0504	21.0		15.6	16.2	19.8	0.270	1.4	0505	40.8		
25/08/1996	0715	31	71.3	49.4	5.7	5.2	93	13.4	14.4	85.5	7.7	5.2	0508	20.0		12.9	14.3	16.9	0.232	2.9	0509	45.6		
26/08/1996	0830	32	68.7	50.4	12.1	9.5	73	13.7	14.5	85.0	0.1	0.1	0511	22.0		13.8	14.5	15.9	0.219	1.0	0512	50.9		
27/08/1996	0830	33	78.3	68.3	17.2	15.1	81	16.0	16.4	85.5	3.6	2.4	0515	21.8		16.1	16.4	13.5	0.187	2.4	0516	48.0		

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan									Standard Pan									
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap		Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap		Sample	^{2}H	^{18}O	Wind
28/08/1996	0830	34	77.5	70.2	16.2	15.2	90	17.6	18.2	84.0	1.0	0.7		0518	22.2		17.5	18.0	11.7	0.164	1.8		0519	45.9		
29/08/1996	0830	35	83.0	62.0	15.9	14.0	81	17.2	17.9	85.0	5.9	4.0		0522	20.8		17.2	17.8	9.6	0.136	2.1		0523	47.0		
30/08/1996	0700	36	79.7	61.5	10.2	9.7	94	16.9	17.8	84.0	1.1	0.7		0525	22.3		16.4	17.7	7.4	0.107	2.2		0526	47.9		
31/08/1996	0845	37	73.1	64.1	16.7	13.0	67	17.9	18.6	84.0	2.6	1.7		0529	22.8		18.0	18.6	5.3	0.080	2.1		0530	48.9		
01/09/1996	0840	38	73.2	52.7	13.7	10.7	70	16.4	17.6	86.0	7.4	5.0		0532	22.3		16.6	17.6	2.5	0.043	2.8		0533	61.2		
	1730																						0536	69.4		
02/09/1996	0830	39	75.8	52.5	13.6	11.0	74	15.3	16.2	84.0	2.2	1.5		0537	23.9			16.1	0.2	0.026	2.3		0538	70.6		
	1200																		-0.5	0.021	0.7		0540	79.1		
	1600																		-1.0	0.015	0.5		0541	83.0		
03/09/1996	0830	40	59.1	58.3	17.5	13.0	59	16.7	17.2	84.0	4.3	2.9		0542	24.5		Dry	17.2		0.011						
End Run 3																										
Run 4																										
03/09/1996	0900	0			17.5	13.0	59	16.7	17.2	84.0	0.0	0.0	STD	3/9/96	-10.9		17.2	17.2	75.5	1.000	0.0	STD	3/9/96	-10.9		
04/09/1996	0830	1	64.3	52.0	13.2	9.5	62	15.5	16.4	84.0	4.2	2.8		0545	-9.2		15.6	16.4	72.8	0.965	2.7		0546	-7.5		
05/09/1996	0830	2	73.7	50.2	13.2	10.2	69	14.8	15.7	85.0	5.3	3.6		0548	-7.0		15.0	15.8	70.0	0.928	2.8		0549	-4.6		
06/09/1996	0715	3	62.1	59.6	15.9	12.4	67	16.4	16.9	84.0	2.5	1.7		0552	-4.1		16.1	16.9	67.5	0.895	2.5		0553	-2.2		
07/09/1996	0900	4	68.7	57.2	14.9	13.7	90	16.6	17.1	84.0	5.8	3.9		0555	-1.4		16.6	17.2	64.0	0.849	3.5		0556	1.9		
08/09/1996	0830	5	83.3	69.7	16.0	14.5	85	16.6	17.4	84.0	2.2	1.5		0559	0.8		16.4	17.4	62.6	0.831	1.4		0560	4.3		
09/09/1996	0830	6	82.2	65.2	15.9	14.1	82	18.5	19.3	84.0	1.9	1.3		0562	4.0		18.5	19.3	60.2	0.799	2.4		0563	7.1		
10/09/1996	0830	7	77.3	64.8	18.3	16.5	84	18.5	19.0	84.0	5.2	3.5		0566	4.4		18.5	19.0	58.7	0.780	1.5		0567	10.1		
11/09/1996	0900	8	86.2	61.6	13.2	12.2	89	16.0	16.8	85.0	6.1	4.1		0569	4.3		16.1	16.9	55.1	0.733	3.6		0570	12.4		
12/09/1996	0830	9	70.9	60.0	14.7	14.0	92	16.9	17.5	84.0	0.1	0.1		0573	6.5		17.0	17.5	52.8	0.702	2.3		0574	11.9		
13/09/1996	0730	10	79.8	58.7	10.2	9.8	94	15.9	16.9	85.0	6.4	4.3		0576	7.8		15.7	16.9	51.0	0.679	1.8		0577	15.5		
14/09/1996	0830	11	61.2	61.6	19.0	14.2	60	17.6	18.0	84.0	0.0	0.0		0580	9.4		17.4	18.0	47.9	0.638	3.1		0581	18.5		
15/09/1996	0830	12	71.4	73.1	18.5	16.0	78	17.4	17.7	84.0	4.9	3.3		0583	11.5		17.4	17.7	45.7	0.609	2.2		0584	21.1		
16/09/1996	0830	13	74.5	71.8	16.8	13.8	72	16.3	16.6	84.0	4.8	3.2		0587	10.6		16.2	16.7	43.1	0.575	2.6		0588	22.1		
17/09/1996	0845	14	68.5	68.6	20.5	17.4	75	17.7	18.0	84.0	1.5	1.0		0590	13.5		17.8	18.0	40.6	0.543	2.5		0591	25.2		
18/09/1996	0830	15	74.3	75.2	17.8	14.0	67	17.1	17.6	85.0	5.3	3.6		0594	12.6		16.9	17.6	38.3	0.512	2.3		0595	25.7		
19/09/1996	0830	16	61.8	53.4	17.5	14.0	68	17.4	18.0	84.0	3.3	2.2		0597	13.8		17.3	18.0	34.5	0.463	3.8		0598	30.6		
20/09/1996	0745	17	70.8	53.2	12.6	10.4	75	15.9	17.1	85.0	8.0	5.4		0601	14.2		15.9	17.1	31.2	0.419	3.3		0602	33.9		
21/09/1996	0830	18	75.6	53.3	15.7	13.0	74	17.1	18.1	84.5	1.1	0.7		0604	16.1		17.3	18.1	28.8	0.388	2.4		0605	39.9		
22/09/1996	0830	19	78.1	67.5	12.9	9.2	62	16.3	17.6	84.5	6.0	4.0		0608	15.9		16.2	17.6	26.0	0.351	2.8		0609	39.7		
23/09/1996	0730	20	58.6	47.7	14.8	11.8	71	16.5	17.3	84.5	5.1	3.4		0611	17.0		16.4	17.3	22.5	0.305	3.5		0612	42.3		
24/09/1996	0800	21	71.0	55.6	14.5	11.5	70	17.1	18.0	84.0	2.9	1.9		0615	19.3		17.2	18.1	20.0	0.272	2.5		0616	45.7		
25/09/1996	0730	22	70.0	49.1	13.2	10.4	72	16.6	17.6	85.0	7.2	4.8		0618	19.8		16.1	17.6	17.0	0.233	3.0		0619	51.3		
26/09/1996	0745	23	58.5	47.6	14.0	10.4	66	15.9	17.4	84.0	2.4	1.6		0622	21.6		15.5	17.4	13.7	0.190	3.3		0623	57.6		
27/09/1996	0730	24	81.4	73.8	16.5	14.4	81	15.8	16.2	84.0	2.7	1.8		0625	20.8		15.8	16.2	12.1	0.169	1.6		0626	46.5		
28/09/1996	0900	25	71.8	63.0	16.4	12.3	62	16.6	17.6	84.0	6.0	4.0		0629	20.0		16.6	17.6	9.2	0.131	2.9		0630	41.3		
29/09/1996	0830	26	68.6	50.2	12.6	9.4	66	16.5	17.9	84.0	4.3	2.9		0632	20.7		15.6	17.9	6.3	0.093	2.9		0633	53.8		
30/09/1996	0830	27	64.4	43.2	13.0	9.0	59	16.0	17.2	85.0	7.8	5.2		0636	21.3		15.7	17.2	2.9	0.048	3.4		0637	71.4		

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
01/10/1996	0730	28	70.1	50.7	13.0	10.9	79	17.2	18.1	84.0	2.3	1.5	0639	23.2			18.1	0.2	0.021	2.7	0640	76.3		
	1230																	-0.5	0.015	0.7	0643	77.0		
End Run 4	1600																	-1.0	0.011	0.5	0644	81.1		
Run 5																								
02/10/1996	0800	0	73.3	56.2	15.9	12.7	70	17.3	18.7	84.0	0.0	0.0	0645	-11.9		17.1	19.0	75.5	1.000	0.0	0646	-10.3		
03/10/1996	0715	1	70.9	48.4	11.2	10.3	88	17.2	18.2	82.0	3.1	2.1	0648	-8.6		17.1	18.4	72.2	0.957	3.3	0649	-8.4		
04/10/1996	0715	2	64.9	50.5	14.4	11.9	74	18.3	19.5	82.0	5.0	3.4	0652	-4.8		18.4	19.8	68.9	0.913	3.3	0653	-3.3		
05/10/1996	0845	3	68.2	48.3	15.7	12.0	66	17.6	19.1	82.0	7.1	4.8	0655	-2.4		17.6	19.3	64.9	0.861	4.0	0656	0.9		
06/10/1996	0830	4	67.8	46.4	15.8	10.9	54	17.1	18.2	84.0	7.9	5.3	0659	0.6		16.9	18.5	61.2	0.813	3.7	0660	5.4		
07/10/1996	0730	5	57.5	43.3	17.9	11.2	45	18.1	19.4	83.0	2.9	1.9	0662	4.6		17.9	19.5	57.8	0.768	3.4	0663	10.3		
08/10/1996	0715	6	61.0	46.9	15.2	14.3	90	19.5	20.6	84.0	9.0	6.0	0666	7.4		19.4	20.8	53.3	0.709	4.5	0667	17.1		
09/10/1996	0730	7	73.2	58.5	16.5	13.6	72	20.9	22.1	82.0	1.5	1.0	0669	11.7		20.7	22.3	50.1	0.667	3.2	0670	20.7		
10/10/1996	0730	8	65.8	50.7	13.6	10.9	72	17.6	18.9	83.0	7.8	5.2	0673	13.1		16.9	19.1	46.2	0.616	3.9	0674	25.3		
11/10/1996	0715	9	68.1	44.8	10.0	7.4	71	15.0	16.4	85.0	8.8	5.9	0676	13.1		14.5	16.6	42.2	0.563	4.0	0677	29.1		
12/10/1996	0830	10	62.1	41.5	16.4	10.0	41	16.7	17.9	83.0	3.5	2.4	0680	17.0		15.9	17.9	38.7	0.518	3.5	0681	34.2		
13/10/1996	0800	11	57.6	43.9	15.4	12.1	68	18.0	19.1	84.0	6.0	4.0	0683	18.0		17.1	19.1	35.0	0.469	3.7	0684	39.2		
14/10/1996	0800	12	72.9	54.5	15.0	13.4	85	19.1	20.1	83.0	4.4	3.0	0687	20.4		18.9	20.2	32.0	0.430	3.0	0688	42.8		
15/10/1996	0815	13	68.0	56.9	16.8	12.5	62	18.1	19.1	83.0	5.5	3.7	0690	21.2		17.4	19.3	29.0	0.390	3.0	0691	44.1		
16/10/1996	0800	14	59.1	44.8	14.6	10.4	59	18.2	19.5	84.0	7.1	4.8	0694	20.9		17.6	19.7	25.0	0.338	4.0	0695	51.3		
17/10/1996	0800	15	62.4	42.1	15.8	11.8	62	17.7	18.7	84.0	7.3	4.9	0697	22.4		16.5	19.0	21.1	0.287	3.9	0698	57.7		
18/10/1996	0745	16	70.6	53.7	14.2	11.4	70	18.3	19.6	83.0	3.4	2.3	0701	24.4		16.7	19.8	18.0	0.246	3.1	0702	59.7		
19/10/1996	0900	17	72.1	51.9	18.4	14.0	60	18.7	20.1	83.0	7.1	4.8	0704	25.0		17.2	20.2	14.7	0.203	3.3	0705	61.8		
20/10/1996	0830	18	64.1	52.9	26.5	16.0	32	20.7	21.9	82.0	3.3	2.2	0708	25.6		19.5	22.0	11.8	0.165	2.9	0709	64.2		
21/10/1996	0815	19	65.2	60.6	19.0	18.6	95	21.6	22.6	84.0	8.8	5.9	0711	25.2		20.0	22.8	8.2	0.118	3.6	0712	56.8		
22/10/1996	0800	20	85.9	73.6	18.5	17.2	88	20.7	21.5	83.0	2.0	1.3	0715	23.5		19.5	21.7	6.8	0.099	1.4	0716	42.3		
23/10/1996	0815	21	74.3	62.4	18.1	15.2	73	19.4	20.5	83.0	4.3	2.9	0718	24.3		17.9	20.6	4.1	0.064	2.7	0719	40.9		
24/10/1996	0815	22	78.8	55.7	13.7	11.1	74	17.7	19.3	84.0	6.6	4.4	0722	23.4		17.4	19.5	1.8	0.034	2.3	0723	41.1		
25/10/1996	0730	23	54.3	42.2	13.0	8.7	56	16.7	18.9	83.0	5.5	3.7	0726	25.2			19.4	Dry	0.000	1.8	N/S	51.0		
26/10/1996	0800	24	56.3	42.6	16.9	11.7	53	18.5	20.3	84.0	7.7	5.2	0729	26.5			20.5				N/S			
27/10/1996	0830	25	54.7	46.2	19.8	13.2	48	19.6	21.1	82.0	4.0	2.7	0731	29.3			21.9				N/S			
End Run 5																								
Run 6																								
27/10/1996	0900	0						18.7	21.4	83.0	0.0	0.0	0734	-11.0		18.9	21.7	120.0	1.000	0.0	0735	-11.1		
28/10/1996	0830	1	56.3	48.3	21.1	14.7	49	21.2	22.5	82.0	5.2	3.5	0736	-5.9		21.5	22.7	115.9	0.966	4.1	0737	-7.8		
29/10/1996	0800	2	51.9	47.0	19.8	14.5	57	20.8	22.6	82.0	8.0	5.4	0739	-0.9		21.3	22.9	110.8	0.924	5.1	0740	-3.1		
30/10/1996	0730	3	44.2	45.9	21.8	19.8	83	23.5	24.4	81.0	7.5	5.0	0743	2.9		23.6	24.5	106.1	0.885	4.7	0744	0.3		
31/10/1996	0745	4	75.5	60.1	18.5	15.5	74	22.1	23.4	82.0	6.6	4.4	0746	6.7		22.4	23.7	101.9	0.850	4.2	0747	3.2		
01/11/1996	0730	5	65.9	45.6	17.7	13.7	65	20.9	22.2	84.0	9.1	6.1	0750	8.3		20.9	22.2	96.9	0.809	5.0	0751	7.0		
02/11/1996	0720	6	60.7	44.2	16.5	12.2	60	20.5	21.8	84.0	5.9	4.0	0753	11.8		20.4	21.9	92.1	0.769	4.8	0754	11.3		

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								Wind
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^2H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^2H	^{18}O	
03/11/1996	0800	7	56.2	44.0	18.8	13.2	54	19.5	21.0	82.0	7.7	5.2	0757	13.9		19.3	21.0	86.9	0.726	5.2	0758	14.4		
04/11/1996	0730	8	42.2	37.7	18.0	13.0	56	19.5	21.1	82.0	9.9	6.7	0760	16.3		19.4	21.3	80.9	0.676	6.0	0761	18.9		
05/11/1996	0745	9	32.4	33.6	19.9	13.5	48	19.8	21.2	82.0	10.8	7.3	0764	20.3		19.5	21.2	74.1	0.620	6.8	0765	25.7		
06/11/1996	0745	10	57.7	56.0	15.5	15.0	95	18.2	18.6	82.0	8.3	5.6	0767	20.6		18.0	18.7	70.5	0.590	3.6	0768	27.0		Start
07/11/1996	0730	11	89.8	75.3	17.3	16.1	89	18.2	18.6	84.0	3.2	2.2	0771	21.0		18.0	18.7	69.1	0.579	1.4	0772	26.4		22.2
08/11/1996	0620	12	74.2	62.6	17.7	15.5	80	20.6	21.5	81.0	1.5	1.0	0774	21.1		20.6	21.6	66.6	0.558	2.5	0775	28.6		37.2
09/11/1996	0730	13	70.4	53.0	20.8	15.7	60	21.0	22.3	82.0	7.3	4.9	0778	22.9		20.8	22.4	62.8	0.526	3.8	0779	32.4		36.9
10/11/1996	0815	14	61.3	51.3	24.5	16.0	41	22.4	23.7	82.0	6.1	4.1	0781	25.9		21.9	23.8	58.8	0.493	4.0	0782	36.1		34.8
11/11/1996	0730	15	48.7	42.7	24.2	16.7	46	23.2	24.4	82.0	8.0	5.4	0785	27.7		22.9	24.5	53.9	0.453	4.9	0786	40.5		28.6
12/11/1996	0745	16	54.6	46.3	22.5	20.7	85	25.6	26.4	82.0	7.4	5.0	0788	28.7		25.4	26.4	49.6	0.417	4.3	0789	45.6		14.6
13/11/1996	0745	17	67.8	50.9	19.4	14.0	55	22.2	23.5	82.0	7.3	4.9	0792	29.5		21.6	23.7	45.0	0.379	4.6	0793	45.2		35.2
14/11/1996	0730	18	67.4	47.3	16.5	13.8	74	21.4	22.5	82.0	7.2	4.8	0795	27.6		20.9	22.6	40.8	0.344	4.2	0796	49.5		31.3
15/11/1996	0645	19	69.5	53.4	18.2	15.2	73	20.2	21.0	82.0	5.5	3.7	0799	30.1		19.5	21.2	37.0	0.313	3.8	0800	51.0		35.7
16/11/1996	0815	20	77.0	61.0	17.4	14.8	77	18.3	19.2	82.0	6.0	4.0	0802	26.0		17.9	19.4	33.8	0.286	3.2	0803	52.1		92.9
17/11/1996	0815	21	67.6	51.5	18.1	13.1	56	19.4	20.5	83.0	5.9	4.0	0806	27.2		18.8	20.6	30.6	0.260	3.2	0807	52.2		46.1
18/11/1996	0730	22	68.3	49.3	18.2	14.7	69	20.6	21.8	82.0	5.5	3.7	0809	29.8		19.9	22.0	27.0	0.230	3.6	0810	56.6		30.4
19/11/1996	0730	23	71.3	55.3	20.9	15.9	60	22.3	23.4	84.0	7.2	4.8	0813	29.4		21.4	23.5	23.7	0.203	3.3	0814	61.8		34.7
20/11/1996	0730	24	72.7	55.7	21.2	17.2	67	23.7	24.8	82.0	5.0	3.4	0816	31.4		22.6	25.0	20.5	0.176	3.2	0817	60.4		24.4
21/11/1996	0730	25	74.4	55.2	22.0	18.7	74	24.8	25.8	82.0	6.9	4.6	0820	29.0		23.9	26.0	16.8	0.146	3.7	0821	60.9		25.2
22/11/1996	0630	26	73.9	56.3	21.0	19.2	85	26.0	27.0	82.0	6.5	4.4	0823	29.7		24.4	27.2	13.0	0.114	3.8	0824	62.0		26.7
23/11/1996	0730	27	78.5	56.0	21.0	17.8	73	25.5	26.6	82.0	7.3	4.9	0827	31.7		23.9	26.7	9.1	0.082	3.9	0828	62.0		33.0
24/11/1996	0800	28	65.3	47.2	18.9	13.4	54	21.7	23.5	82.5	8.9	6.0	0830	31.1		19.4	23.8	4.8	0.046	4.3	0831	65.2		46.3
25/11/1996	0730	29	57.5	40.5	17.6	12.9	58	20.8	22.0	82.0	8.6	5.8	0834	30.4			22.0	0.5	0.015	4.3	0835	73.8		49.7
26/11/1996	0730	30	59.8	47.0	19.6	16.2	71	21.7	22.9	82.0	7.4	5.0	0840	30.4			23.2		0.007		0837 @1120	81.5		48.4
End Run 6		Std pans ends 1500 November 25 CV pan ends 0730 November 26																	0.003	0.5	0838 @1320	83.4		
																			0.000		0839 @1500	74.4		
Run 7																								
26/11/1996	0800	0						20.0	22.9	82.0	0.0	0.0	0843	-12.7		19.6	23.2	100.0	1.000	0.0	0844	-11.7		
27/11/1996	0710	1	59.6	44.3	16.9	12.1	57	20.3	21.7	82.0	6.7	4.5	0845	-7.3		20.3	21.9	95.6	0.956	4.4	0846	-7.6		52.6
28/11/1996	0620	2	65.6	48.7	15.2	13.6	86	20.5	21.7	82.0	7.0	4.7	0848	-3.3		20.4	21.9	91.1	0.912	4.5	0849	-3.5		40.9
29/11/1996	0750	3	66.7	50.2	21.2	15.2	52	21.7	23.1	81.0	6.6	4.4	0852	0.6		21.7	23.3	86.8	0.869	4.3	0853	-2.0		37.4
30/11/1996	0720	4	66.0	54.9	21.2	18.6	79	23.0	23.9	81.0	6.2	4.2	0855	3.7		22.8	24.0	82.3	0.824	4.5	0856	1.8		29.7
01/12/1996	0815	5	72.3	62.3	21.0	17.8	73	21.4	22.3	82.0	6.6	4.4	0859	4.2		21.2	22.4	78.6	0.788	3.7	0860	4.9		50.2
02/12/1996	0710	6	71.7	60.0	19.6	16.8	76	21.7	22.7	82.0	4.5	3.0	0862	6.2		21.6	22.9	75.1	0.753	3.5	0863	6.6		31.1
03/12/1996	0740	7	63.6	46.3	17.8	11.8	49	20.6	22.2	82.0	7.3	4.9	0866	9.7		20.4	22.4	70.4	0.706	4.7	0867	11.1		38.8
04/12/1996	0720	8	60.7	42.4	18.2	13.6	60	20.6	21.9	82.0	8.2	5.5	0869	13.9		20.3	22.1	65.8	0.661	4.6	0870	17.9		34.7
05/12/1996	0740	9	60.2	44.5	17.9	13.9	65	20.6	22.0	82.0	8.1	5.4	0873	15.9		20.4	22.2	60.9	0.612	4.9	0874	23.2		42.3
06/12/1996	0620	10	54.3	39.6	14.1	10.7	65	19.4	20.6	82.0	8.9	6.0	0876	18.5		19.0	20.8	55.8	0.561	5.1	0877	25.7		42.6
07/12/1996	0750	11	54.8	41.4	18.4	12.3	49	19.5	21.0	82.0	8.0	5.4	0880	20.5		19.0	21.2	50.8	0.512	5.0	0881	31.2		51.0
08/12/1996	0745	12	52.5	44.4	19.5	14.3	57	21.6	22.9	82.0	7.7	5.2	0883	21.8		21.2	22.9	46.3	0.467	4.5	0884	37.0		30.9
09/12/1996	0720	13	68.3	52.4	20.2	15.8	62	22.8	24.4	82.0	6.5	4.4	0887	22.9		22.2	24.4	42.6	0.430	3.7	0888	40.9		23.4

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
10/12/1996	0745	14	67.4	51.4	20.4	15.8	62	23.4	24.6	82.0	7.4	5.0	0890	25.2		22.8	24.7	37.8	0.383	4.8	0891	43.1		35.7
11/12/1996	0745	15	69.0	51.6	22.0	18.1	68	23.5	24.6	82.0	7.8	5.2	0894	25.4		23.1	24.7	33.5	0.340	4.3	0895	49.7		39.0
12/12/1996	0745	16	70.6	51.4	18.9	15.8	73	19.2	20.6	83.0	9.2	6.2	0897	26.5		18.9	20.8	28.4	0.290	5.1	0898	50.1		98.1
13/12/1996	0645	17	72.6	56.1	18.4	15.2	71	21.5	22.6	82.0	6.6	4.4	0901	26.0		20.6	22.8	24.8	0.254	3.6	0902	50.4		61.8
14/12/1996	0800	18	69.3	50.9	18.0	14.6	70	21.1	22.5	82.0	7.9	5.3	0904	27.9		20.0	22.6	20.2	0.208	4.6	0905	56.7		46.9
15/12/1996	0830	19	58.3	50.0	21.0	14.8	51	20.6	22.3	82.0	7.8	5.2	0908	27.6		19.2	22.5	15.9	0.166	4.3	0909	59.5		69.9
16/12/1996	0730	20	39.3	40.9	19.7	14.8	60	20.5	22.0	82.0	11.8	7.9	0911	28.6		18.8	22.2	10.3	0.110	5.6	0912	68.6		90.0
17/12/1996	0740	21	43.6	43.9	20.7	15.5	59	20.9	22.5	82.0	11.2	7.5	0915	29.1		18.7	22.7	4.8	0.055	5.5	0916	71.5		97.8
	1730																	2.5	0.033		0918	80.4		
	2200																	1.0	0.021		0919	91.7		
18/12/1996	0710	22	35.3	38.2	21.0	15.1	53	21.9	23.5	82.0	11.5	7.7	0920	29.4			23.7	0.0	0.015	4.8	0921	68.3		80.5
End Run 7																								
Run 8																								
18/12/1996	0900	0								82.0	0.0	0.0	0924	-9.6				100.0	1.000	0.0	0925	-11.7		
19/12/1996	0730	1	33.7	31.6	27.3	15.4	26	23.4	24.7	81.0	8.2	5.5	0926	-5.3		23.2	24.8	93.5	0.936	6.5	0927	-7.9		63.5
20/12/1996	0620	2	46.6	45.6	23.0	19.5	72	25.4	26.4	81.0	9.7	6.5	0929	-1.5		25.2	26.5	88.5	0.886	5.0	0930	-3.2		33.3
21/12/1996	0700	3	65.9	54.3	19.8	16.0	68	23.5	24.9	81.0	8.5	5.7	0933	2.6		23.4	25.1	83.0	0.831	5.5	0934	2.1		36.8
22/12/1996	0810	4	54.2	42.0	19.0	13.0	50	20.2	21.7	81.0	11.5	7.7	0936	8.8		19.8	21.9	76.6	0.768	6.4	0937	8.5		66.4
23/12/1996	0800	5	57.6	47.4	20.2	14.8	56	21.3	22.9	82.0	7.8	5.2	0940	10.3		21.2	23.2	71.5	0.717	5.1	0941	11.2		43.8
24/12/1996	0620	6	57.1	46.0	15.8	12.2	66	19.6	20.9	82.0	10.2	6.9	0943	13.6		19.4	20.0	65.8	0.661	5.7	0944	17.5		61.1
25/12/1996	0710	7	51.5	40.1	15.2	10.5	55	18.4	19.7	82.0	10.2	6.9	0947	16.8		17.8	19.9	60.0	0.603	5.8	0948	21.6		64.4
26/12/1996	0710	8	50.6	42.0	18.0	12.2	50	19.5	21.0	82.0	7.2	4.8	0950	19.8		18.9	21.3	54.9	0.553	5.1	0951	28.3		48.4
27/12/1996	0720	9	52.4	45.3	19.0	14.4	60	20.7	22.2	82.0	8.9	6.0	0954	22.2		20.2	22.4	50.0	0.504	4.9	0955	32.0		45.4
28/12/1996	0730	10	56.9	47.9	19.0	14.5	61	20.6	21.9	82.0	9.4	6.3	0957	22.9		20.0	22.0	44.7	0.451	5.3	0958	38.0		50.8
29/12/1996	0720	11	53.2	46.9	18.2	13.8	61	20.3	21.5	82.0	9.4	6.3	0961	25.1		19.6	21.7	39.6	0.401	5.1	0962	43.8		60.8
30/12/1996	0720	12	59.8	50.0	19.0	14.5	61	20.6	22.0	82.0	7.9	5.3	0964	26.3		19.9	22.3	34.6	0.351	5.0	0965	47.8		55.9
31/12/1996	0710	13	49.1	44.9	21.8	16.2	57	21.5	22.7	82.0	8.9	6.0	0967A	27.8		20.8	22.8	29.6	0.301	5.0	0968	53.2		52.5
01/01/1997	0740	14	37.9	42.7	33.2	20.5	30	25.6	26.4	82.0	9.6	6.5	0970	28.9		24.7	26.4	24.1	0.247	5.5	0971	60.2		55.9
02/01/1997	0710	15	46.0	51.2	28.5	23.5	65	27.7	28.5	82.0	7.5	5.0	0974	29.0		26.9	28.5	19.2	0.198	4.9	0975	63.1		32.6
03/01/1997	0610	16	58.1	54.6	25.2	23.0	83	28.5	29.4	82.0	7.7	5.2	0977	28.2		27.3	29.4	14.5	0.152	4.7	0978	60.2		20.8
04/01/1997	0740	17	67.5	54.3	22.2	18.8	72	24.9	26.1	82.0	10.2	6.9	0981	28.4		23.2	26.3	9.6	0.103	4.9	0982	57.3		48.1
05/01/1997	0830	18	55.7	48.6	20.5	14.2	50	20.7	22.4	82.0	10.0	6.7	0984	28.5		18.8	22.6	5.0	0.057	4.6	0985	63.6		61.2
	1900																		0.033		0988	68.9		
06/01/1997	0700	19	47.9	44.2	18.0	13.2	58	20.0	21.6	82.0	9.5	6.4	0989	29.3			21.8	0.6	0.018	4.4	0990	78.8		57.4
	1000																	0.0	0.015	0.6	0992	78.9		
	1230																	-1.0	0.009	1.0	0993	92.5		
	1400																	Dry	0.000		0994	102.2		
07/01/1997	0550	20	31.7	34.4	21.3	14.8	49	22.9	24.3	82.0	10.3	6.9	0995	30.5			24.3							62.1
End Run 8																								

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
Run 9																								
07/01/1997	0630	0											0998	-11.3				100.0	1.000		0999	-11.5		
08/01/1997	0700	1	38.5	38.9	26.6	17.0	37	23.9	25.1	82.0	10.8	7.3	1000	-4.7		24.5	25.2	93.0	0.931	7.0	1001	-5.4		55.2
09/01/1997	0700	2	52.6	48.2	23.3	20.2	75	25.7	26.7	82.0	10.3	6.9	1003	-0.1		26.3	26.9	86.8	0.869	6.2	1004	-0.3		28.5
10/01/1997	0600	3	76.3	59.8	22.4	21.1	90	26.5	27.5	82.0	7.2	4.8	1007	3.0		27.0	27.7	81.9	0.820	4.9	1008	4.8		18.3
11/01/1997	0740	4	75.7	57.6	26.3	19.8	55	25.6	26.6	82.0	7.9	5.3	1010	8.2		26.1	26.7	76.1	0.763	5.8	1011	8.6		27.5
12/01/1997	0740	5	69.8	59.9	22.3	19.2	75	24.4	25.4	82.0	7.2	4.8	1014	8.7		24.8	25.5	70.8	0.710	5.3	1015	10.5		40.6
13/01/1997	0730	6	61.2	52.8	20.3	15.3	59	21.4	22.7	82.0	8.4	5.6	1017	9.5		22.0	22.9	65.8	0.661	5.0	1018	15.5		59.2
14/01/1997	0630	7	50.5	45.2	19.0	14.0	58	21.4	22.7	82.0	8.9	6.0	1021	12.7		21.9	22.9	59.5	0.598	6.3	1022	20.3		46.1
15/01/1997	0600	8	55.5	48.7	21.0	15.6	57	23.5	24.5	82.0	7.8	5.2	1024	13.6		23.8	24.6	54.0	0.544	5.5	1025	24.8		36.9
16/01/1997	0700	9	50.3	46.6	23.8	17.8	56	23.4	24.6	82.0	10.0	6.7	1028	16.9		23.7	24.7	48.7	0.491	5.3	1029	31.2		48.2
17/01/1997	0610	10	44.8	42.8	25.2	17.2	44	24.4	25.6	82.0	9.9	6.7	1031	19.3		24.6	25.7	41.9	0.424	6.8	1032	38.0		38.9
18/01/1997	0700	11	56.4	51.2	22.9	20.9	84	25.0	25.8	82.0	10.1	6.8	1035	21.3		25.2	26.0	35.3	0.358	6.6	1036	44.0		36.2
19/01/1997	0715	12	70.4	59.1	19.3	15.9	71	21.3	22.4	83.0	9.3	6.3	1038	21.0		21.6	22.5	30.2	0.307	5.1	1039	48.0		48.1
20/01/1997	0740	13	55.9	48.6	19.0	13.5	54	19.0	20.3	83.0	6.7	4.5	1042	22.9		19.1	20.4	24.8	0.254	5.4	1043	53.6		57.9
21/01/1997	0640	14	52.8	46.3	15.8	12.3	67	17.9	19.0	83.5	10.3	6.9	1045	22.4		17.9	19.0	19.6	0.202	5.2	1046	59.0		65.2
22/01/1997	0640	15	34.7	36.2	18.5	13.7	58	18.6	19.7	83.0	8.8	5.9	1049	24.4		18.7	19.8	13.1	0.138	6.5	1050	70.8		76.9
23/01/1997	0600	16	52.7	47.6	18.1	13.6	60	20.5	21.7	82.0	8.1	5.4	1052	26.0		20.3	21.9	8.0	0.087	5.1	1053	76.3		60.5
24/01/1997	0600	17	45.7	44.4	20.8	14.8	52	21.3	22.1	82.0	7.7	5.2	1055A	28.5		20.3	22.2	2.5	0.033	5.5	1056	92.2		62.3
	1300																	0.5	0.018	2.0	1058	101.7		
25/01/1997	0600	18	47.0	47.4	22.8	21.4	89	23.8	24.2	82.0	11.3	7.6	1059	27.0			24.2	Dry		0.5				47.6
End Run 9																								
Run 10																								
25/01/1997	0800	0								82.0	0.0	0.0	1062	-12.8				100.0	1.000	0.0	1063	-10.2		
26/01/1997	0730	1	62.7	53.4	16.9	12.8	64	18.4	19.4	83.0	10.8	7.3	1064	-4.7		18.7	19.5	94.7	0.947	5.3	1065	-5.4		80.8
27/01/1997	0740	2	46.8	43.5	17.7	12.3	52	18.6	19.6	82.0	6.9	4.6	1067	-0.4		18.8	19.6	89.6	0.897	5.1	1068	-1.2		59.8
28/01/1997	0715	3	43.2	40.1	25.8	14.8	29	20.9	22.0	80.0	5.9	4.0	1071	4.2		21.0	22.0	84.1	0.842	5.5	1072	1.0		55.4
29/01/1997	0620	4	39.3	39.3	24.0	21.1	77	24.8	25.6	82.0	12.4	8.3	1074	7.2		24.8	25.6	78.1	0.783	6.0	1075	6.0		40.0
30/01/1997	0630	5	66.2	56.2	17.4	14.8	77	21.0	21.8	82.0	9.0	6.0	1078	9.3		20.9	21.9	73.5	0.737	4.6	1079	10.1		62.4
31/01/1997	0600	6	53.5	49.3	17.9	13.1	58	20.0	21.2	82.0	8.0	5.4	1081	12.5		20.2	21.3	67.8	0.681	5.7	1082	15.6		64.9
01/02/1997	0640	7	49.3	48.1	21.3	16.9	63	21.9	22.8	82.0	7.2	4.8	1085	15.0		21.8	22.8	62.8	0.631	5.0	1086	20.4		54.9
02/02/1997	0720	8	50.2	57.2	29.5	24.3	66	25.0	25.4	82.0	8.1	5.4	1089	16.8		24.8	25.4	58.6	0.589	4.2	1090	24.3		46.1
03/02/1997	0700	9	64.4	69.9	26.7	23.9	80	25.8	26.2	83.0	6.5	4.4	1093	13.1		25.8	26.2	55.6	0.559	3.0	1094	19.9		29.8
04/02/1997	0610	10	77.4	66.4	20.6	18.2	78	22.9	23.7	83.0	6.7	4.5	1097	14.2		22.6	23.8	51.9	0.523	3.7	1098	21.2		66.9
05/02/1997	0710	11	56.4	50.5	18.8	14.1	60	19.7	20.5	82.0	8.2	5.5	1101	15.1		19.4	20.6	46.7	0.471	5.2	1102	25.6		89.5
06/02/1997	0620	12	59.0	50.2	19.0	14.3	60	21.2	22.1	83.0	8.5	5.7	1105	17.5		20.7	22.3	42.7	0.431	4.0	1106	30.2		50.6
07/02/1997	0620	13	57.5	53.2	21.9	18.8	75	23.7	24.3	82.0	5.1	3.4	1109	19.7		23.2	24.4	37.5	0.380	5.2	1110	35.0		44.3
08/02/1997	0700	14	62.8	56.4	19.4	15.9	70	19.9	20.6	83.0	10.0	6.7	1113	19.3		19.6	20.8	33.2	0.337	4.3	1114	38.6		77.4
09/02/1997	0645	15	40.6	43.7	19.7	14.5	58	19.5	20.2	82.0	10.8	7.3	1117	22.2		18.6	20.3	27.5	0.281	5.7	1118	47.7		81.2
10/02/1997	0615	16	56.5	54.5	19.3	15.0	63	20.5	21.1	82.0	6.5	4.4	1121	24.0		19.7	21.3	23.5	0.241	4.0	1122	49.9		59.1

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
11/02/1997	0650	17	50.2	47.6	20.0	14.5	55	21.0	21.9	82.0	8.0	5.4	1125	25.0		19.5	22.0	18.8	0.194	4.7	1126	55.2		60.8
12/02/1997	0640	18	56.3	47.3	15.8	14.8	90	22.4	23.2	83.0	9.8	6.6	1129	25.4		20.2	23.3	14.5	0.152	4.3	1130	61.2		35.4
13/02/1997	0640	19	68.2	56.4	17.2	16.4	92	22.6	23.5	82.0	6.5	4.4	1133	26.3		21.2	23.6	11.1	0.118	3.4	1134	60.6		36.9
14/02/1997	0600	20	63.7	54.8	18.4	15.4	73	21.0	21.6	82.0	7.1	4.8	1137	26.3		19.5	21.7	7.0	0.077	4.1	1138	59.8		61.5
15/02/1997	0650	21	55.1	49.4	17.8	13.9	65	18.9	19.6	82.0	9.0	6.0	1141	26.8		17.5	19.8	3.0	0.038	4.0	1142	69.1		68.8
	1500																	1.7	0.025	1.3	1145	71.0		
	2100																	0.0	0.015	1.7	1146	70.7		
16/02/1997	0650	22	63.8	56.2	15.8	14.8	90	19.5	20.2	83.0	7.9	5.3	1147	26.8			20.4	0.0	0.015	0.0	1148	64.1		52.9
	1500																	-1.0	0.009	1.0	1151	67.8		
17/2/97	0610	23	66.0	61.7	18.9	16.6	80	21.9	22.5	83.0	5.2	3.5	1152	28.5			22.7							41.4
End Run 10		CF pan ends 0610 February 17						Standard pan ends 1500 hrs Feb 16																
Run 11																								
17/02/1997	0700	0								82.0	0.0	0.0	1155	-10.8				100.0	1.000	0.0	1156	-11.1		
18/02/1997	0610	1	61.1	53.8	18.7	15.0	68	21.3	22.0	80.0	3.7	2.5	1157	-5.5		21.8	22.1	95.7	0.957	4.3	1158	-6.9		58.5
19/02/1997	0620	2	65.9	59.7	21.5	19.5	83	24.0	24.6	81.0	6.7	4.5	1161	-2.3		23.9	24.6	91.6	0.917	4.1	1162	-3.1		55.6
20/02/1997	0730	3	74.8	61.5	22.0	19.7	81	24.2	24.6	83.0	9.9	6.7	1165	1.2		23.9	24.6	88.2	0.883	3.4	1166	-0.5		35.1
21/02/1997	0600	4	70.4	61.2	18.8	17.8	91	21.1	21.5	81.0	2.4	1.6	1169	3.1		21.0	21.6	84.7	0.848	3.5	1170	0.4		27.7
22/02/1997	0700	5	66.4	60.0	21.0	17.3	69	21.2	21.7	80.0	4.2	2.8	1173	5.0		21.3	21.8	80.8	0.809	3.9	1174	4.0		57.1
23/02/1997	0700	6	50.0	54.8	22.5	18.3	66	21.8	22.5	81.0	9.9	6.7	1177	5.3		21.7	22.6	75.5	0.757	5.3	1178	5.5		90.3
24/02/1997	0630	7	73.4	75.3	21.9	20.9	92	22.2	22.5	81.0	4.9	3.3	1181	4.4		22.2	22.5	73.0	0.732	2.5	1182	3.7		98.6
25/02/1997	0730	8	68.9	73.1	27.6	23.6	72	26.0	26.2	81.0	2.6	1.7	1185	2.9		25.9	26.2	71.4	0.716	1.6	1186	8.8		29.7
26/02/1997	0630	9	55.3	63.4	30.5	22.9	53	27.2	27.5	78.0	1.9	1.3	1189	6.9		27.2	27.5	67.9	0.682	3.5	1190	10.2		30.7
27/02/1997	0700	10	58.5	58.6	25.6	24.0	87	27.5	28.0	82.0	15.2	10.2	1193	7.3		27.2	28.0	62.9	0.632	5.0	1194	12.6		32.1
28/02/1997	0610	11	65.7	58.5	20.5	15.5	60	22.9	23.8	82.0	8.3	5.6	1197	10.1		22.7	23.8	57.8	0.581	5.1	1198	16.1		65.1
01/03/1997	0750	12	37.5	39.0	19.1	14.5	60	18.1	18.9	83.0	14.6	9.8	1201	14.4		17.7	19.0	50.8	0.512	7.0	1202	23.6		109.2
02/03/1997	0650	13	61.8	60.4	17.7	16.7	91	20.7	21.2	83.0	4.5	3.0	1205	15.6		20.4	21.2	47.8	0.482	3.0	1206	26.2		38.0
03/03/1997	0640	14	46.1	52.4	20.4	15.9	62	20.8	21.6	81.0	5.0	3.4	1209	16.4		20.4	21.8	43.4	0.438	4.4	1210	29.6		75.3
04/03/1997	0610	15	39.3	41.6	17.6	13.2	60	19.4	20.4	83.0	14.8	9.9	1213			18.4	20.5	37.6	0.381	5.8	1214	35.2		112.9
05/03/1997	0620	16	47.3	42.2	13.7	11.9	82	21.0	21.8	84.0	9.6	6.5	1217	21.3		19.8	21.9	32.3	0.328	5.3	1218	41.5		56.0
06/03/1997	0620	17	51.0	47.1	17.9	14.6	71	21.6	22.3	81.0	2.3	1.5	1221	22.4		20.6	22.4	28.6	0.292	3.7	1222	48.2		33.1
07/03/1997	0620	18	57.1	51.5	16.4	12.4	62	19.3	20.0	81.0	10.2	6.9	1225	22.5		18.3	20.1	24.2	0.248	4.4	1226	52.0		81.4
08/03/1997	0720	19	51.0	48.1	18.2	13.4	58	18.4	19.1	81.0	7.9	5.3	1229	24.4		17.1	19.2	20.0	0.206	4.2	1230	57.6		82.0
09/03/1997	0715	20	54.2	53.1	20.9	16.3	62	20.5	21.2	81.0	5.1	3.4	1233	27.1		19.5	21.3	16.1	0.168	3.9	1234	62.1		66.4
10/03/1997	0730	21	62.8	59.8	20.8	19.2	88	21.2	21.6	82.0	8.6	5.8	1237	26.6		20.2	21.7	13.0	0.137	3.1	1238	60.5		35.5
11/03/1997	0645	22	67.7	60.6	16.9	14.7	79	19.6	20.3	81.0	5.3	3.6	1241	25.5		18.1	20.4	10.1	0.108	2.9	1242	75.8		64.6
12/03/1997	0600	23	50.6	47.1	11.2	17.3	58	17.3	18.0	81.0	7.5	5.0	1245	26.2		15.5	18.0	6.2	0.069	3.9	1246	65.3		75.0
13/03/1997	0730	24	42.4	42.4	18.0	12.6	52	17.3	18.0	81.0	7.5	5.0	1249	27.5		15.8	17.9	2.2	0.030	4.0	1250	73.1		73.0
	1720																	0.0	0.015	2.2	1253	78.3		
14/03/1997	0615	25	53.2	51.0	17.5	14.4	72	18.2	18.8	81.0	7.0	4.7	1254	26.7			18.9	-1.0	0.009		1256	53.1		59.4
	0900																	-1.2	0.008		1258	48.5		

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
	1200																Dry	-1.5	0.006	1.5	1259	46.6		
15/03/1997	0730	26	39.4	42.2	24.8	15.3	36	19.1	19.7	80.0	6.1	4.1	N/S											82.4
End Run 11																								
Run 12																								
15/03/1997	1000	0								82.0	0.0	0.0	1262	-11.2				75.0	1.000	0.0	1263	-11.2		
16/03/1997	0700	1	59.4	58.9	21.1	17.8	73	20.5	20.6	81.0	5.9	4.0	1264	-6.6		20.6	20.6	71.7	0.956	3.3	1265	-6.2		46.7
17/03/1997	0730	2	71.0	64.9	19.9	16.9	74	19.7	20.0	82.0	5.0	3.4	1268			19.5	20.0	69.0	0.921	2.7	1269			42.0
18/03/1997	0640	3	74.0	60.3	15.0	14.5	95	20.5	21.1	82.0	4.7	3.2	1272	-2.8		19.8	21.1	66.2	0.884	2.8	1273	-1.3		29.3
19/03/1997	0700	4	73.1	55.7	13.5	12.9	94	19.3	20.0	82.0	5.7	3.8	1276			18.5	20.0	63.0	0.842	3.2	1277			23.9
20/03/1997	0710	5	67.7	58.6	16.0	14.7	88	19.5	20.0	81.0	4.3	2.9	1280	4.5		18.9	19.8	60.2	0.805	2.8	1281	8.2		37.8
21/03/1997	0630	6	68.8	59.7	15.0	14.0	90	19.2	20.2	82.0	5.6	3.8	1284			19.2	20.2	57.2	0.765	3.0	1285			34.6
22/03/1997	0750	7	60.8	62.7	21.2	16.2	60	19.0	19.5	81.0	2.7	1.8	1288	7.8		18.7	19.5	53.8	0.720	3.4	1289	13.4		63.1
23/03/1997	0730	8	53.9	56.6	19.8	16.0	68	19.4	19.9	83.0	10.5	7.1	1292			18.9	19.9	50.0	0.670	3.8	1293			82.3
24/03/1997	0650	9	57.9	58.3	18.3	15.2	73	19.8	20.4	82.0	5.1	3.4	1296	12.8		19.2	20.3	46.6	0.625	3.4	1297	18.0		52.9
25/03/1997	0615	10	72.6	61.8	15.0	14.5	95	20.4	21.5	83.0	5.8	3.9	1300			19.8	21.4	44.0	0.591	2.6	1301			35.6
26/03/1997	0650	11	66.8	58.9	16.8	14.8	81	20.0	20.6	82.0	4.1	2.8	1304	13.0		19.1	20.5	40.8	0.549	3.2	1305	24.5		55.2
27/03/1997	0720	12	56.7	52.5	16.5	12.0	58	16.9	17.6	82.0	6.1	4.1	1308			15.9	17.6	38.2	0.514	2.6	1309			50.4
28/03/1997	0820	13	40.0	43.7	19.5	14.5	54	17.5	18.1	81.0	6.0	4.0	1312	16.2		17.0	18.2	33.5	0.452	4.7	1313	32.6		83.7
29/03/1997	0800	14	67.9	65.4	17.6	15.2	78	17.0	17.4	84.0	9.0	6.0	1316			16.6	17.4	31.2	0.422	2.3	1317			88.3
30/03/1997	0640	15	88.9	83.2	16.5	15.8	92	17.4	17.7	85.0	3.2	2.2	1320	15.5		16.8	17.7	30.5	0.413	0.7	1321	30.0		45.9
31/03/1997	0645	16	75.1	70.5	15.8	14.5	88	19.5	20.1	83.0	0.5	0.3	1324			18.4	20.1	28.9	0.392	1.6	1325			43.2
01/04/1997	0630	17	79.7	70.1	18.2	16.2	82	20.5	21.0	82.0	1.5	1.0	1328	18.1		19.5	21.0	27.2	0.369	1.7	1329	31.9		25.1
02/04/1997	0620	18	57.7	53.6	14.8	10.8	61	17.0	17.7	82.0	7.2	4.8	1332			15.3	17.8	24.3	0.331	2.9	1333			72.2
03/04/1997	0630	19	51.4	52.8	17.0	13.5	68	18.2	18.7	81.0	3.8	2.6	1336	18.5		17.9	18.7	20.2	0.277	4.1	1337	40.5		109.2
04/04/1997	0630	20	55.9	62.5	21.0	18.0	75	21.0	21.4	82.0	8.1	5.4	1340			20.2	21.5	18.0	0.248	2.2	1341			76.1
05/04/1997	0720	21	71.9	69.3	20.0	17.0	74	19.9	20.2	82.0	3.9	2.6	1344	20.6		19.3	20.4	15.7	0.218	2.3	1345	37.5		78.3
06/04/1997	0710	22	75.0	71.7	19.0	17.0	82	19.8	20.3	82.0	6.3	4.2	1348			19.2	20.4	13.2	0.185	2.5	1349			74.0
07/04/1997	0800	23	69.7	72.1	22.0	19.0	76	21.3	21.6	82.0	3.0	2.0	1352	16.7		20.9	21.7	11.5	0.162	1.7	1353	25.0		65.5
08/04/1997	0650	24	84.5	74.6	16.9	16.2	95	21.0	21.5	82.0	4.5	3.0	1356			20.4	21.6	10.0	0.142	1.5	1357			12.6
09/04/1997	0730	25	71.6	62.9	22.2	18.0	66	22.4	22.9	82.0	2.6	1.7	1360	15.6		21.5	23.0	7.8	0.113	2.2	1361	23.9		15.5
10/04/1997	0720	26	72.7	67.7	21.5	21.0	96	22.3	22.6	82.0	4.8	3.2	1364			21.6	22.6	5.6	0.084	2.2	1365			18.5
11/04/1997	0610	27	84.9	75.3	19.0	18.7	96	22.0	22.5	82.0	2.7	1.8	1368	16.7		21.0	22.5	4.5	0.070	1.1	1369	23.4		9.5
12/04/1997	0820	28	78.9	60.4	17.0	14.5	77	19.3	19.8	84.0	6.5	4.4	1372			17.6	19.9	2.0	0.037	2.5	1373	27.1		20.0
	1700																	1.0	0.028	1.0	1376	37.8		
13/04/1997	0750	29	68.8	54.7	16.7	14.5	80	19.0	19.6	82.0	2.9	1.9	1377	18.8			19.8	-0.5	0.015	1.5	1378	42.0		26.3
	1440																	-1.0	0.012	0.5	1381	52.8		
14/04/1997	0740	30	63.3	59.2	18.8	15.8	74	19.1	19.6	82.0	4.3	2.9	1382				19.8	Dry						70.6
End Run 12																								

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								Wind
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^2H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^2H	^{18}O	Wind
Run 13																								
14/04/1997	1000	0								82.0	0.0	0.0	1385	-13.6				75.0	1.000	0.0	1386	-13.9		
15/04/1997	0700	1	59.2	61.1	19.8	16.8	74	20.5	20.5	82.0	4.7	3.2	1387	-9.2		20.7	20.5	71.8	0.958	3.2	1388	-10.8		44.6
16/04/1997	0730	2	71.3	58.9	15.0	14.4	95	20.4	21.0	83.0	7.3	4.9	1391			20.0	21.0	68.6	0.916	3.2	1392			24.8
17/04/1997	0710	3	73.3	62.4	15.0	14.5	95	19.7	20.2	83.0	4.1	2.8	1395	-4.9		19.5	20.2	65.9	0.880	2.7	1396	-3.9		14.6
18/04/1997	0600	4	74.3	63.6	15.3	14.8	95	20.9	21.5	82.0	3.0	2.0	1399			20.7	21.5	63.7	0.851	2.2	1400			13.8
19/04/1997	0800	5	79.4	65.9	16.8	16.2	95	19.6	20.1	82.0	4.9	3.3	1403	-0.7		19.5	20.0	61.1	0.817	2.6	1404	1.8		17.4
20/04/1997	0710	6	83.2	64.6	14.9	14.4	95	19.8	20.4	83.0	4.0	2.7	1407			19.6	20.4	58.8	0.786	2.3	1408			14.1
21/04/1997	0700	7	85.0	69.8	15.4	14.8	95	20.1	20.6	82.0	2.3	1.5	1411	1.3		19.9	20.6	57.0	0.762	1.8	1412	5.1		12.9
22/04/1997	0740	8	79.5	56.2	10.9	10.2	95	16.5	17.2	84.0	7.4	5.0	1415			16.4	17.1	54.7	0.732	2.3	1416			8.0
23/04/1997	0730	9	77.5	59.0	10.5	9.9	94	16.0	16.6	83.0	1.6	1.1	1419	4.1		16.1	16.8	52.5	0.703	2.2	1420	10.6		10.5
24/04/1997	0610	10	73.9	62.1	13.8	12.0	82	17.0	17.5	82.0	1.7	1.1	1423			17.1	17.5	50.5	0.677	2.0	1424			17.7
25/04/1997	0800	11	75.1	62.1	15.8	14.2	85	17.7	18.3	83.0	5.4	3.6	1427	7.3		17.8	18.4	48.1	0.645	2.4	1428	14.3		18.5
26/04/1997	0740	12	67.2	67.9	22.4	20.9	87	21.3	21.4	81.0	1.0	0.7	1431			21.3	21.4	46.4	0.623	1.7	1432			5.7
27/04/1997	0800	13	76.8	72.9	20.0	16.2	68	19.9	20.2	81.0	1.1	0.7	1435	9.0		20.2	19.9	44.8	0.602	1.6	1436	19.6		14.9
28/04/1997	0700	14	60.5	56.0	18.8	14.0	59	17.2	17.4	81.0	4.1	2.8	1439			17.0	17.4	42.3	0.569	2.5	1440			36.1
29/04/1997	0650	15	58.4	59.5	18.5	14.5	65	17.6	17.9	81.0	2.5	1.7	1443	13.4		17.6	17.9	40.2	0.541	2.1	1444	25.2		17.3
30/04/1997	0700	16	78.0	75.2	16.5	15.5	90	17.0	17.1	81.0	4.6	3.1	1447			17.0	17.2	38.8	0.522	1.4	1448			17.8
01/05/1997	0650	17	86.6	81.9	16.1	15.6	95	17.7	18.0	82.0	2.4	1.6	1451	12.1		17.6	18.0	37.5	0.505	1.3	1452	24.3		28.0
02/05/1997	0610	18	75.5	55.9	9.0	8.5	94	15.7	16.4	84.0	5.8	3.9	1455			15.6	16.5	35.4	0.477	2.1	1456			9.2
03/05/1997	0840	19	74.8	65.8	16.2	15.5	95	17.4	17.6	83.0	1.2	0.8	1459	13.4		17.4	17.6	33.5	0.452	1.9	1460	30.2		11.8
04/05/1997	0815	20	70.7	57.1	12.2	9.4	70	14.1	14.8	83.0	4.0	2.7	1463			14.1	14.9	31.0	0.419	2.5	1464			21.7
05/05/1997	0710	21	72.9	54.5	9.5	9.0	94	13.8	14.4	85.0	5.6	3.8	1467	15.8		13.8	14.5	29.2	0.396	1.8	1468	36.7		18.8
06/05/1997	0800	22	59.1	57.4	12.5	8.0	53	12.5	12.9	82.0	1.3	0.9	1471			12.4	12.9	26.6	0.361	2.6	1472			43.7
07/05/1997	0750	23	57.2	46.2	12.0	8.0	57	11.5	12.0	84.0	7.1	4.8	1475	18.4		11.4	12.0	24.0	0.327	2.6	1476	44.9		44.2
08/05/1997	0730	24	47.2	42.9	10.5	8.0	71	13.1	13.7	81.0	1.5	1.0	1479			13.1	13.8	21.0	0.287	3.0	1480			51.2
09/05/1997	0650	25	48.7	46.6	11.0	8.0	66	12.5	12.9	82.0	7.4	5.0	1483	20.9		12.4	12.9	18.0	0.248	3.0	1484	56.4		59.4
10/05/1997	0815	26	47.8	53.2	15.0	10.5	57	12.3	12.5	82.0	2.4	1.6	1487			12.2	12.5	15.6	0.216	2.4	1488			77.0
11/05/1997	0800	27	55.6	61.9	14.7	12.2	75	13.6	13.9	82.0	6.2	4.2	1491	18.5		13.6	13.9	12.8	0.179	2.8	1492	42.4		96.0
12/05/1997	0820	28	74.0	75.0	15.0	13.0	80	13.7	13.9	83.0	3.7	2.5	1495			13.8	13.9	11.7	0.165	1.1	1496			67.8
13/05/1997	0750	29	83.7	87.8	16.5	15.0	85	15.2	15.2	83.0	1.4	0.9	1499	13.4		15.1	15.2	11.0	0.156	0.7	1500	15.6		48.6
14/05/1997	0640	30	79.3	69.4	12.0	11.7	97	16.7	17.1	82.0	1.7	1.1	1503			16.5	17.2	9.3	0.133	1.7	1504			22.7
15/05/1997	0750	31	73.4	68.6	17.2	15.2	81	18.1	18.5	81.0	1.8	1.2	1507	10.3		18.0	18.5	7.5	0.109	1.8	1508	3.6		29.4
16/05/1997	0610	32	83.1	72.0	11.8	11.2	95	16.5	17.2	83.0	4.1	2.8	1511			16.5	17.2	6.5	0.096	1.0	1512			5.7
17/05/1997	0750	33	75.5	69.3	18.1	16.2	82	18.7	19.0	82.0	1.5	1.0	1515	9.1		19.0	18.6	4.8	0.074	1.7	1516	8.8		11.3
18/05/1997	0815	34	76.5	79.8	19.1	18.5	95	19.5	19.6	81.0	0.8	0.5	1519			19.5	19.6	4.0	0.063	0.8	1520	3.6		29.5
19/05/1997	0730	35	83.9	69.5	10.9	10.2	94	15.4	15.9	84.0	6.4	4.3	1523	8.3		15.1	15.9	1.9	0.035	2.1	1524	7.6		28.2
	1500																	1.5	0.030	0.4	1527	3.4		
20/05/1997	0710	36	80.1	73.6	12.8	12.0	92	16.2	16.5	83.0	1.0	0.7	1528				16.5	0.5	0.024	1.0	1529	3.1		19.9
	1800																	-1.0	0.012	1.5	1532	17.4		
21/05/1997	0710	37	78.9	58.6	10.0	9.6	95	15.4	16.0	84.0	4.6	3.1	1533	8.5			16.0	-2.0	0.005	1.0	1534	28.1		14.4

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^2H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^2H	^{18}O	Wind
	1500																	Dry	0.000	0.5	1537	28.2		
End Run 13		CF pan ends at 0710, Std pan ends at 1500																						
Run 14																								
22/05/1997	0720	0	74.0	67.2	13.5	11.0	84	13.8	15.0	84.0	0.0	0.0	1538	-14.0		13.1	15.1	50.0	1.000	0.0	1539	-13.0		17.6
23/05/1997	0600	1	55.8	65.3	21.0	17.3	70	16.8	16.9	82.0	3.4	2.3	1542	-11.9		16.9	16.9	47.5	0.951	2.5	1543	-10.9		83.7
24/05/1997	0840	2	76.5	73.2	15.2	14.7	95	15.4	15.5	83.0	3.6	2.4	1546			15.4	15.5	46.1	0.923	1.4	1547			33.0
25/05/1997	0850	3	76.2	79.1	17.8	13.8	65	15.4	15.6	84.0	2.7	1.8	1550	-6.7		15.4	15.6	45.0	0.902	1.1	1551	-5.2		55.0
26/05/1997	0715	4	65.9	64.1	16.7	13.4	70	15.0	15.1	84.0	2.9	1.9	1554			15.0	15.1	43.2	0.866	1.8	1555			38.1
27/05/1997	0650	5	69.7	71.6	17.2	13.5	66	15.5	15.6	84.0	1.8	1.2	1558	-4.7		15.5	15.6	42.3	0.848	0.9	1559	1.5		36.4
28/05/1997	0740	6	86.6	73.8	10.5	10.2	96	16.1	16.7	84.0	2.7	1.8	1562			16.0	16.8	40.7	0.817	1.6	1563			19.8
29/05/1997	0740	7	83.5	61.6	9.2	8.9	96	14.9	15.5	84.0	2.9	1.9	1566	-2.7		14.6	15.6	38.4	0.772	2.3	1567	5.3		8.0
30/05/1997	0610	8	64.7	55.4	14.0	11.0	70	15.5	16.0	84.0	3.1	2.1	1570			15.4	15.9	36.5	0.734	1.9	1571			31.2
31/05/1997	0900	9	71.4	73.0	15.7	14.6	95	14.5	14.5	84.0	4.0	2.7	1574	1.2		14.5	14.5	34.7	0.699	1.8	1575	11.3		81.9
01/06/1997	0810	10	78.8	79.1	15.3	14.8	95	15.7	15.6	84.0	1.5	1.0	1578			15.6	15.7	33.7	0.679	1.0	1579			46.6
02/06/1997	1010	11	90.7	88.4	17.6	16.9	95	16.3	16.1	84.0	1.4	0.9	1582	0.3		16.3	16.3	32.9	0.663	0.8	1583	10.4		15.4
03/06/1997	0740	12	73.5	74.7	16.5	14.8	84	15.5	15.3	84.0	1.0	0.7	1586			15.2	15.4	31.8	0.642	1.1	1587			51.3
04/06/1997	0730	13	66.7	69.2	14.5	13.8	94	14.3	14.4	83.0	2.2	1.5	1590	2.9		14.3	14.4	30.1	0.608	1.7	1591	13.3		88.0
05/06/1997	0800	14	69.2	70.7	14.1	13.3	92	14.2	14.4	83.0	3.1	2.1	1594			14.2	14.4	28.6	0.579	1.5	1595			99.0
06/06/1997	0600	15	81.4	82.8	16.0	14.3	83	15.6	15.7	83.0	1.7	1.1	1598	3.8		15.5	15.6	28.0	0.567	0.6	1599	16.6		33.1
07/06/1997	0820	16	89.9	84.0	13.3	13.0	96	15.4	15.7	83.0	1.6	1.1	1602			15.1	15.7	27.2	0.551	0.8	1603			5.2
08/06/1997	0810	17	72.6	70.9	16.5	16.0	95	17.0	16.7	83.0	1.6	1.1	1606	6.5		16.6	17.0	25.8	0.523	1.4	1607	19.3		22.5
09/06/1997	0700	18	75.7	73.0	15.3	11.3	61	15.0	14.5	82.0	2.2	1.5	1610			14.4	15.0	24.2	0.492	1.6	1611			65.0
10/06/1997	0710	19	78.4	64.4	10.7	9.7	88	14.4	14.9	82.0	3.2	2.2	1614	5.3		13.9	14.9	22.9	0.466	1.3	1615	18.4		10.1
11/06/1997	0740	20	83.3	77.0	14.0	12.5	84	15.2	15.5	84.0	2.0	1.3	1618			14.9	15.4	21.9	0.447	1.0	1619			24.9
12/06/1997	0815	21	87.3	71.7	15.3	14.0	87	14.7	14.9	84.0	2.1	1.4	1622	6.8		14.6	14.9	20.7	0.423	1.2	1623	19.2		17.4
13/06/1997	0600	22	85.4	76.6	13.1	12.6	95	16.2	16.6	84.0	1.5	1.0	1626			16.0	16.6	19.7	0.403	1.0	1627			20.1
14/06/1997	0800	23	65.9	57.3	11.8	8.2	63	14.2	15.5	84.0	2.4	1.6	1630	7.3		14.1	15.5	17.7	0.364	2.0	1631	26.0		12.4
15/06/1997	0800	24	70.5	50.6	10.7	8.7	66	13.6	14.4	84.0	5.0	3.4	1634			13.2	14.4	15.5	0.321	2.2	1635			31.5
16/06/1997	0750	25	67.8	61.3	12.2	10.2	78	14.0	14.5	83.0	2.5	1.7	1638	9.5		13.9	14.5	13.8	0.287	1.7	1639	34.1		33.8
17/06/1997	0750	26	75.3	67.7	15.0	11.5	66	14.3	14.6	83.0	2.5	1.7	1642			14.1	14.7	12.1	0.254	1.7	1643			13.7
18/06/1997	0640	27	56.1	57.9	16.8	11.5	53	14.5	14.9	82.0	2.8	1.9	1646	11.7		14.4	14.9	10.2	0.216	1.9	1647	41.4		43.7
19/06/1997	0650	28	66.1	69.0	14.5	14.2	96	16.0	16.1	83.0	4.1	2.8	1650			15.7	16.2	8.3	0.179	1.9	1651			34.4
20/06/1997	0550	29	66.4	69.2	16.4	13.0	67	14.5	14.6	83.0	3.5	2.4	1654	14.0		14.5	14.6	6.8	0.149	1.5	1655	46.5		63.4
21/06/1997	0850	30	82.5	77.4	13.3	12.9	95	14.8	15.1	83.0	2.5	1.7	1658			14.6	15.1	5.6	0.126	1.2	1659			31.3
22/06/1997	0800	31	84.2	72.1	12.3	11.7	94	14.7	15.2	83.0	1.7	1.1	1662	14.7		14.5	15.2	4.2	0.098	1.4	1663	37.0		8.6
23/06/1997	0740	32	84.5	77.8	13.0	12.5	95	15.6	16.0	83.0	1.5	1.0	1666			15.3	16.0	3.8	0.090	0.4	1667	31.1		13.1
24/06/1997	0800	33	83.2	66.5	11.4	9.6	80	13.9	14.5	83.0	2.6	1.7	1670	13.5		13.5	14.6	2.2	0.059	1.6	1671	33.2		17.7
25/06/1997	0810	34	77.3	72.1	10.4	10.1	95	14.5	14.9	83.0	2.2	1.5	1674			14.1	14.9	0.8	0.039	1.4	1675	39.1		24.7
26/06/1997	0750	35	82.5	69.2	8.4	8.0	95	13.7	14.4	83.0	2.1	1.4	1678	16.2		N/R	14.4	0.0	0.029	0.8	1679	39.5		5.3
	1800																		0.023		1682	43.1		

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
27/06/1997	0600	36	82.5	69.7	9.1	9.0	98	14.2	14.7	83.0	1.9	1.3	1683			N/R	14.7	-1.0	0.017	1.0	1684	44.0		4.9
	1400																Dry	-2.0	0.007	1.0	1687	42.1		
28/06/1997	0815	37	82.1	74.9	12.9	12.2	92	15.3	15.6	83.0	2.0	1.3	1688	16.4			15.7							4.1
End Run 14																								
Run 15																								
28/06/1997	1000	0								83.0	0.0	0.0	1689	-13.5				50.0	1.000	0.0	1690	-13.7		
29/06/1997	0800	1	79.5	70.5	13.4	12.0	85	14.8	15.1	84.0	2.8	1.9	1693			14.6	15.1	48.9	0.978	1.1	1694			18.2
30/06/1997	0750	2	76.8	56.7	4.4	4.2	95	12.2	13.0	84.0	5.7	3.8	1697	-9.8		11.9	13.0	46.6	0.933	2.3	1698	-7.1		13.5
01/07/1997	0720	3	64.4	48.4	7.4	4.9	67	10.5	11.4	84.0	3.3	2.2	1701			10.6	11.4	44.9	0.900	1.7	1702			15.9
02/07/1997	0750	4	40.9	41.7	12.3	6.5	40	9.9	10.2	83.0	4.0	2.7	1705	-6.8		9.8	10.2	41.9	0.841	3.0	1706	-0.8		70.5
03/07/1997	0720	5	50.8	55.9	11.6	10.3	82	11.3	11.5	85.0	6.2	4.2	1709			11.3	11.5	39.5	0.793	2.4	1710			112.8
04/07/1997	0610	6	87.4	80.3	8.9	8.7	96	11.7	12.1	85.0	1.9	1.3	1713	-3.1		11.6	12.2	38.5	0.774	1.0	1714	1.9		14.0
05/07/1997	0855	7	83.3	83.0	15.3	12.7	74	13.9	14.1	85.0	1.0	0.7	1717			13.9	14.1	38.0	0.764	0.5	1718			32.1
06/07/1997	0810	8	84.2	83.4	13.7	13.3	95	14.5	14.7	84.0	1.4	0.9	1721	-1.9		14.4	14.7	37.1	0.746	0.9	1722	4.9		27.2
07/07/1997	0800	9	77.1	70.3	9.3	8.3	88	12.4	12.8	84.0	2.1	1.4	1725			12.4	12.8	35.5	0.714	1.6	1726			63.7
08/07/1997	0800	10	80.7	56.7	2.2	2.0	95	9.6	10.5	84.0	3.2	2.2	1729	-1.3		9.4	10.5	33.6	0.677	1.9	1730	7.9		16.8
09/07/1997	0750	11	79.4	61.4	6.5	6.3	95	10.5	11.2	85.0	2.0	1.3	1733			10.5	11.2	32.3	0.651	1.3	1734			7.7
10/07/1997	0830	12	79.5	58.8	4.2	4.0	96	9.6	10.4	84.0	2.6	1.7	1737	1.2		9.4	10.4	30.8	0.622	1.5	1738	13.0		18.5
11/07/1997	0610	13	80.1	54.9	1.4	1.2	96	9.5	10.5	84.0	2.5	1.7	1741			9.2	10.5	29.4	0.594	1.4	1742			8.0
12/07/1997	0825	14	76.1	56.5	8.5	5.5	64	9.0	9.7	84.0	2.5	1.7	1745	3.2		9.0	9.7	27.8	0.563	1.6	1746	18.0		11.2
13/07/1997	0840	15	71.3	78.1	14.5	14.0	95	12.4	12.3	84.0	2.0	1.3	1749			12.4	12.4	27.0	0.547	0.8	1750			42.3
14/07/1997	0800	16	87.9	81.3	3.9	3.7	95	10.0	10.8	84.0	0.7	0.5	1753	5.4		9.9	10.9	26.3	0.533	0.7	1754	18.8		36.4
15/07/1997	0740	17	76.4	54.3	2.1	1.8	95	9.1	10.1	84.0	2.8	1.9	1757			8.9	10.2	24.3	0.494	2.0	1758			13.9
16/07/1997	0810	18	64.3	54.8	7.2	5.2	61	10.0	10.5	83.0	2.4	1.6	1761	6.7		9.9	10.6	23.3	0.474	1.0	1762	27.1		35.7
17/07/1997	0810	19	66.4	50.2	4.0	3.5	92	9.0	9.9	83.0	3.6	2.4	1765			8.9	9.9	20.9	0.427	2.4	1766			29.0
18/07/1997	0610	20	69.4	51.2	2.0	2.0	100	9.4	10.2	84.0	2.9	1.9	1769	10.1		9.1	10.2	19.5	0.399	1.4	1770	38.1		22.0
19/07/1997	0850	21	72.9	55.7	7.3	6.7	92	9.5	10.2	84.0	2.7	1.8	1773			9.9	10.2	17.7	0.364	1.8	1774			8.3
20/07/1997	0800	22	73.6	56.6	5.2	4.5	95	9.5	10.2	84.0	2.3	1.5	1777	12.2		9.4	10.3	16.2	0.334	1.5	1778	44.5		9.1
21/07/1997	0740	23	70.5	53.0	4.0	3.5	92	9.8	10.5	83.0	2.7	1.8	1781			9.5	10.5	14.7	0.305	1.5	1782			12.6
22/07/1997	0815	24	55.9	46.2	4.8	3.8	86	9.5	10.3	83.0	3.4	2.3	1785	14.2		9.4	10.3	12.5	0.262	2.2	1786	56.4		21.9
23/07/1997	0740	25	47.3	42.2	10.5	5.4	45	11.0	11.6	82.0	2.9	1.9	1789			10.9	11.6	10.6	0.224	1.9	1790			25.7
24/07/1997	0610	26	61.4	62.8	13.5	11.5	79	13.3	13.6	82.0	3.0	2.0	1793	18.2		13.3	13.6	9.2	0.197	1.4	1794	70.6		35.7
25/07/1997	0610	27	78.6	76.8	9.3	9.0	95	12.5	12.9	82.0	2.5	1.7	1797			12.4	12.9	7.5	0.163	1.7	1798			93.7
26/07/1997	0800	28	81.7	77.6	15.2	13.2	80	13.9	14.1	83.0	1.7	1.1	1801	16.5		13.9	14.1	6.8	0.149	0.7	1802	43.8		23.2
27/07/1997	0810	29	75.2	77.8	14.1	13.4	93	14.4	14.5	82.0	1.4	0.9	1805			14.3	14.5	6.0	0.134	0.8	1806	34.6		69.3
28/07/1997	0740	30	83.5	67.3	8.5	8.1	93	13.2	13.9	83.0	2.8	1.9	1809	16.8		13.0	13.9	4.3	0.100	1.7	1810	36.8		7.9
29/07/1997	0710	31	84.1	71.4	9.5	9.2	92	14.2	14.9	83.0	1.8	1.2	1813			14.0	14.9	3.2	0.079	1.1	1814	35.1		9.5
30/07/1997	1200	32	82.5	67.6	21.0	14.8	51	16.5	16.6	83.0	2.5	1.7	1817	17.8		16.5	16.6	2.0	0.055	1.2	1818	36.6		18.9
31/07/1997	0915	33	75.6	64.7	16.2	12.8	67	14.8	15.1	82.0	2.2	1.5	1821	17.8		15.2	15.1	0.7	0.038	1.3	1822	43.4		8.4
	1800																	N/R	0.029		1825	47.9		

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
01/08/1997	0940	34	77.2	64.9	13.9	11.9	79	15.7	15.5	83.0	2.8	1.9	1826	17.9			15.5	-1.0	0.017	1.7	1827	46.8		10.7
	2030												1830					Dry	0.001		1830	49.6		
02/08/1997	1310	35	82.0	61.4	18.9	14.6	63	17.3	17.4	83.0	3.1	2.1	1831	18.6			17.4							17.7
End Run 15																								
Run 16																								
03/08/1997	0800	0	77.8	70.7	12.8	10.8	79		14.1	85.0	0.0	0.0	1834	-14.1			14.1	50.0	1.000	0.0	1835	-13.9		4.7
04/08/1997	0940	1	79.2	82.0	16.2	15.8	96	14.7	14.7	84.0	1.4	0.9	1838			14.8	14.7	49.0	0.980	1.0	1839			96.8
05/08/1997	0810	2	77.7	72.6	14.2	10.0	59	14.5	15.3	84.0	1.5	1.0	1842	-9.6		14.5	15.3	47.5	0.951	1.5	1843	-7.9		51.9
06/08/1997	0715	3	70.3	67.2	15.4	13.1	82	14.5	14.6	83.0	2.8	1.9	1846			14.4	14.6	46.2	0.925	1.3	1847			79.0
07/08/1997	0940	4	79.9	73.9	15.7	14.1	84	15.5	16.0	84.0	2.6	1.7	1850	-6.1		15.8	16.1	44.5	0.892	1.7	1851	-2.7		41.1
08/08/1997	0600	5	87.5	74.3	13.0	12.7	96	15.9	15.9	84.0	1.6	1.1	1854			15.9	15.9	43.5	0.872	1.0	1855			10.8
09/08/1997	0750	6	72.8	69.5	14.2	13.8	96	14.7	15.1	83.0	2.8	1.9	1858	-5.1		14.7	15.1	41.9	0.841	1.6	1859	1.0		50.2
10/08/1997	0820	7	83.2	66.5	7.4	7.1	96	11.9	12.7	83.0	2.8	1.9	1862			11.9	12.8	40.0	0.803	1.9	1863			45.8
11/08/1997	0720	8	74.9	51.3	3.0	2.8	96	10.9	12.1	84.0	3.3	2.2	1866	-1.1		10.9	12.1	38.1	0.766	1.9	1867	6.9		19.9
12/08/1997	0720	9	76.9	59.1	5.5	5.2	96	11.4	12.5	84.0	2.2	1.5	1870			11.6	12.6	36.5	0.734	1.6	1871			11.4
13/08/1997	0730	10	74.0	56.5	6.0	5.4	92	11.7	12.7	83.0	2.7	1.8	1874	-0.2		11.5	12.8	34.9	0.703	1.6	1875	12.2		16.3
14/08/1997	0730	11	69.6	69.5	13.9	12.7	88	14.4	14.9	83.0	2.2	1.5	1878			14.5	14.9	33.5	0.675	1.4	1879			44.0
15/08/1997	0610	12	77.2	77.7	16.2	12.0	61	15.6	16.1	83.0	2.0	1.3	1882	3.1		15.4	16.0	32.1	0.648	1.4	1883	15.3		84.9
16/08/1997	0900	13	77.6	63.1	12.7	8.7	59	14.0	14.9	83.0	3.8	2.6	1886			14.3	14.9	30.2	0.610	1.9	1887			52.2
17/08/1997	0830	14	68.0	49.9	11.0	7.7	63	12.6	13.8	83.0	4.0	2.7	1890	5.6		12.8	13.8	28.0	0.567	2.2	1891	23.3		19.8
18/08/1997	0800	15	71.3	51.0	8.3	6.8	81	12.1	13.2	83.0	3.5	2.4	1894			12.0	13.2	25.7	0.522	2.3	1895			18.6
19/08/1997	0740	16	67.4	53.8	10.0	7.2	67	12.7	13.7	83.0	2.6	1.7	1898	8.5		12.9	13.8	24.2	0.492	1.5	1899	32.0		14.4
20/08/1997	0730	17	70.4	52.6	6.2	5.4	88	12.2	13.3	83.0	3.6	2.4	1902			12.0	13.4	22.0	0.449	2.2	1903			17.5
21/08/1997	0730	18	72.9	56.4	7.0	6.5	93	12.8	13.9	83.0	2.8	1.9	1906	10.6		12.9	14.0	20.3	0.415	1.7	1907	39.3		13.4
22/08/1997	0610	19	76.4	63.4	6.8	6.4	94	14.2	15.1	83.0	2.1	1.4	1910			13.9	15.2	18.7	0.384	1.6	1911			13.3
23/08/1997	0800	20	76.1	62.0	11.9	9.4	73	13.8	14.6	83.0	3.1	2.1	1914	12.3		13.8	14.7	16.9	0.348	1.8	1915	42.6		23.8
24/08/1997	0750	21	63.2	47.2	7.7	6.9	89	12.4	13.5	83.0	4.4	3.0	1918			12.4	13.6	14.3	0.297	2.6	1919			30.8
25/08/1997	0830	22	56.7	51.6	12.6	9.0	63	12.9	14.0	83.0	3.5	2.4	1922	15.3		13.0	14.1	12.0	0.252	2.3	1923	54.4		46.8
26/08/1997	0750	23	41.7	45.5	15.5	10.5	52	13.9	14.6	83.0	5.7	3.8	1926			13.9	14.7	8.6	0.185	3.4	1927			89.6
27/08/1997	0710	24	60.8	67.7	16.5	13.5	72	15.4	15.6	83.0	4.1	2.8	1930	18.7		15.3	15.6	6.8	0.149	1.8	1931	68.6		63.1
28/08/1997	0800	25	75.6	67.9	12.9	11.4	84	15.2	15.9	83.0	3.0	2.0	1934			15.0	16.1	5.0	0.114	1.8	1935	56.2		51.9
29/08/1997	0600	26	79.7	59.7	7.7	7.2	94	13.4	14.4	83.0	3.4	2.3	1938	19.1		13.5	14.5	3.0	0.075	2.0	1939	49.8		48.2
30/08/1997	0840	27	80.2	64.5	12.6	9.2	64	13.1	13.9	83.0	2.7	1.8	1942			13.0	14.0	1.8	0.051	1.2	1943	44.8		21.6
31/08/1997	0800	28	71.1	54.5	9.5	8.5	88	13.2	14.4	83.0	3.3	2.2	1946	19.4		N/R	14.6	-0.1	0.028	1.9	1947	61.4		18.9
	1700																	-2.0	0.007	1.9	1950	76.2		
01/09/1997	0720	29	68.5	50.7	9.8	8.4	83	13.8	14.9	83.0	3.3	2.2	1951			N/R	15.1	Dry		1.0	N/S			17.3
02/09/1997	0800	30	66.7	63.0	12.3	9.8	73	12.2	12.8	83.0	2.4	1.6	1954	21.6			12.9							75.5
03/09/1997	0700	31	78.3	66.9	12.2	10.5	81	13.4	14.2	83.0	3.1	2.1	1957	22.6		N/R	14.3	Pan moist from possible hygrscopic effect of salt crust						34.5
04/09/1997	0700	32	75.9	58.9	6.8	6.4	94	13.1	14.2	83.0	2.7	1.8	1960	21.3			14.4							26.7
05/09/1997	0600	33	60.4	60.9	16.0	13.2	73	15.7	16.3	83.0	2.3	1.5	1963	21.4			16.4							41.4

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
06/09/1997	0910	34	83.6	77.1	14.8	11.8	71	14.6	15.4	83.0	2.8	1.9	1966	19.2			15.6							80.7
End Run 16																								
Run 17																								
06/09/1997	1000	0								83.0	0.0	0.0	1969	-13.6				100.0	1.000	0.0	1970	-13.9		
07/09/1997	0820	1	65.5	60.1	14.2	13.9	96	15.0	15.6	84.0	3.4	2.3	1971			15.2	15.7	97.7	0.977	2.3	1972			59.2
08/09/1997	0710	2	81.8	70.9	14.0	13.5	95	15.7	16.2	84.0	2.1	1.4	1975	-11.3		15.9	16.4	96.1	0.961	1.6	1976	-10.3		20.1
09/09/1997	0730	3	79.9	70.3	11.3	10.9	96	15.8	16.8	83.0	2.4	1.6	1979			16.1	17.0	94.3	0.943	1.8	1980			40.4
10/09/1997	0645	4	78.2	59.1	10.5	8.7	79	14.2	15.4	84.0	3.0	2.0	1983	-7.5		14.5	15.6	92.8	0.929	1.5	1984	-7.6		31.5
11/09/1997	0700	5	71.8	57.7	7.8	7.4	95	14.5	15.6	84.0	3.9	2.6	1987			14.9	15.9	89.9	0.900	2.9	1988			45.6
12/09/1997	0630	6	76.8	72.5	9.9	9.4	95	12.8	14.6	84.0	2.4	1.6	1991	-5.7		12.8	14.9	88.5	0.886	1.4	1992	-5.4		33.9
13/09/1997	0940	7	76.6	63.3	15.2	12.5	73	16.5	17.3	84.0	3.5	2.4	1995			16.2	16.5	86.3	0.864	2.2	1996			48.0
14/09/1997	0730	8	79.4	64.5	13.9	11.9	79	16.4	17.2	84.0	2.9	1.9	1999	-1.0		16.5	17.4	84.5	0.846	1.8	2000	-1.1		25.8
15/09/1997	0710	9	71.6	60.3	14.6	12.0	74	16.6	17.5	83.0	3.6	2.4	2003			16.8	17.6	82.0	0.821	2.5	2004			30.3
16/09/1997	0710	10	60.4	57.8	12.5	11.9	92	17.5	18.5	83.0	4.7	3.2	2007	2.7		17.6	18.7	79.5	0.797	2.5	2008	3.7		58.3
17/09/1997	0650	11	79.1	64.0	12.3	11.8	94	18.3	19.2	83.0	3.7	2.5	2011			18.1	19.3	77.5	0.777	2.0	2012			23.8
18/09/1997	0610	12	81.1	63.4	14.5	14.2	96	19.0	19.9	83.0	3.5	2.4	2015	6.3		19.0	19.9	75.0	0.752	2.5	2016	7.5		23.6
19/09/1997	0610	13	85.5	66.3	13.0	12.5	95	19.4	20.3	83.0	3.4	2.3	2019			19.2	20.5	72.6	0.728	2.4	2020			14.6
20/09/1997	0700	14	77.8	60.3	13.5	12.5	89	18.9	20.0	83.0	4.0	2.7	2023	9.2		18.9	20.1	70.2	0.704	2.4	2024	10.2		21.3
21/09/1997	0715	15	72.2	58.2	15.0	13.9	89	19.2	20.2	83.0	4.3	2.9	2027			19.2	20.3	67.4	0.677	2.8	2028			21.9
22/09/1997	0750	16	77.7	61.3	15.1	13.0	79	18.7	19.8	83.0	4.2	2.8	2031	9.9		18.8	19.9	65.0	0.653	2.4	2032	15.3		29.3
23/09/1997	0650	17	79.5	58.1	12.5	11.9	94	18.6	19.8	83.0	4.5	3.0	2035			18.4	20.0	62.3	0.626	2.7	2036			21.3
24/09/1997	0600	18	73.3	63.1	16.5	14.4	81	19.9	21.0	82.0	3.8	2.6	2039	12.7		19.7	21.1	59.8	0.601	2.5	2040	20.1		35.3
25/09/1997	0610	19	69.0	46.1	11.0	9.2	79	17.7	19.1	82.0	6.9	4.6	2043			17.9	19.3	55.6	0.559	4.2	2044			43.8
26/09/1997	0610	20	70.8	53.7	12.4	11.9	94	18.0	19.0	83.0	5.6	3.8	2047	15.4		18.0	19.0	52.9	0.533	2.7	2048	26.1		26.7
27/09/1997	0840	21	77.4	57.1	15.8	12.8	71	17.1	18.3	83.0	3.5	2.4	2051			16.9	18.4	50.3	0.507	2.6	2052			24.5
28/09/1997	0730	22	76.6	57.4	13.1	12.2	89	17.7	18.7	83.0	3.8	2.6	2055	16.6		17.4	18.9	48.0	0.484	2.3	2056	30.3		18.1
29/09/1997	0730	23	70.5	56.6	15.2	14.1	89	18.2	19.3	83.0	4.1	2.8	2059			17.7	19.4	45.6	0.460	2.4	2060			21.4
30/09/1997	0600	24	78.1	62.0	13.9	13.3	94	20.1	20.9	83.0	3.8	2.6	2063	16.4		20.6	21.1	43.2	0.436	2.4	2064	32.7		22.7
01/10/1997	0600	25	71.0	59.4	15.3	13.4	81	19.9	21.0	83.0	4.5	3.0	2067			19.8	21.1	39.9	0.404	3.3	2068			46.9
02/10/1997	0600	26	68.2	49.4	8.5	8.0	94	17.0	18.2	84.0	5.6	3.8	2071	18.1		16.4	18.3	37.8	0.383	2.1	2072	37.5		31.6
03/10/1997	0610	27	61.9	44.7	7.8	7.4	94	17.2	18.4	83.0	5.8	3.9	2075			16.4	18.6	33.5	0.340	4.3	2076			35.2
04/10/1997	0640	28	68.2	55.9	14.6	12.9	82	18.4	19.7	83.0	4.7	3.2	2079	20.4		18.4	19.8	30.6	0.311	2.9	2080	44.0		39.5
05/10/1997	0745	29	58.8	51.9	15.0	11.1	61	17.0	18.5	83.0	7.2	4.8	2083			16.4	18.7	28.0	0.286	2.6	2084			96.6
06/10/1997	0730	30	35.6	36.3	19.3	10.9	32	17.8	19.0	83.0	8.3	5.6	2087	23.7		16.9	19.1	22.0	0.226	6.0	2088	55.3		89.3
07/10/1997	0600	31	60.8	54.7	15.2	14.6	94	19.8	20.4	83.0	6.5	4.4	2091			20.5	20.0	19.2	0.198	2.8	2092			40.9
08/10/1997	0600	32	77.9	66.6	17.0	16.6	96	21.1	21.6	83.0	4.0	2.7	2095	23.3		21.1	21.7	16.7	0.174	2.5	2096	56.2		32.7
09/10/1997	0615	33	75.7	63.6	14.9	11.4	66	17.9	18.9	83.0	4.2	2.8	2099			17.9	19.0	13.3	0.140	3.4	2100			89.6
10/10/1997	0610	34	66.2	58.5	15.9	13.9	81	17.3	17.9	83.0	5.5	3.7	2103	24.4		17.3	17.9	10.6	0.113	2.7	2104	52.6		118.9
11/10/1997	0540	35	57.9	50.2	13.3	10.3	69	17.5	18.4	83.0	4.9	3.3	2107			17.5	18.5	6.9	0.076	3.7	2108	61.5		68.2
12/10/1997	0730	36	69.4	54.8	17.1	14.0	71	19.2	20.0	83.0	4.6	3.1	2111	24.8		19.2	20.1	4.2	0.049	2.7	2112	71.2		24.4

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
13/10/1997	0600	37	75.1	57.6	11.0	10.8	98	19.8	20.9	83.0	4.2	2.8	2115			19.6	21.0	1.3	0.021	2.9	2116	70.9		26.6
	2000																	-1.0	0.009	2.3	2119	67.2		
14/10/1997	0600	38	73.9	57.4	12.9	10.8	78	19.2	20.3	83.0	4.7	3.2	2120	25.7			21.0	-2.0	0.003	1.0	2121	66.0		39.6
	1000																	-2.5	0.001	0.5	2124	66.3		
	1200																	Dry	0.000		2125	68.1		
15/10/1997	0600	39	69.7	52.7	12.3	11.4	89	19.7	20.8	83.0	5.7	3.8	2126	26.0			21.0	N/S		N/S	N/S			42.6
16/10/1997	0600	40	66.7	50.0	10.2	9.4	90	18.6	19.7	83.0	6.1	4.1	2129	27.5			20.0	N/S		N/S	N/S			47.9
17/10/1997	0610	41	62.8	49.0	13.9	10.8	70	18.0	19.3	83.0	6.1	4.1	2132	28.2			19.4	N/S		N/S	N/S			61.9
18/10/1997	0650	42	43.5	38.1	9.5	13.0	64	16.9	18.3	83.0	8.6	5.8	2135	27.4			18.4	N/S		N/S	N/S			92.4
End Run 17																								
Run 18																								
18/10/1997	0930	0								83.0	0.0	0.0	2138	-14.7				150.0	1.000	0.0	2139	-13.3		
19/10/1997	0650	1	39.0	35.4	14.2	9.9	58	17.7	19.0	83.0	8.0	5.4	2140	-8.3		17.8	19.3	145.8	0.972	4.2	2141	-10.0		75.5
20/10/1997	0600	2	28.2	30.0	17.4	10.3	39	18.3	19.4	82.0	9.5	6.4	2144	-2.4		18.2	19.6	139.3	0.929	6.5	2145	-7.3		98.5
21/10/1997	0600	3	39.8	43.5	19.8	15.1	61	21.0	21.6	82.0	8.2	5.5	2148			21.0	21.7	134.3	0.896	5.0	2149			68.8
22/10/1997	0600	4	50.4	44.2	14.8	13.5	87	22.1	23.0	82.0	7.4	5.0	2152	4.7		22.1	23.2	129.5	0.864	4.8	2153	-1.0		39.6
23/10/1997	0610	5	61.5	54.7	16.9	16.5	96	23.1	23.9	82.0	5.8	3.9	2156			23.2	24.1	125.6	0.838	3.9	2157			20.5
24/10/1997	0620	6	73.6	56.5	16.8	14.0	75	21.9	23.0	82.0	6.3	4.2	2160	9.5		22.1	23.3	121.7	0.812	3.9	2161	3.9		47.8
25/10/1997	0630	7	74.1	54.6	14.4	13.8	94	19.3	20.2	82.0	6.1	4.1	2164			19.3	20.4	118.1	0.788	3.6	2165			31.1
26/10/1997	0610	8	68.0	47.3	9.8	9.5	96	19.4	20.5	82.0	5.5	3.7	2168	12.6		19.4	20.8	114.2	0.763	3.9	2169	7.0		23.6
27/10/1997	0600	9	69.5	49.8	13.1	12.3	92	20.5	21.6	82.0	5.5	3.7	2172			20.7	21.8	110.4	0.737	3.8	2173			23.0
28/10/1997	0600	10	72.0	56.5	15.2	14.9	97	21.5	22.3	82.0	5.4	3.6	2176	15.1		21.7	22.5	107.0	0.715	3.4	2177	11.1		31.0
29/10/1997	0610	11	60.0	45.1	14.6	11.2	67	19.1	20.2	82.0	7.8	5.2	2180			19.4	20.4	102.1	0.682	4.9	2181			56.0
30/10/1997	0610	12	51.4	38.5	10.0	7.3	69	15.4	16.7	82.0	9.1	6.1	2184	18.4		15.5	17.0	96.2	0.643	5.9	2185	17.3		78.2
31/10/1997	0610	13	39.7	31.4	12.0	7.2	50	17.2	18.3	82.0	7.8	5.2	2188			17.3	18.6	91.8	0.614	4.4	2189			62.7
01/11/1997	0615	14	57.2	43.5	11.7	10.4	86	17.9	18.9	82.0	7.8	5.2	2192	24.4		17.9	19.2	87.5	0.586	4.3	2193	25.1		51.6
02/11/1997	0630	15	59.2	50.6	15.8	12.0	64	18.8	19.9	82.0	6.2	4.2	2196			18.9	20.2	83.2	0.557	4.3	2197			65.2
03/11/1997	0550	16	44.7	42.2	18.5	11.5	42	21.4	22.3	82.0	7.6	5.1	2200	25.3		21.4	22.5	78.9	0.528	4.3	2201	30.8		56.0
04/11/1997	0600	17	58.4	51.0	19.5	17.5	83	22.0	22.6	82.0	9.2	6.2	2204	25.0		22.0	22.8	74.3	0.498	4.6	2205	33.6		52.4
05/11/1997	0600	18	72.2	57.8	14.7	12.9	83	19.4	20.2	82.0	5.3	3.6	2208	25.3		19.4	20.4	70.7	0.474	3.6	2209	34.7		43.1
06/11/1997	0615	19	58.4	47.3	12.6	9.5	68	17.6	18.7	82.0	7.3	4.9	2212			17.6	18.9	66.4	0.446	4.3	2213			67.0
07/11/1997	0610	20	46.0	37.6	13.4	8.9	56	17.5	18.9	82.0	8.7	5.8	2216	29.2		17.4	19.2	61.2	0.411	5.2	2217	42.3		91.1
08/11/1997	0645	21	58.0	46.2	15.9	11.9	62	18.5	19.6	82.0	7.5	5.0	2220			18.4	19.8	57.2	0.385	4.0	2221			68.4
09/11/1997	0640	22	55.4	46.0	15.2	14.3	90	20.5	21.5	81.0	7.8	5.2	2224	31.6		20.5	21.7	52.4	0.353	4.8	2225	51.4		48.0
10/11/1997	0600	23	64.2	52.4	17.1	14.3	74	21.7	22.6	81.0	6.4	4.3	2228			21.9	22.8	48.6	0.328	3.8	2229			29.1
11/11/1997	0610	24	54.7	48.2	17.7	14.0	67	20.2	21.1	81.0	9.0	6.0	2232	30.7		20.0	21.3	43.3	0.292	5.3	2233	56.8		79.3
12/11/1997	0610	25	48.4	46.5	18.4	14.4	65	19.5	20.4	81.0	10.8	7.3	2236			19.5	20.6	37.2	0.252	6.1	2237			128.3
13/11/1997	0640	26	69.9	62.2	16.5	13.3	69	17.6	18.5	81.0	6.3	4.2	2240	30.3		17.7	18.6	34.5	0.234	2.7	2241	59.4		79.4
14/11/1997	0600	27	64.4	53.6	14.0	10.8	68	17.4	18.4	81.0	4.6	3.1	2245			17.3	18.6	31.0	0.211	3.5	2246			40.7
15/11/1997	0620	28	57.8	47.6	16.4	12.4	62	18.5	19.4	81.0	6.9	4.6	2250	30.0		18.7	19.5	27.1	0.185	3.9	2251	64.1		64.6

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^2H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^2H	^{18}O	Wind
16/11/1997	0650	29	50.6	42.6	14.2	10.4	62	16.8	18.0	81.0	9.5	6.4	2255			16.4	18.2	21.9	0.150	5.2	2256			88.2
17/11/1997	0600	30	44.1	38.0	13.4	9.8	63	17.3	18.4	81.0	8.9	6.0	2260	31.3		17.1	18.6	17.0	0.118	4.9	2261	79.3		82.6
18/11/1997	0550	31	57.8	43.2	14.8	9.5	50	19.2	20.2	81.0	7.9	5.3	2265			19.2	20.4	12.4	0.087	4.6	2266	84.9		54.2
19/11/1997	0600	32	57.0	42.7	11.2	10.6	93	19.2	20.2	81.0	8.2	5.5	2270	33.4		19.4	20.4	7.4	0.054	5.0	2271	96.2		38.1
20/11/1997	0550	33	65.3	49.8	17.7	14.9	77	21.0	21.7	81.0	6.6	4.4	2275			21.2	21.8	3.5	0.028	3.9	2276	98.5		27.1
	1700																	1.5	0.015	2.0	2280	92.9		
21/11/1997	0600	34	72.4	63.7	19.8	17.4	78	20.1	20.6	81.0	5.1	3.4	2281	33.6			20.6	0.5	0.012	1.0	2282	69.6		30.8
	1700																	0.2	0.011	0.3	2286	44.3		
22/11/1997	0640	35	78.8	70.8	17.7	15.9	84	18.8	19.3	81.0	3.6	2.4	2287	31.0			19.4	-1.0	0.006	1.2	2288	38.4		44.4
	1600																	-2.0	0.002	1.0	2292	39.4		
23/11/1997	0620	36	74.3	58.3	15.9	14.2	84	19.8	20.7	82.0	4.3	2.9	2293	31.8			20.9	Dry			N/S			25.3
24/11/1997	0550	37	74.9	55.3	14.6	13.8	92	20.6	21.5	82.0	5.7	3.8	2297	31.7			21.7							20.9
25/11/1997	0540	38	76.9	69.1	18.4	17.4	91	20.5	21.1	82.0	4.2	2.8	2301	29.7			21.3							22.5
26/11/1997	0610	39	83.1	68.5	18.4	17.2	90	21.8	22.4	82.0	3.5	2.4	2305	29.2			22.6							18.2
27/11/1997	0620	40	75.8	56.8	14.5	13.9	94	20.1	21.1	81.0	5.9	4.0	2309	29.5			21.4							26.2
28/11/1997	0600	41	70.9	57.6	19.5	17.6	82	22.0	22.7	82.0	6.2	4.2	2313	28.5			22.9							27.0
29/11/1997	0600	42	66.6	50.8	15.0	13.0	80	20.4	21.3	82.0	7.2	4.8	2317	29.1			21.5							42.1
End Run 18		CF pan ends 0600 hr																						
Runs 19/20																								
29/11/97	0900	0						20.2	22.1	83.0	0.0	0.0	2321	-14.5		20.6	22.4	200.0	1.000	0.0	2322	-13.2		
30/11/1997	0615	1	67.8	51.5	14.7	14.2	95	20.3	21.2	82.0	7.3	4.9	2323	-9.6		20.8	21.4	195.0	0.975	5.0	2324	-11.4		37.2
01/12/1997	0540	2	68.2	57.5	17.8	16.9	92	22.2	22.8	82.0	6.0	4.0	2328	-4.5		22.7	23.0	188.3	0.942	6.7	2329	-8.5		42.5
02/12/1997	0600	3	64.9	64.7	19.2	14.4	59	17.5	17.7	83.0	6.1	4.1	2333			18.4	18.2	183.8	0.919	4.5	2334			58.5
03/12/1997	0550	4	57.3	57.5	18.2	14.2	65	20.4	21.2	82.0	6.5	4.4	2338	2.4		20.7	21.1	178.9	0.895	4.9	2339	-4.1		64.6
04/12/1997	0540	5	68.2	58.6	17.2	15.4	83	20.4	21.4	82.0	6.7	4.5	2343			21.0	21.5	174.2	0.872	4.7	2344			51.4
05/12/1997	0550	6	63.5	55.7	19.0	15.0	65	20.5	21.2	82.0	7.5	5.0	2348	6.6		20.9	21.3	169.3	0.847	4.9	2349	-0.6		63.5
06/12/1997	0640	7	55.3	49.3	16.8	12.8	64	17.2	18.0	82.0	10.1	6.8	2353			17.6	18.2	162.5	0.813	6.8	2354			87.4
07/12/1997	0610	8	54.2	48.6	17.0	13.0	64	17.6	18.6	82.0	7.7	5.2	2358	12.2		18.2	18.8	157.2	0.787	5.3	2359	4.1		73.6
08/12/1997	0550	9	57.8	49.8	17.4	12.6	57	19.4	20.3	82.0	7.5	5.0	2363			20.0	20.4	152.2	0.762	5.0	2364			60.8
09/12/1997	0550	10	53.9	45.9	20.5	13.7	46	20.3	21.2	82.0	8.4	5.6	2368	17.1		20.8	21.3	146.4	0.733	5.8	2369	10.6		56.3
10/12/1997	0540	11	40.8	36.2	15.3	13.0	77	20.7	21.7	82.0	10.9	7.3	2373			21.2	21.9	139.1	0.697	7.3	2374			55.4
11/12/1997	0540	12	64.0	57.2	21.0	19.4	86	23.3	23.7	82.0	8.3	5.6	2378	21.1		23.5	23.8	134.1	0.672	5.0	2379	15.8		31.0
12/12/1997	0550	13	77.8	58.9	18.9	16.7	80	22.5	23.0	82.0	6.4	4.3	2383	22.5		22.7	23.1	129.8	0.650	4.3	2384			13.4
13/12/1997	0550	14	59.3	51.3	16.7	12.1	59	18.4	19.2	82.0	9.0	6.0	2388	23.4		18.7	19.3	124.0	0.621	5.8	2389	20.9		75.3
14/12/1997	0600	15	55.7	49.6	16.7	13.2	68	17.8	18.4	82.0	8.0	5.4	2393	25.4		18.4	18.6	118.8	0.596	5.2	2394			80.1
15/12/1997	0540	16	42.4	43.0	20.5	13.7	46	18.7	19.4	82.0	9.5	6.4	2397	26.8		19.4	19.4	113.3	0.568	5.5	2398	25.0		83.5
16/12/1997	0550	17	60.2	54.0	20.1	17.1	74	20.6	21.2	82.0	9.9	6.7	2401	27.7		20.7	21.2	108.0	0.542	5.3	2402			85.6
17/12/1997	0550	18	70.1	62.1	15.0	13.5	85	18.6	19.0	82.0	7.0	4.7	2405	26.9		18.8	19.0	103.9	0.521	4.1	2406	30.4		77.7
18/12/1997	0610	19	71.9	60.8	17.7	15.9	84	19.3	19.8	82.0	6.5	4.4	2409	27.4		19.5	19.9	100.2	0.503	3.7	2410			51.8
19/12/1997	0600	20	73.1	62.0	18.0	16.0	82	19.3	19.7	82.0	6.7	4.5	2413	27.2		19.5	19.8	96.1	0.483	4.1	2414	31.8		44.9

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
20/12/1997	0550	21	64.7	56.6	12.3	11.0	86	16.8	17.3	82.0	6.8	4.6	2417	28.1		17.0	17.3	92.3	0.464	3.8	2418			68.9
21/12/1997	0610	22	62.6	56.8	18.8	15.5	72	19.4	20.0	82.0	5.9	4.0	2421	29.4		19.4	20.0	89.0	0.447	3.3	2422	35.4		56.6
22/12/1997	0550	23	58.9	53.6	21.2	14.2	46	21.0	21.6	82.0	6.1	4.1	2425	28.7		21.0	21.8	85.0	0.427	4.0	2426			52.5
23/12/1997	0630	24	40.3	41.1	27.8	16.9	32	23.2	23.7	82.0	9.0	6.0	2429	30.7		23.0	23.8	79.5	0.400	5.5	2430	40.7		49.0
24/12/1997	0550	25	56.5	53.2	18.8	15.1	68	20.7	21.3	82.0	9.0	6.0	2433	31.2		20.8	21.4	74.2	0.373	5.3	2434			59.6
25/12/1997	0600	26	56.0	50.4	18.2	13.6	60	19.5	20.1	81.0	8.3	5.6	2437	28.4		19.5	20.2	69.2	0.349	5.0	2438	43.7		77.0
26/12/1997	0550	27	45.0	45.4	20.3	14.5	53	20.3	20.8	81.0	9.2	6.2	2441	29.9		20.2	21.0	64.2	0.324	5.0	2442			74.8
27/12/1997	0550	28	54.0	54.3	22.2	20.8	88	24.3	24.6	81.0	9.8	6.6	2445	31.0		24.2	24.5	59.3	0.299	4.9	2446	49.5		61.1
28/12/1997	0600	29	73.2	61.8	18.0	15.0	73	19.7	20.4	81.0	6.5	4.4	2449	29.9		19.5	20.5	55.7	0.281	3.6	2450			64.1
29/12/1997	0540	30	61.2	55.4	18.0	14.0	65	19.9	20.6	88.0	15.8	10.6	2453	28.5		19.6	20.8	51.3	0.259	4.4	2454	54.1		75.9
30/12/1997	0540	31	67.5	59.2	16.0	15.2	92	22.4	23.0	81.0	0.0	0.0	2457	30.7		22.0	23.0	47.4	0.240	3.9	2458			59.8
Float jammed on CF pan, pan flooded night of December 30/31, CF Run 20 terminated. STD pan Run 20 continues																								
Start Cons Vol Run 20																								
31/12/1997	0620	0	75.4	62.5	18.8	17.5	88		22.4	86.0	0.0	0.0	2461	-11.0		21.6	22.6	43.8	0.222	3.6	2462	56.2		33.7
01/01/1998	0550	1	65.3	57.7	19.1	14.6	61	20.8	21.4	86.0	11.5	7.7	2465	-7.1		20.5	21.5	40.0	0.203	3.8	2466			55.2
02/01/1998	0540	2	58.2	53.2	17.0	12.7	61	18.9	19.6	86.0	9.5	6.4	2469	-1.9		18.6	19.7	35.4	0.180	4.6	2470	57.6		79.8
03/01/1998	0620	3	61.2	51.9	17.8	12.8	56	19.2	19.9	83.0	2.7	1.8	2473	0.1		18.7	20.0	31.0	0.158	4.4	2474			63.6
04/01/1998	0610	4	63.7	56.8	18.8	14.2	61	19.8	20.4	82.0	7.2	4.8	2477	4.1		19.4	20.4	27.1	0.139	3.9	2478	62.6		53.1
05/01/1998	0540	5	50.2	54.2	20.8	15.8	60	21.7	22.3	81.0	6.8	4.6	2481			21.2	22.4	22.0	0.113	5.1	2482			69.8
06/01/1998	0550	6	43.1	47.8	23.4	16.8	52	23.9	24.3	84.0	15.6	10.5	2485	10.4		23.4	24.4	18.0	0.094	4.0	2486	72.6		56.3
07/01/1998	0540	7	30.2	37.4	25.0	14.2	29	24.2	24.6	81.0	8.0	5.4	2488			23.7	24.7	11.9	0.063	6.1	2489	88.8		47.0
08/01/1998	0530	8	56.6	52.9	22.6	20.9	86	25.0	25.3	81.0	11.6	7.8	2491	17.6		24.5	25.3	6.1	0.034	5.8	2492	95.1		42.4
09/01/1998	0550	9	69.5	62.8	21.4	16.7	62	22.1	22.5	81.0	7.1	4.8	2494			21.5	22.6	2.0	0.014	4.1	2495	68.2		59.0
	1800																	-1.0	0.004	3.0	2497	68.5		
10/01/1998	0550	10	69.2	61.1	20.9	17.5	72	22.1	22.4	82.0	12.0	8.1	2498	19.2			22.4	Dry	0.000	2.0	2499	36.4		44.5
11/01/1998	0540	11	75.9	68.0	19.5	18.9	94	21.8	22.1	81.0	5.5	3.7	2501											33.1
12/01/1998	0550	12	79.5	70.3	19.0	16.5	78	21.7	22.1	81.0	6.3	4.2	2503	20.3										52.4
13/01/1998	0550	13	74.9	65.1	21.1	18.8	81	22.5	22.7	81.0	5.5	3.7	2505											40.6
14/01/1998	0540	14	84.2	70.5	19.5	18.8	93	23.0	23.3	81.0	5.4	3.6	2507	22.6										26.9
15/01/1998	0530	15	84.7	68.3	19.1	18.6	95	23.5	23.8	81.0	6.3	4.2	2509											25.7
16/01/1998	0520	16	81.8	77.5	21.4	20.0	88	21.6	21.8	84.0	9.3	6.3	2511	19.0										30.8
17/01/1998	0540	17	63.6	67.2	14.8	11.4	67	13.9		82.0	2.4	1.6	2512	20.7										79.6
18/01/1998		18	56.8	70.2	Not read January 18 & 19						5.6	3.8												65.4
19/01/1998		19	56.6	73.1	Values are av of 3 days						5.6	3.8												65.4
20/01/1998	0550	20	58.5	73.7	19.4	15.9	70	19.7		83.0	5.7	3.8	2513	20.7										65.5
21/01/1998	0545	21	72.7	63.9	18.3	14.9	70	19.9	20.5	81.0	5.1	3.4	2514	22.6										72.3
22/01/1998	0600	22	62.7	53.9	11.9	9.9	78	16.6	16.9	84.0	13.0	8.7	2516	22.8										81.1
23/01/1998	0600	23	66.7	58.0	17.8	14.8	73	18.3	18.6	81.0	4.2	2.8	2518	24.8										57.5
24/01/1998	0540	24	69.7	63.0	18.7	14.2	61	19.5	19.8	81.0	6.8	4.6	2520	24.7										55.1
25/01/1998	0540	25	57.4	59.2	21.5	15.0	50	20.0	20.4	81.0	8.2	5.5	2522	24.9										57.2
26/01/1998	0600	26	49.8	51.4	18.5	13.0	53	22.6	23.2	80.0	9.0	6.0	2524	24.7										52.0

Date	Time	Day	Humidity		Psychrometer			Constant Volume Pan								Standard Pan								
			Air	Norm	Dry	Wet	RH	Pan T	Bath T	Level	Mano	Evap	Sample	^{2}H	^{18}O	Pan T	Bath T	Level	V/Vo	Evap	Sample	^{2}H	^{18}O	Wind
27/01/1998	0600	27	49.0	51.9	21.2	16.4	61	23.0	23.6	80.0	9.2	6.2	2526	26.0										48.8
28/01/1998	0610	28	52.3	53.9	19.5	15.3	64	21.6	22.1	80.0	11.6	7.8	2528	27.0										83.2
29/01/1998	0550	29	75.8	63.3	15.6	15.0	94	22.2	22.6	80.0	8.3	5.6	2530	26.7										45.1
30/01/1998	0600	30	63.7	55.7	14.4	13.0	84	21.7	22.4	80.0	9.7	6.5	2532	27.1										31.6
31/01/1998	0610	31	73.9	59.3	14.5	13.8	93	21.3	21.8	80.0	6.7	4.5	2534	28.4										37.2
01/02/1998	0550	32	80.1	65.6	14.5	14.0	95	20.2	20.7	80.0	7.4	5.0	2536	27.3										44.8
02/02/1998	0710	33	70.3	60.0	17.8	14.2	69	19.6	20.3	80.0	6.4	4.3	2537	27.4										65.3
03/02/1998	0740	34	68.4	57.0	20.5	14.9	56	20.9	21.4	80.0	7.2	4.8	2538	28.2										48.3
04/02/1998	0740	35	71.5	62.3	20.1	16.3	67	20.5	21.1	80.0	7.7	5.2	2539	27.2										61.0
05/02/1998	0720	36	59.0	54.5	17.9	13.1	58	17.9	18.5	80.0	8.5	5.7	2540	28.0										84.6
06/02/1998	0720	37	61.7	53.2	17.6	13.0	60	19.0	19.5	82.0	9.2	6.2	2541	27.9										58.1
07/02/1998	0730	38	57.6	53.3	16.7	11.5	54	16.8	17.3	85.0	12.0	8.1	2542	28.5										82.2
08/02/1998	0740	39	62.9	54.8	20.9	13.7	45	18.2	18.7	82.0	5.9	4.0	2543	29.1										64.1
09/02/1998	0740	40	38.0	41.6	25.7	14.7	27	21.7	22.3	81.0	8.5	5.7	2544	31.1										45.3
10/02/1998	0740	41	56.8	53.1	20.8	15.9	60	21.6	21.9	81.0	8.8	5.9	2545	32.0										28.2
11/02/1998	0730	42	73.5	63.0	19.5	17.2	80	19.2	19.4	81.0	7.6	5.1	2546	30.8										23.5
12/02/1998	0730	43	72.2	59.8	22.8	15.3	45	21.4	21.8	81.0	5.5	3.7	2547	31.6										39.0
13/02/1998	0740	44	61.0	54.9	22.5	19.0	72	21.5	21.8	81.0	6.5	4.4	2548	29.2										37.4
14/02/1998	0700	45	59.0	60.5	22.7	17.4	60	22.0	22.5	81.0	6.6	4.4	2549	30.8										35.6

Equipment shut down 0700 February 14 1998. Days of continuous operation 688

δ_A Air Vapour Sampling

Appendix 12.2

Date	Start	End	Time	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Comments
22/07/96	1120	1600	280	5.0	1.400	D	137.828	128.371	9.457					
						A	87.786	87.705	0.081	99.15	A 001	-89.9	-13.58	
29/07/96	1130	1430	180	4.0	0.720	D	133.758	128.371	5.387					
						A	87.728	87.705	0.023	99.57	A 002	-71.0	-10.78	
05/08/96	1130	1500	210	2.0	0.420	D	130.220	128.371	1.849					
						A	87.727	87.705	0.022	98.82	A 003	-105.7		Insufficient sample for oxygen
14/08/96	1145	1500	195	4.0	0.780	D	132.412	128.371	4.041					
						A	87.714	87.705	0.009	99.78	A 004	-82.2	-12.94	
19/08/96	1100	1500	240	5.0	1.200	D	134.256	128.371	5.885					
						A	87.749	87.705	0.044	99.26	A 005	-67.3	-10.78	
26/08/96	1110	1530	260	5.0	1.300	D	136.689	128.371	8.318					
						A	87.748	87.705	0.043	99.49	A 006	-86.4	-14.14	
02/09/96	1220	1630	250	4.0	1.000	D	135.004	128.371	6.633					
						A	87.725	87.705	0.020	99.70	A 007	-72.8	-11.55	
09/09/96	1140	1520	200	4.2	0.840	D	135.130	128.371	6.759					
						A	87.723	87.705	0.018	99.73	A 008	-77.1	-12.09	
16/09/96	1100	1510	250	5.0	1.250	D	137.523	128.371	9.152					
						A	87.799	87.705	0.094	98.98	A 009	-74.8		
22/09/96	1220	1600	220	4.0	0.880	D	132.863	128.371	4.492					
						A	87.725	87.705	0.020	99.56	A 010	-80.9	-12.30	
01/10/96	1220	1620	240	5.0	1.200	D	136.678	128.371	8.307					
						A	87.766	87.705	0.061	99.27	A 011	-79.9		
07/10/96	1150	1550	240	4.0	0.960	D	133.462	128.371	5.091					
						A	87.757	87.705	0.052	98.99	A 012	-68.8	-9.70	
14/10/96	1130	1530	240	4.0	0.960	D	137.155	128.371	8.784					
						A	87.748	87.705	0.043	99.51	A 013	-65.0		
21/10/96	1120	1520	240	4.0	0.960	D	138.725	128.371	10.354					Flow varied from 4.0 to 2.5
						A	87.725	87.705	0.020	99.81	A 014	-81.4	-11.80	
28/10/96	1045	1515	270	4.0	1.080	D	135.952	128.371	7.581					
						A	87.742	87.705	0.037	99.51	A 015	-64.3		
04/11/96	1030	1430	240	4.0	0.960	D	133.836	128.371	5.465					
						A	87.734	87.705	0.029	99.47	A 016	-83.0	-11.34	
11/11/96	1020	1600	340	4.0	1.360	D	134.465	128.371	6.094					
						A	87.761	87.705	0.056	99.09	A 017	-60.3		

Date	Start	End	Time	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Comments
18/11/96	1020	1540	320	5.0	1.600	D	139.736	128.371	11.365					
						A	87.736	87.705	0.031	99.73	A 018	-76.0	-11.23	
25/11/96	1035	1500	265	5.0	1.325	D	137.807	128.371	9.436					
						A	87.773	87.705	0.068	99.28	A 019	-79.4		
02/12/96	1020	1400	220	4.0	0.880	D	134.899	128.371	6.528					
						A	87.724	87.705	0.019	99.71	A 020	-86.6	-12.41	
09/12/96	1020	1500	280	4.0	1.120	D	138.368	128.371	9.997					
						A	87.735	87.705	0.030	99.70	A 021	-75.6		
16/12/96	1030	1400	210	4.0	0.840	D	134.110	128.371	5.739					
						A	87.741	87.705	0.036	99.38	A 022	-87.8	-12.20	
23/12/96	1110	1510	240	5.0	1.200	D	139.292	128.371	10.921					
						A	87.775	87.705	0.070	99.36	A 023	-87.7		
30/12/96	1015	1345	210	5.0	1.050	D	135.320	128.371	6.949					
						A	87.765	87.705	0.060	99.14	A 024	-80.2	-11.98	
06/01/97	1000	1400	240	5.0	1.200	D	135.224	128.371	6.853					
						A	87.800	87.705	0.095	98.63	A 025	-90.6		
13/01/97	1045	1430	225	5.0	1.125	D	138.003	128.371	9.632					
						A	87.829	87.705	0.124	98.73	A 026	-85.5	-12.33	
20/01/97	1115	1500	225	4.0	0.900	D	135.365	128.371	6.994					
						A	87.710	87.705	0.005	99.93	A 027	-96.7		
27/01/97	1010	1340	210	5.0	1.050	D	133.738	128.371	5.367					
						A	87.756	87.705	0.051	99.06	A 028	-91.8	-13.56	
03/02/97	1045	1400	195	5.0		D	139.784	128.371	11.413					Flow varied from 5.0 to 2.0
						A	87.754	87.705	0.049	99.57	A 029	-86.3		
10/02/97	1015	1400	225	5.0	1.125	D	137.613	128.371	9.242					
						A	87.797	87.705	0.092	99.01	A 030	-85.2	-12.83	
17/02/97	1045	1430	225	4.0	0.900	D	135.823	128.371	7.452					
						A	87.736	87.705	0.031	99.59	A 031	-84.4		
24/02/97	1130	1440	190	4.0	0.760	D	137.089	128.371	8.718					
						A	87.750	87.705	0.045	99.49	A 032	-93.1	-13.57	
03/03/97	0715	1130	255	4.0	1.020	D	134.455	128.371	6.084					
						A	87.755	87.705	0.050	99.18	A 033	-89.8		
10/03/97	0910	1240	210	4.0	0.840	D	136.860	128.371	8.489					
						A	87.736	87.705	0.031	99.64	A 034	-72.8	-9.91	
17/03/97	0920	1350	270	4.0	1.080	D	136.690	128.371	8.319					
						A	87.756	87.705	0.051	99.39	A 035	-81.7		

Date	Start	End	Time	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Comments
24/03/97	0850	1340	290	4.0	1.160	D	136.680	128.371	8.309					
						A	87.792	87.705	0.087	98.96	A 036	-82.1	-12.22	
31/03/97	1010	1410	240	4.0	0.960	D	137.426	128.371	9.055					
						A	87.865	87.705	0.160	98.26	A 037	-75.7		
07/04/97	0945	1415	270	4.0	1.080	D	138.535	128.371	10.164					
						A	87.770	87.705	0.065	99.36	A 038	-112.3	-15.91	
14/04/97	0920	1400	280	4.0	1.120	D	136.700	128.371	8.329					
						A	87.784	87.705	0.079	99.06	A 039	-80.0		
21/04/97	1030	1400	210	4.0	0.840	D	134.157	128.371	5.786					
						A	87.725	87.705	0.020	99.66	A 040	-90.0	-12.83	
28/04/97	1240	1600	200	4.0	0.800	D	133.311	128.371	4.940					
						A	87.739	87.705	0.034	99.32	A 041	-79.6		
05/05/97	0900	1330	270	4.0	1.080	D	135.203	128.371	6.832					
						A	87.758	87.705	0.053	99.23	A 042	-82.8	-12.72	
12/05/97	1220	1620	240	4.0	0.960	D	136.397	128.371	8.026					
						A	87.744	87.705	0.039	99.52	A 043	-121.4		
19/05/97	1040	1440	240	4.0	0.960	D	135.942	128.371	7.571					
						A	87.736	87.705	0.031	99.59	A 044	-116.6	-16.53	
26/05/97	0915	1330	255	4.0	1.020	D	135.368	128.371	6.997					
						A	87.732	87.705	0.027	99.62	A 045	-89.2		
02/06/97	1030	1600	330	4.0	N/N	D	137.831	128.371	9.460					Flow varied from 4.0 to 2.3
						A	87.744	87.705	0.039	99.59	A 046	-99.1	-14.00	
09/06/97	0910	1320	250	4.0	1.000	D	134.114	128.371	5.743					
						A	87.944	87.705	0.239	96.00	A 047	-90.7		
16/06/97	1000	1400	240	4.0	0.960	B	134.940	129.900	5.040					
						C	129.980	129.964	0.016	99.68	A 048	-90.3	-12.43	
21/06/97	2110	0040	210	4.0	0.840	B	135.500	129.900	5.600		A 049	-86.3		Concurrent with E 004
23/06/97	1100	1420	200	4.0	0.800	A	92.820	87.705	5.115		A 050	-90.1	-13.06	
26/06/97	1800	2130	210	4.0	0.840	B	136.920	129.900	7.020		A 051	-81.4		Concurrent with E 005
30/06/97	1000	1400	240	4.0	0.960	D	131.920	128.371	3.549					
						A	87.740	87.705	0.035	99.02	A 052	-96.9	-14.33	
07/07/97	1000	1400	240	5.0	1.200	D	134.280	128.371	5.909					
						A	87.840	87.705	0.135	97.77	A 053	-92.8		

Date	Start	End	Time	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Comments
	2000	2330	210	4.0	0.840	B	134.720	129.900	4.820		A 054	-89.3	-13.39	Concurrent with E 006
10/07/97	1800	2200	240	4.0	0.960	D	133.120	128.371	4.749		A 055	-102.3		Concurrent with E 007
14/07/97	1015	1415	240	4.0	0.960	D	132.840	128.371	4.469					
						A	87.750	87.705	0.045	99.00	A 056	-90.7	-14.25	
16/07/97	1745	2200	255	4.0	1.020	B	133.940	129.900	4.040		A 057	-75.2		Concurrent with E 008
17/07/97	1740	2040	180	4.0	0.720	B	133.470	129.900	3.570		A 058	-68.4	-8.92	Concurrent with E 009
21/07/97	0940	1420	280	4.0	1.120	D	132.320	128.371	3.949					
						A	87.750	87.705	0.045	98.87	A 059	-78.7		
22/07/97	0500	0725	145	4.0	0.580	B	132.200	129.900	2.300		A 060	-76.6	-9.27	Concurrent with E 010
28/07/97	1015	1415	240	4.0	0.960	D	134.960	128.371	6.589					
						A	87.720	87.705	0.015	99.77	A 061	-88.0		
02/08/97	1745	2000	135	4.0	0.540	B	134.000	129.900	4.100		A 062	-81.4	-10.19	Concurrent with E 011
04/08/97	1130	1515	225	2.5	0.562	D	132.880	128.371	4.509					
						A	87.690	87.705	-0.015	100.33	A 063	-91.8		
11/08/97	0940	1330	230	4.0	0.920	D	132.590	128.371	4.219					
						A	87.740	87.705	0.035	99.18	A 064	-96.1	-14.72	
	1745	1945	120	4.0	0.480	B	133.010	129.900	3.110		A 065	-91.5		Concurrent with E 012
18/08/97	1010	1410	240	4.0	0.960	D	132.170	128.371	3.799					Trap B broken, new dry weight: 124.87
						A	87.770	87.705	0.065	98.32	A 066	-86.5	-13.03	
	1745	1945	120	4.0	0.480	B	127.770	124.87	2.900		A 067	-79.1		Concurrent with E 013
23/08/97	0505	0700	110	4.0	0.440	B	127.150	124.58	2.570		A 068	-93.4	-13.31	Concurrent with E 014
25/08/97	1020	1420	240	4.0	0.960	D	132.830	128.44	4.390					
						A	87.760	87.72	0.040	99.10	A 069	-80.2		
30/08/97	1810	2000	110.0	4.0	0.440	B	127.510	124.58	2.930		A 070	-88.6	-12.79	Concurrent with E 015
01/09/97	0915	1415	300	4.0	1.200	D	137.300	128.44	8.860					
						A	87.790	87.72	0.070	99.22	A 071	-97.0		

Date	Start	End	Time	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Comments
08/09/97	0950	1350	240	4.0	0.960	D	135.460	128.44	7.020					
						A	87.760	87.72	0.040	99.43	A 072	-87.8	-12.70	
15/09/97	0920	1320	240	4.0	0.960	D	134.470	128.44	6.030					
						A	87.740	87.72	0.020	99.67	A 073	-82.2		
17/09/97	1830	2030	120	4.0	0.480	B	129.120	124.58	4.540		A 074	-78.8	-11.22	Concurrent with E 016
22/09/97	0950	1350	240	4.0	0.960	D	136.040	128.44	7.600					
						A	87.740	87.72	0.020	99.74	A 075	-79.7		
29/09/97	1000	1400	240	4.0	0.960	B	131.310	124.58	6.730					
						C	130.220	130.21	0.010	99.85	A 076	-90.2	-12.90	
04/10/97	0400	0600	120	4.0	0.480	B	128.340	124.58	3.760		A 077	-97.7		Concurrent with E 017
06/10/97	0810	1310	300	4.0	1.200	D	133.220	128.44	4.780		A 078	-89.4	-12.83	
	1500	1650	110	4.0	0.440	B	126.760	124.58	2.180		A 079	-85.7		
13/10/97	0500	0630	90	4.0	0.360	B	127.470	124.58	2.890		A 080	-90.5	-11.28	Concurrent with E 018
	0830	1230	240	4.0	0.960	D	135.470	128.44	7.030					
						A	87.750	87.72	0.030	99.58	A 081	-79.4		
19/10/97	0900	1300	240	4.0	0.960	D	132.300	128.44	3.860					
						A	87.730	87.72	0.010	99.74	A 082	-85.2	-12.71	
21/10/97	0615	0700	45	4.0	0.180	B	125.970	124.58	1.390		A 083	-70.2		Concurrent with E 019
26/10/97	0815	1245	270	4.0	1.080	D	134.640	128.44	6.200					
						A	87.730	87.72	0.010	99.84	A 084	-93.5	-14.02	
02/11/97	0720	1240	310	4.0	1.240	D	135.700	128.44	7.260					
						A	87.760	87.72	0.040	99.45	A 085	-89.1		
04/11/97	0630	0800	90	4.0	0.360	D	131.730	128.44	3.290		A 086	-72.6	-8.85	
07/11/97	0635	0800	85	4.0	0.340	D	129.990	128.44	1.550		A 087	-84.2		
09/11/97	0850	1250	240	4.0	0.960	B	129.830	124.58	5.250					
						A	87.750	87.72	0.030	99.43	A 088	-75.8	-11.61	Preceeded immediately by E 020
16/11/97	0745	1330	345	4.0	1.380	D	134.490	128.44	6.050					
						A	87.780	87.72	0.060	99.02	A 089	-107.8		
19/11/97	0620	0750	90	4.0	0.360	B	126.960	124.58	2.380		A 090	-79.2	-10.66	Concurrent with E 021
23/11/97	0645	0840	115	4.0	0.460	B	128.270	124.58	3.690		A 091	-88.9		
	0900	1300	240	4.0	0.960	D	136.980	128.44	8.540					
						A	87.750	87.72	0.030	99.65	A 092	-84.5	-12.18	
26/11/97	0650	0750	60	4.0	0.240	D	130.600	128.44	2.160		A 093	-78.3		
28/11/97	0640	0740	60	4.0	0.240	D	130.640	128.44	2.200		A 094	-77.4	-9.54	
30/11/97	0730	0850	80	4.0	0.320	D	131.250	128.44	2.810					
						A	87.730	87.72	0.010	99.65	A 095	-83.6		

Date	Start	End	Time	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Comments
	0910	1240	210	4.0	0.840	B	130.940	124.58	6.360		A 096	-78.4	-11.36	
05/12/97	0640	0740	60	4.0	0.240	D	131.340	128.44	2.900		A 097	-95.2		
07/12/97	0830	1230	240	4.0	0.960	D	133.980	128.44	5.540					
						A	87.730	87.72	0.010	99.82	A 098	-98.1	-13.45	
	1230	1330	60	4.0	0.240	B	126.650	124.58	2.070		A 099	-85.0		
11/12/97	0630	0800	90	4.0	0.360	B	128.220	124.58	3.640		A 100	-74.8	-9.62	
13/12/97	0650	0810	80	4.0	0.320	B	126.360	124.58	1.780		A 101	-89.4		
14/12/97	0700	1240	340	4.0	1.360	D	135.550	128.44	7.110					
						A	87.750	87.72	0.030	99.58	A 102	-93.4	-13.43	
16/12/97	0630	0750	80	4.0	0.320	D	131.340	128.44	2.900		A 103	-73.1		
21/12/97	0710	1200	290	4.0	1.160	D	137.220	128.44	8.780					
						A	87.750	87.72	0.030	99.66	A 104	-84.5	-11.56	
23/12/97	0715	0815	60	4.0	0.240	D	129.620	128.44	1.180		A 105	-79.3		
26/12/97	0650	0800	70	4.0	0.280	D	130.170	128.44	1.730		A 106	-91.3	-11.77	
28/12/97	0700	1240	340	4.0	1.360	D	139.550	128.44	11.110					
						A	87.760	87.72	0.040	99.64	A 107	-86.2		
04/01/98	0700	1220	320	4.0	1.280	D	138.090	128.44	9.650					
						A	87.790	87.72	0.070	99.28	A 108	-81.8		
										Averages		-85.2	-12.26	

δ_E Lake Vapour Sampling

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
05:09:96	0345	0630	165	No	75 at 5	0.74	D	132.844	128.371	4.473		E 001	-105.9	-16.23	Start 15 at 5	Pickup at East Lake rain gauge #2
					90 at 4		A	87.737	87.705	0.032	99.29				End 30 at 5	

Time	Air T	RH	Water T
0345	6.6	100	16.5
0400	6.5		
0415	6.1		
0430	5.8	100	
0445	6.0		
0500	5.7	96	
0515	5.7		
0530	5.5	96	
0545	5.5		16.0
0600	5.5		
0615	5.5	94	
0630	5.5		15.7

Vapour drift tended to be off shore, varying between NE and SE

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
08:10:96	0050	0530	280	No	4.0	1.12	B	138.900	129.900	9.000		E 002	-107.2	-15.82	Start 20 at 10	Pickup at East Lake rain gauge #2
							C	129.986	129.964	0.022	99.76				End 20 at 10	

Time	Air T	RH	Water T
0040	13.1	95	22.2
0100	12.5		
0130	12.0		
0200	12.0	95	21.6
0230	11.7		
0300	11.5	98	21.5
0330	11.2		
0400	11.0	96	21.0
0430	10.8		
0500	10.5	95	20.5
0530	10.5		

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
14:06:97	1900	2300	240	No	4.0	0.960	D	133.572	128.371	5.201		E 003	-111.6	-17.17	Start 20 at 8	Floating pickup adjacent Ts 6 thermistors
							A	87.752	87.705	0.047	99.10				End 20 at 8	Visible condensation in link from permanent line to trap, purged with nitrogen through trap

Time	Air T	RH	Ts 6	Bath T
1900	9.6	90	17.8	17.3
1930		94	17.5	17.1
2000	8.0	94	17.2	17.0
2030	7.2		16.9	17.0
2100			16.5	16.7
2130			16.2	16.5
2200			16.0	16.5
2230	7.0	95	15.8	16.4
2300	6.7	95	15.6	16.2

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^{2}H	^{18}O	Nitrogen (min, l/min)	Comments
21:06:97	2110	0040	210	No	4.0	0.840	D	135.220	128.371	6.849		E 004	-104.2	-15.24	End 20 at 8	Line to trap insulated, no visible condensation This is permanent line to floating trap Concurrent with A 049

Time	Air T	RH	Ts 6	Bath T	
2110	10.5	95	16.9	17.0	Calm, minor cloud
2200	10.0	95	16.5	16.8	Calm, 50% cloud cover
2300	10.5	95	16.1	16.5	Calm, 70% cloud cover, drizzle at 2330, 100% cloud cover
2400	12.0	98	15.8	16.5	Calm, 90% to 50% cloud cover
0040	11.8	95	15.7	16.4	Calm, 20% cloud cover

26:06:97	1800	2130	210	No	4.0	0.840	D	135.410	128.371	7.039		E 005	-95.7	-14.14 -14.09	End 20 at 8	Concurrent with A 051

Time	Air T	RH	Ts 6	Bath T	
1800	14.8	89	20.0	18.6	Calm, scattered high cloud
1900	13.6	95	19.1	18.4	
1930					Ground fog forming on adjacent hockey fields
2000	13.0	98	18.1	18.0	Calm, clear sky, fog partially dispersed
2100	12.2	95	17.0	17.6	Calm, sky clear, fog almost dispersed
2130	11.2	95	16.6	17.5	Calm, clear sky

07:07:97	2000	2330	210	No	4.0	0.840	C	134.260	129.964	4.296		E 006	-107.1	-16.14	End 15 at 8	Concurrent with A 054

Time	Air T	RH	Ts 6	Bath T
2000	7.0	95	13.2	14.1
2030	7.8	95	12.9	14.0
2100	6.9	95	12.6	13.9
2130	6.5	95	12.5	13.7
2200	5.5	95	12.2	13.5
2230	5.0	95	11.7	13.4
2300	5.0	95	11.3	13.3
2330	4.5	96	11.1	13.1

10:07:97	1800	2200	240	No	4.0	0.960	A	91.950	87.705	4.245		E 007	-119.2	-18.4	End 15 at 8	Concurrent with A 055

Time	Air T	RH	Ts 6	Bath T
1800	6.8	95	15.5	14.2
1830	6.2	95	15.3	14.0
1900	5.1	95	14.8	13.9
1930	4.6	95	14.3	13.6
2000	4.1	95	13.7	13.5
2030	3.4	95	13.3	13.3
2100	3.2	95	12.7	13.0
2130	2.8	95	12.4	12.9
2200	2.7	95	12.0	12.8

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
16:07:97	1745	2200	255	No	4.0	1.020	C	135.490	129.964	5.526		E 008	-101.2	-16.26	End 15 at 8	Concurrent with A 057

Time	Air T	RH	Ts 6	Bath T	
1745	9.0	78	14.9	13.5	winds calm sky clear, scattered cirrus
1800	8.4	82	14.8	13.5	
1830	7.7	86	14.5	13.4	cirrus increasing
1900	11.3	56	14.2	13.2	high cirrus, light easterly drift
1930	11.4	59	13.9	13.2	light easterly drift
2000	10.5	66	13.7	13.1	calm, sky mostly clear, 25% scattered cirrus
2030	10.0	69	13.3	13.0	E drift, 50% cirrus cover
2100	9.7	69	12.8	12.9	
2130	9.5	70	12.5	12.8	sky almost clear, slight hazy cirrus light E drift
2200	8.0	76	12.3	12.7	hazy cirrus, large moon dog, wind calm

Anemometer 1.11km in 82 minutes, drift 13.5m/minute average

17:07:97	1740	2040	180	No	4.0	0.720	C	133.850	129.900	3.950		E 009	-105.8	-16.53	End 15 at 8	Concurrent with A 058 Minor condensation in line

Time	Air T	RH	Ts 6	Bath T	
1740	10.7	78	16.3	14.4	sky clear, scattered cirrus, calm
1800	9.5	77	15.9	14.2	calm, sky clear
1830	8.5	82	15.5	14.0	calm, sky clear
1900	7.3	83	14.9	13.8	calm, sky clear
1930	6.5	87	14.5	13.6	calm, sky clear
2000	6.0	89	14.0	13.5	some condensation in line between pans and traps, heated with lamp and re-vapourized
2030	5.3	94	13.7	13.4	calm, sky clear
2040	5.2	94	13.6	13.4	calm, sky clear

22:07:97	0500	0725	145	No	4.0	0.580	C	132.340	129.900	2.440		E 010	-108.3	-15.66	End 15 at 8	Concurrent with A 060 Good run, no condensation

Time	Air T	RH	Ts 6	Bath T	
0500	2.3	89	8.2	11.4	calm, sky clear
0530	1.8	90	8.1	11.1	calm, sky clear
0600	1.3	90	7.9	11.0	calm, sky clear
0630	1.2	91	7.8	10.6	calm, sky clear
0700	0.8	93	7.7	10.5	calm, sky clear
0725	0.9	94	7.5	10.5	calm, sky clear sun up, frost on hockey fields

02:08:97	1745	2000	135	No	4.0	0.540	C	133.850	129.900	3.950		E 011	-98.6	-14.53	End 15 at 8	Concurrent with A 062 Good run, no condensation

Time	Air T	RH	Ts 6	Bath T	
1745	13.7	89	19.1	18.8	calm, sky clear
1800	13.0	90	18.9	18.6	calm, sky clear
1830	11.7	90	18.4	18.5	calm, sky clear
1900	11.0	91	18.0	18.4	calm, sky clear
1930	10.6	93	17.6	18.1	scattered cloud to north, calm
2000	10.5	94	17.4	17.9	scattered cloud to north, calm

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
11:08:97	1745	1945	120	No	4.0	0.480	C	133.080	129.900	3.180		E 012	-101.5	-15.04	End 15 at 8	Concurrent with A 065 Good run, no condensation

Time	Air T	RH	Ts 6	Bath T	
1745	12.4	75	16.7	16.0	calm, sky clear
1800	11.5	78	16.6	16.0	calm, sky clear
1830	10.2	87	16.4	15.9	calm, sky clear
1900	9.5	88	16.2	15.6	calm, sky clear
1930	9.0	93	15.9	15.5	calm, sky clear
1945	8.7	94	15.8	15.5	calm, sky clear

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
18:08:97	1745	1945	120	No	4.0	0.480	C	133.350	129.900	3.450		E 013	-94.9	-14.64	End 15 at 8	Concurrent with A 067 Good run, no condensation

Time	Air T	RH	Ts 6	Bath T	
1745	13.6	69	18.0	16.8	Sky 50% high cloud, clearing, dead calm
1800	12.6	70	18.0	16.8	Sky 50% high cloud, clearing, dead calm
1830	11.8	78	17.8	16.6	Sky 50% high cloud, clearing, dead calm
1900	10.4	82	17.5	16.5	calm, sky clear
1930	9.5	84	17.3	16.4	calm, sky clear
1945	8.9	88	17.1	16.3	calm, sky clear

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
23:08:97	0505	0700	110	No	4.0	0.440	C	132.600	130.210	2.390		E 014	-106.5	-15.61	End 15 at 8	Concurrent with A 068 Slight East drift first 30 minutes

Time	Air T	RH	Ts 6	Bath T	
0505	9.8	77	13.7	15.4	Sky clear, slight eastery drift
0600	8.5	88	13.4	15.2	Sky clear, slight eastery drift
0630	7.5	88	13.3	15.0	Sky clear, calm
0700	7.0	90	13.3	15.0	Sky clear, calm

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
30:08:97	1810	2000	110	No	4.0	0.440	C	133.480	130.210	3.270		E 015	-89.4	-13.85	End 15 at 8	Minor condensation in feed line between pans and trap Purged with nitrogen through trap Concurrent with A 070

Time	Air T	RH	Ts 6	Bath T	
1810	14.5	69	20.0	18.9	Sky clear, calm
1830	13.8	72	19.8	18.8	Sky clear, occasional eastery drift
1900	14.3	71	19.5	18.8	Sky clear, occasional eastery drift
1930	14.2	74	19.2	18.5	Sky clear, occasional eastery drift
2000	11.8	82	19.0	18.5	Sky clear, occasional eastery drift

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
17:09:97	1830	2030	120	No	4.0	0.480	C	not measured				E 016	-100.9	-15.45		Concurrent with A 074

Time	Air T	RH	Ts 6	Bath T	
1830	17.5	83	22.9	22.0	Sky clear, calm
1900	15.8	85	22.8	22.0	Sky clear, calm
1930	14.6	87	22.6	22.0	Sky clear, calm
2000	14.5	84	22.4	21.8	Sky clear, calm
2030	14.6	88	22.3	21.6	Sky clear, calm

Date	Start	End	Time	CO_2	Flow (l/min)	Volume (cu m)	Trap	Wt Wet	Wt Dry	Water	Efficiency	Sample	^2H	^{18}O	Nitrogen (min, l/min)	Comments
04:10:97	0400	0600	120	No	4.0	0.480	C	133.680	130.210	3.470		E 017	-106.2	-15.18		Concurrent with A 077

Time	Air T	RH	Ts 6	Bath T	
0400	11.8	94	19.7	20.4	Sky clear, calm
0430	11.5		19.5	20.3	Sky clear, calm
0500	12.1	90	19.4	20.1	Sky clear, calm
0530	11.6	92	19.3	20.0	Sky clear, calm
0600	11.6	90	19.2	19.9	Sky clear, calm

13:10:97	0500	0630	90	No	4.0	0.360	C	133.270	130.210	3.060		E 018	-100.6	-15.18		Concurrent with A 080

Time	Air T	RH	Ts 6	Bath T	
0500	10.2	98	20.5	21.2	Sky clear, calm
0530	10.0	98	20.4	21.1	Sky clear, calm
0600	10.0	98	20.2	21.0	Sky clear, calm
0630	10.5	95	20.0	20.9	Sky clear, calm

21:10:97	0615	0700	45	No	4.0	0.180	C	131.920	130.210	1.710		E 019	-78.5	-10.45		Concurrent with A 083

Time	Air T	RH	Ts 6	Bath T	
0615	19.4	61	22.0	21.8	20% cloud following overcast humid night
0700	21.1	54	21.9	21.7	20% cloud following overcast humid night, calm

09:11:97	0645	0728	43	No	5.0	0.215	D	130.580	128.440	2.140		E 020	-72.4	-8.30		Run immediately preceeds A 088 A 088 starts 0850

Time	Air T	RH	Ts 6	Bath T	
0645	15.0	90		21.7	Sky clear, calm, sunny
0730	20.2	51	18.6	21.7	Sky clear, calm, sunny, warm, no condensation
					Unique conditions, sun up and air T increasing rapidly, but no wind

19:11:97	0620	0750	90	No	4.0	0.360	C	132.980	130.210	2.770		E 021	-67.6	-6.90		Concurrent with A 090

Time	Air T	RH	Ts 6	Bath T	
0620	11.5	93	14.7	20.4	Sky clear, calm, sunny
0750	19.4	45	16.0	20.5	Sky clear, calm, sunny, warm, no condensation
					Unique conditions, sun up and air T increasing rapidly, but no wind
					From 0700, sun shining directly on pickup in water, some E drift 0745-0750