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

[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).

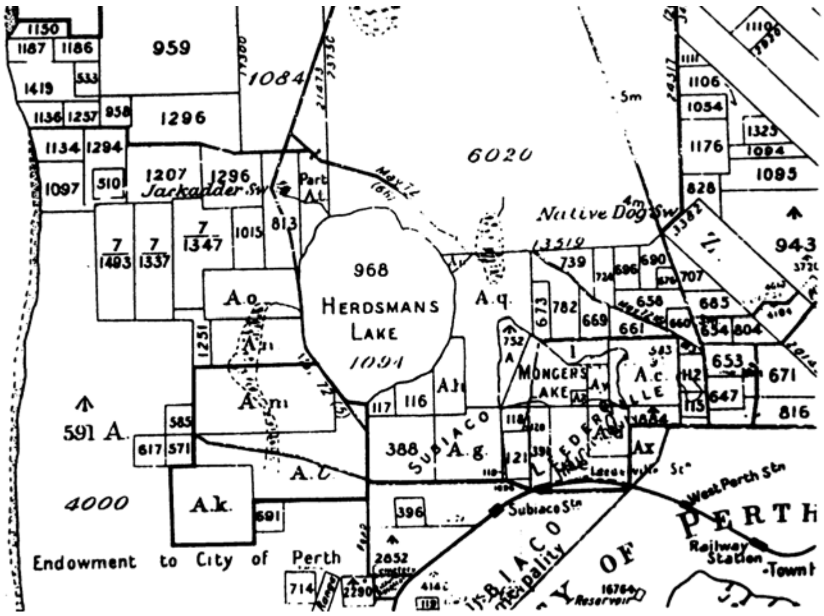


Figure 2.1 Limekilns Estate as it appeared on a 1898 Lands and Surveys map (adapted from de Burgh 1986). Perry Lakes, situated within Location A.k. were sufficiently insignificant to be ignored. Low country to the northeast within Locations A.l. and A.m. (present day Floreat Oval and McLean Park) are 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).

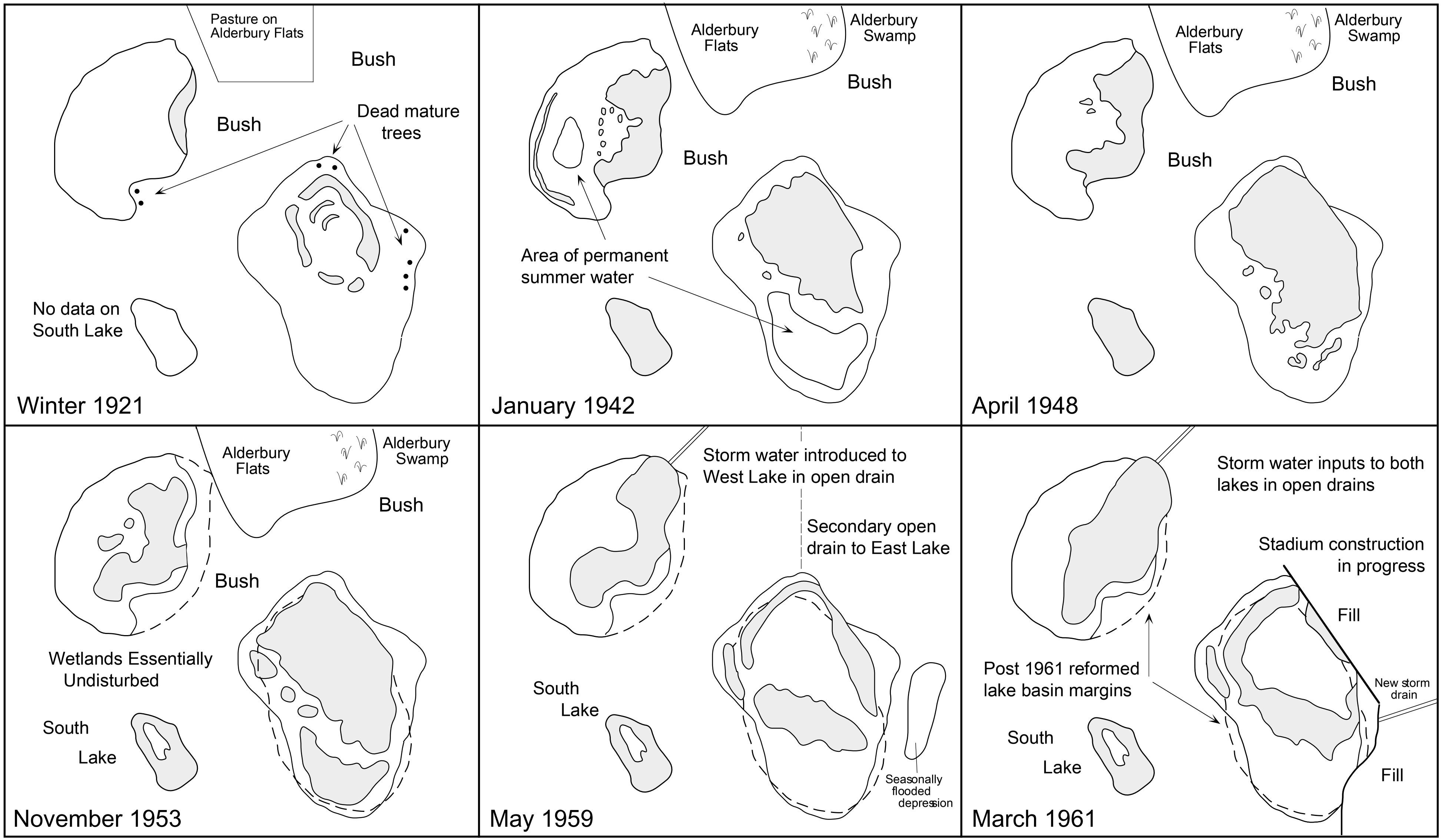
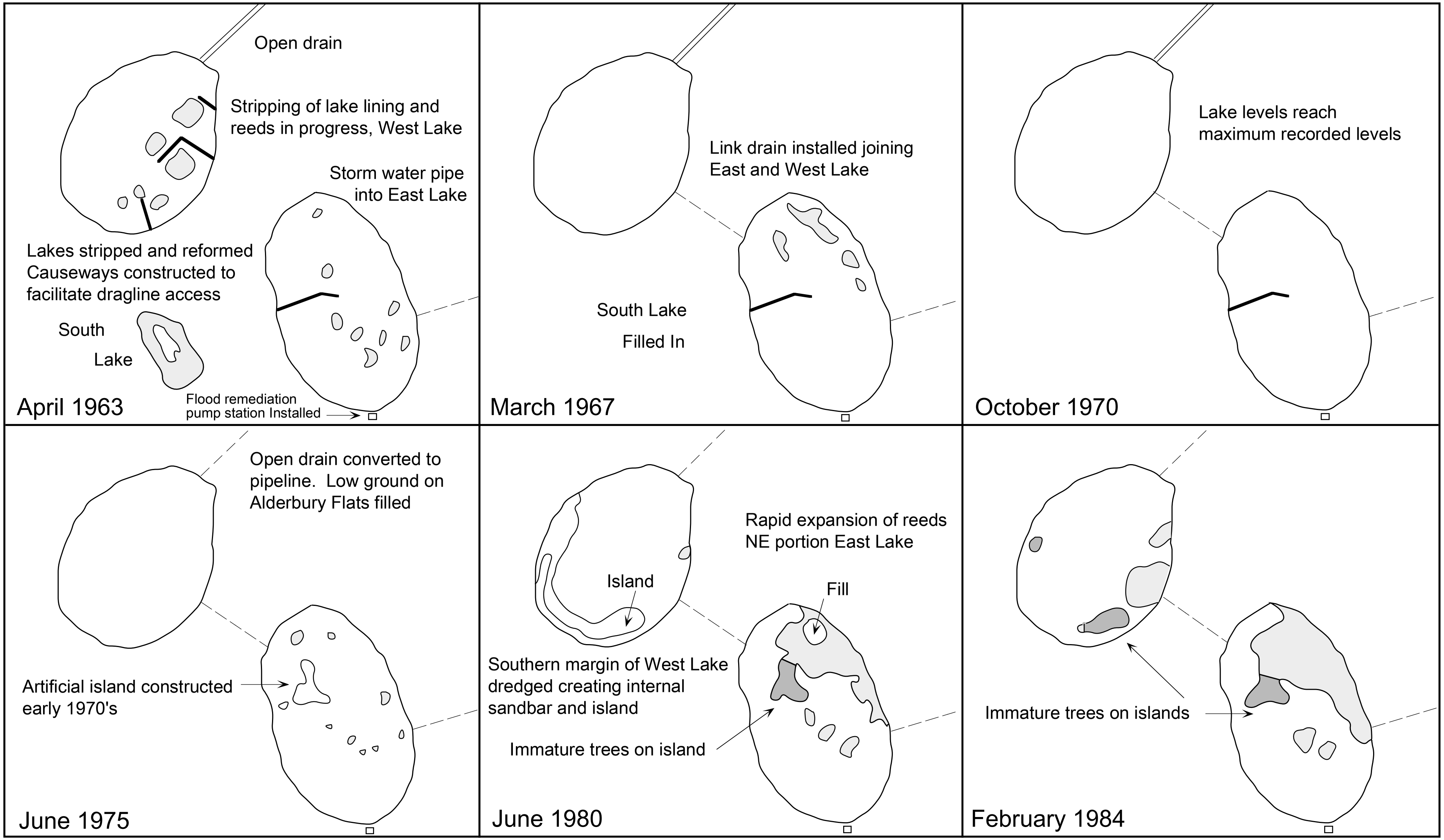
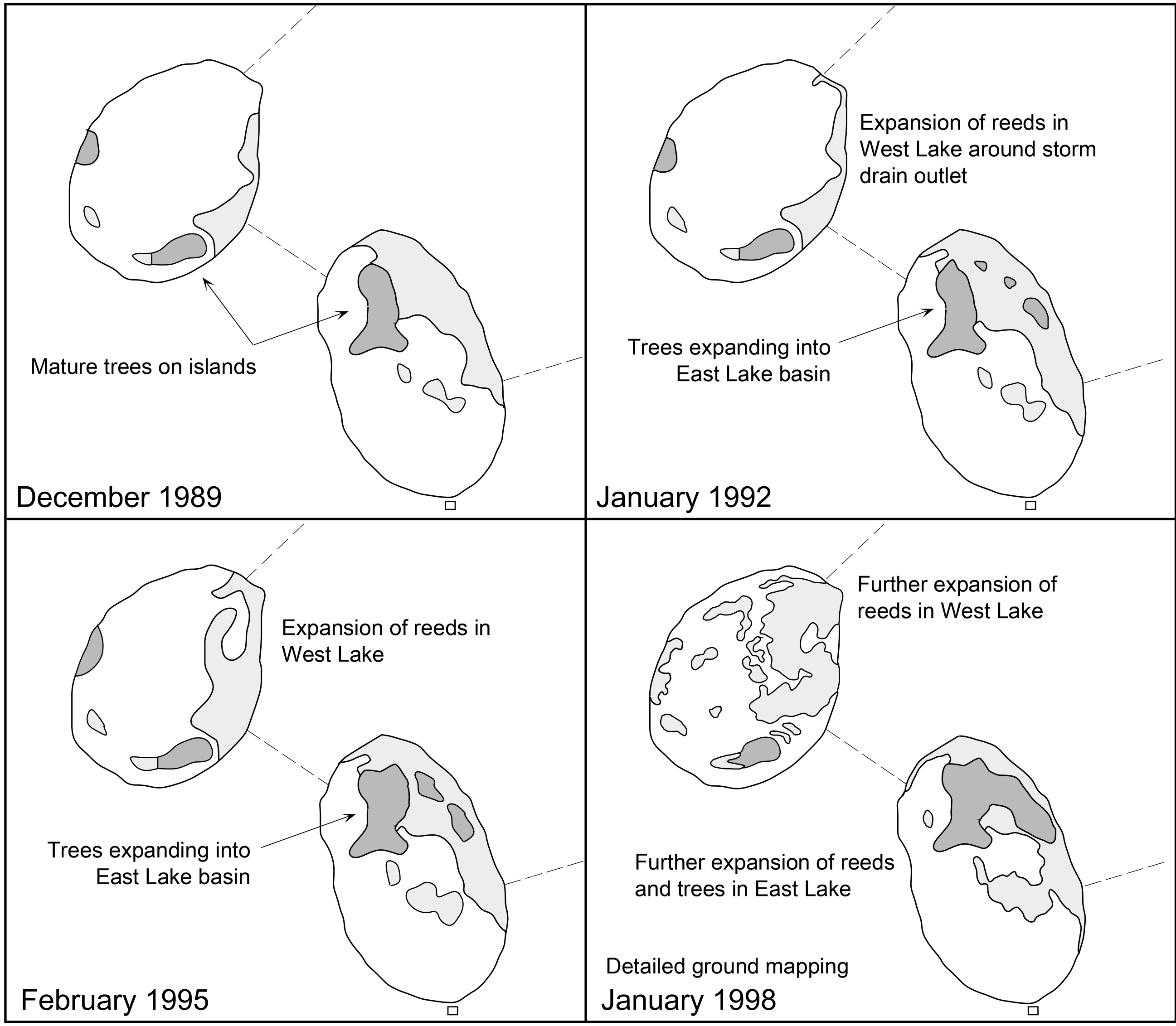

Winter 1921
Pasture on Alderbury Flats
Bush
Bush
Dead mature trees
No data on South Lake
January 1942
Alderbury Flats
Alderbury Swamp
Bush
Bush
Area of permanent summer water
April 1948
Alderbury Flats
Alderbury Swamp
Bush
Bush
November 1953
Alderbury Flats
Alderbury Swamp
Bush
Bush
Wetlands Essentially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

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
Flood remediation pump station Installed
April 1963
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

Scale 0 150 1: 10 000

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

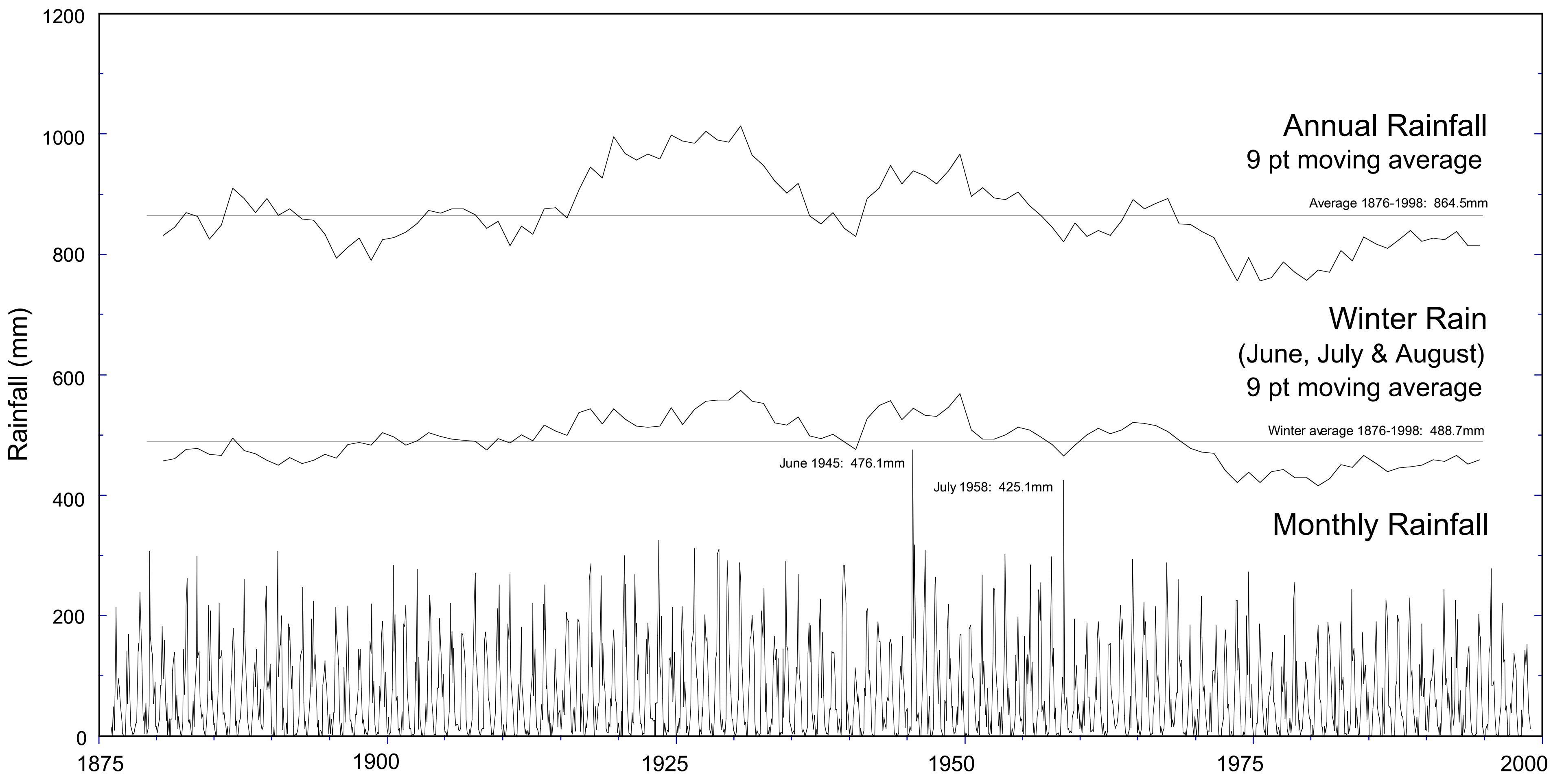


Figure 2.3

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

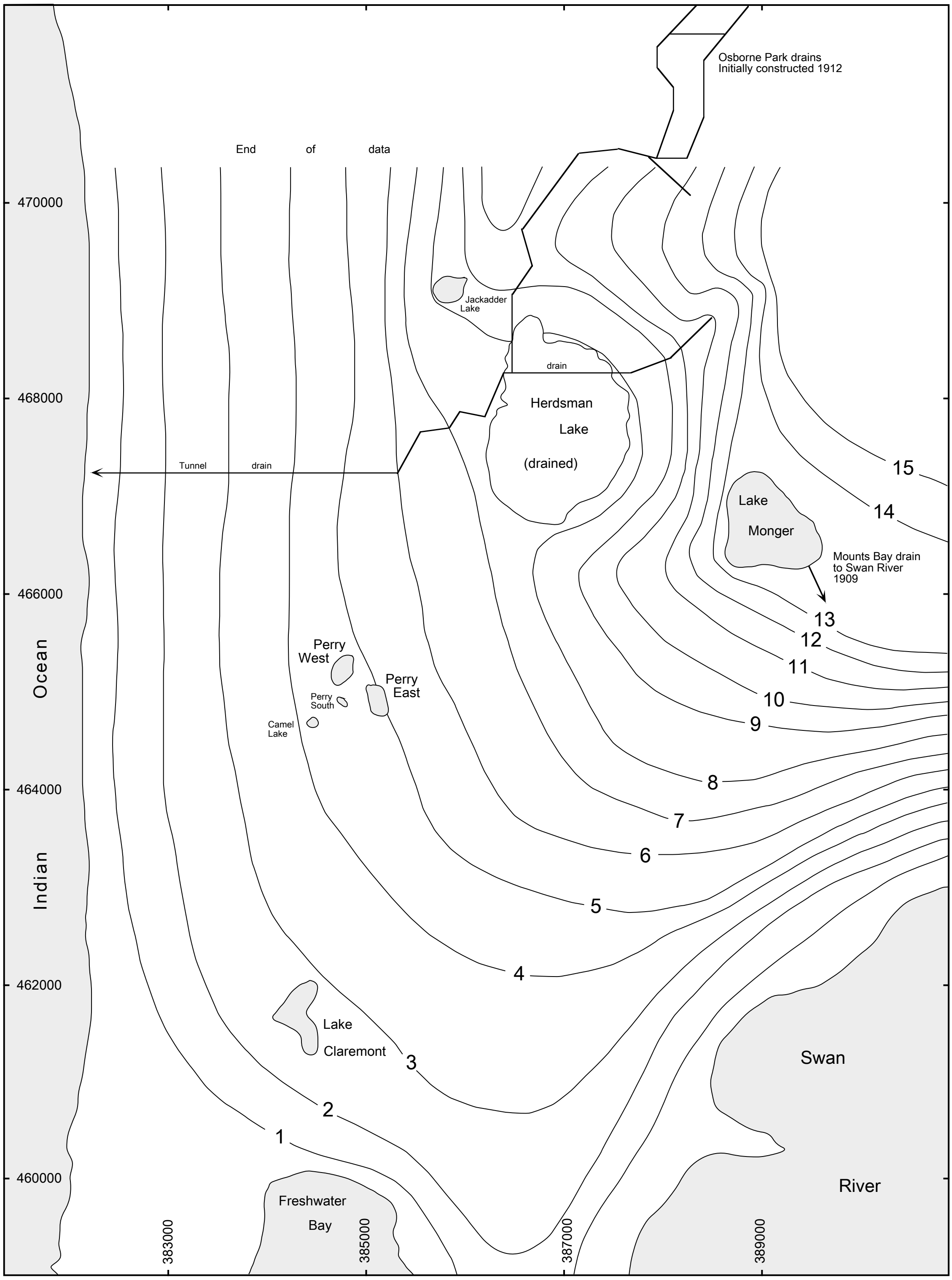
2.3.1 Regional Groundwater Levels

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.

[2] El Niño-Southern Oscillation



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

Scale: 1: 65000

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).

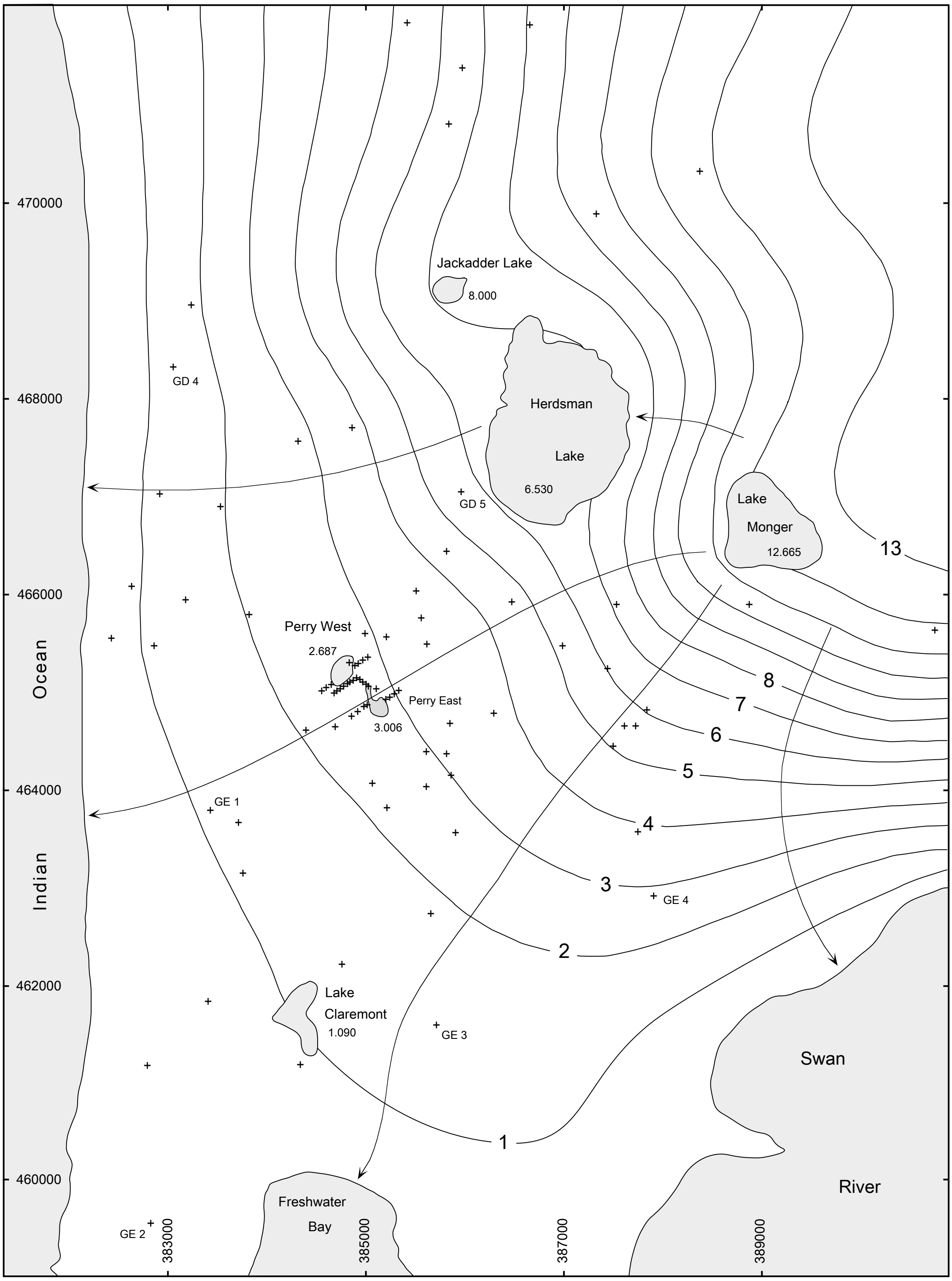
The use of public irrigation bores for groundwater monitoring is problematic. Such bores are screened towards their base and are not therefore fully penetrating and do not necessarily measure the water table. At a regional scale however they may provide a usable estimate. Summer minimum levels (Figure 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

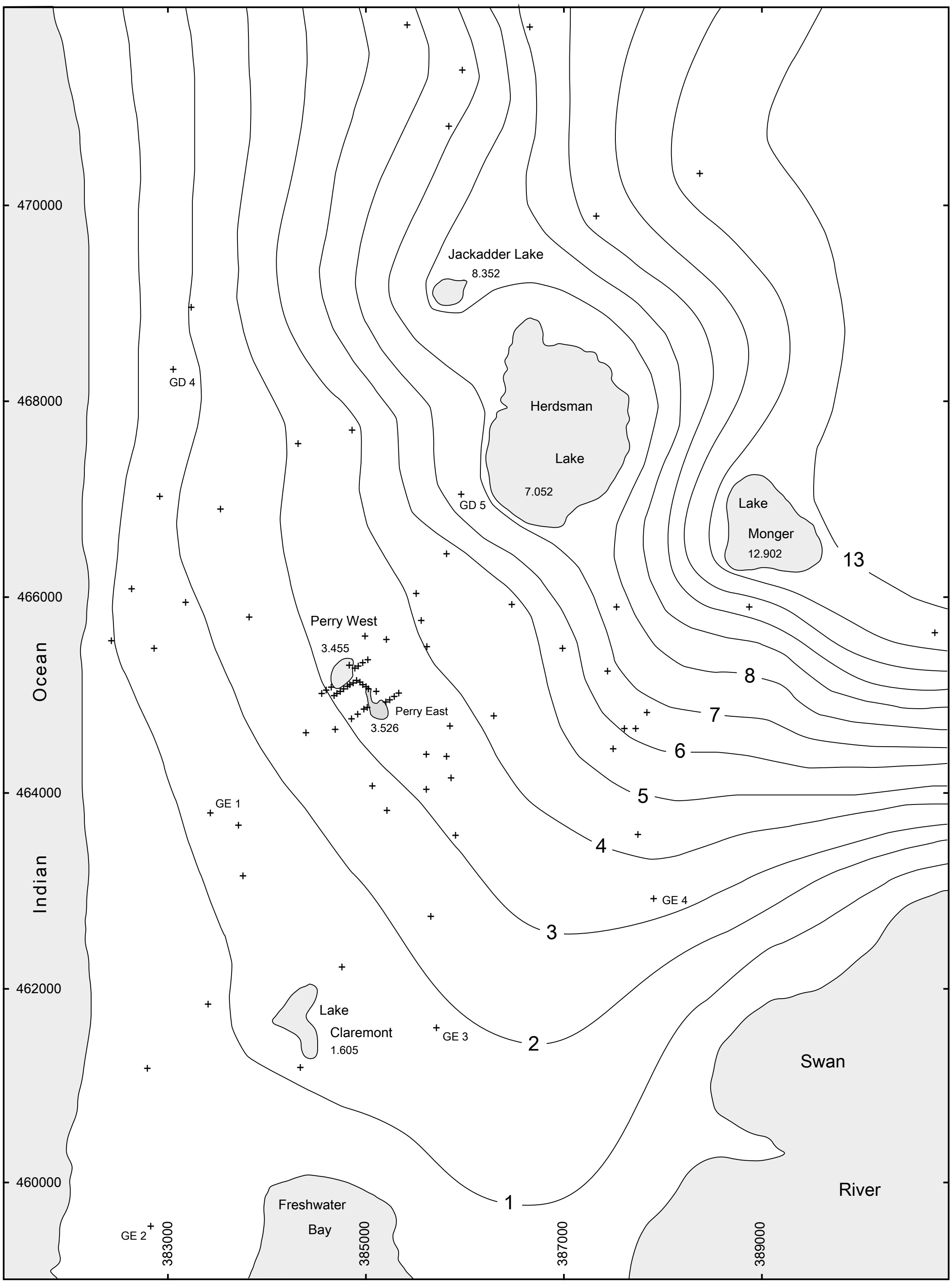
+ GE 3 Gnangara Mound monitoring well referred to in text

← 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

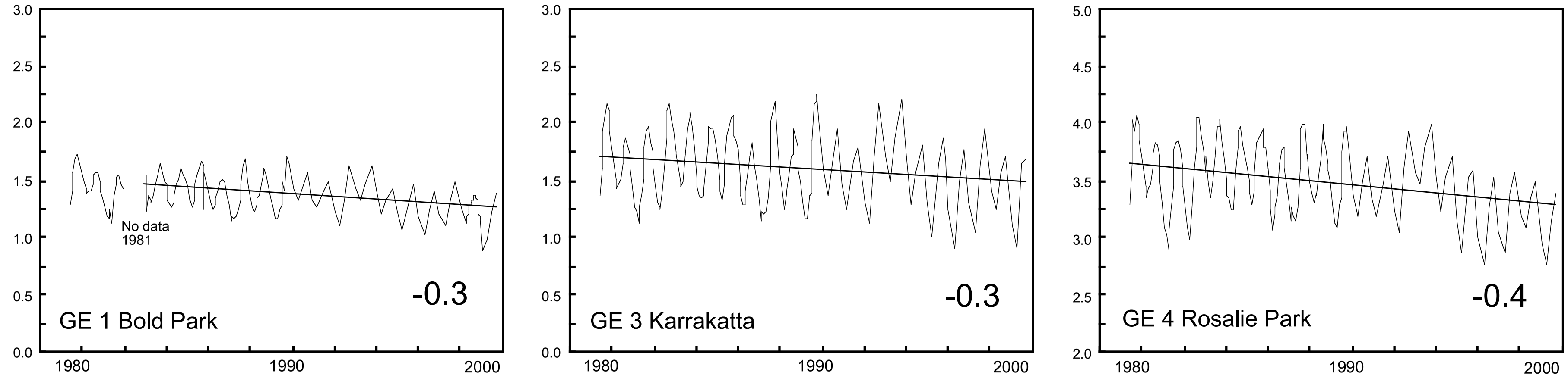
Records of other wetlands in the Perry Lakes sector provide additional longer term water table information.

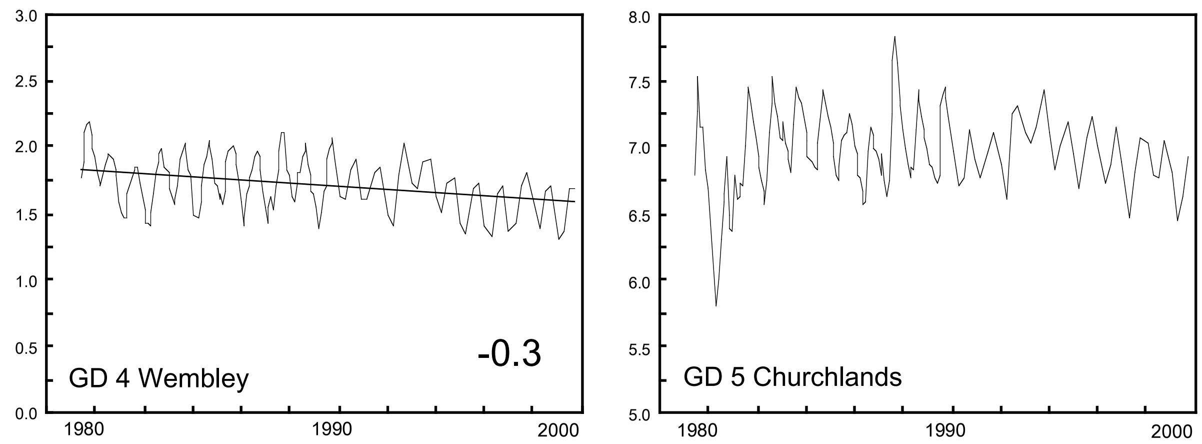
Lake Monger

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.

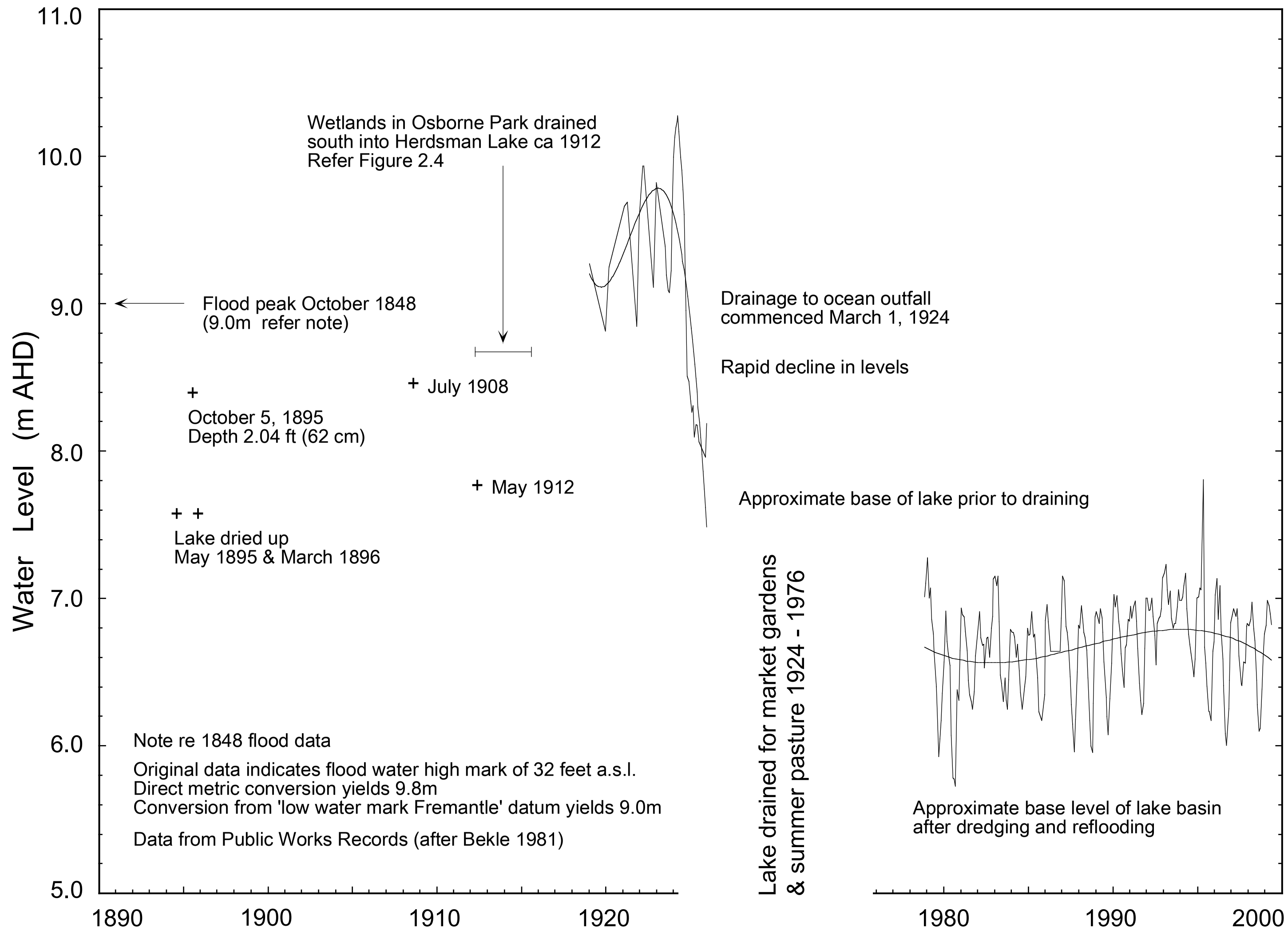
When dry, the water table beneath the lake would be less than lake bed RL, surveyed prior to drainage as 28 feet LWMF (refer notes Table 2.2) or 7.78m AHD. This is at least 1m higher than in May 1997 (Figure 2.5) and indicates that during the dry period in the 1890's the summer water table around Herdsman 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

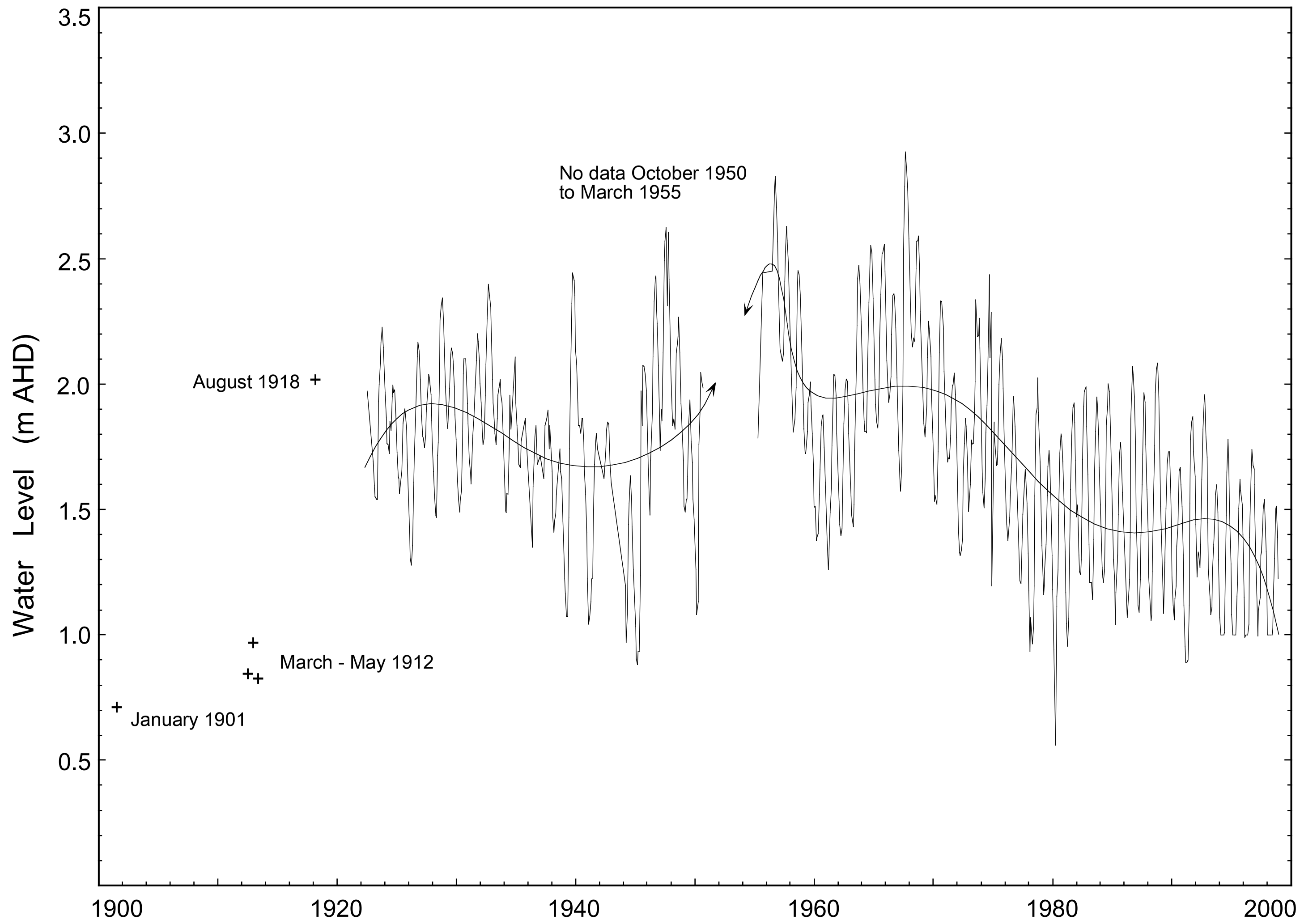
Spot data from:
Serventy (1948)
Bekle (1981)
Le Page (1986)

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

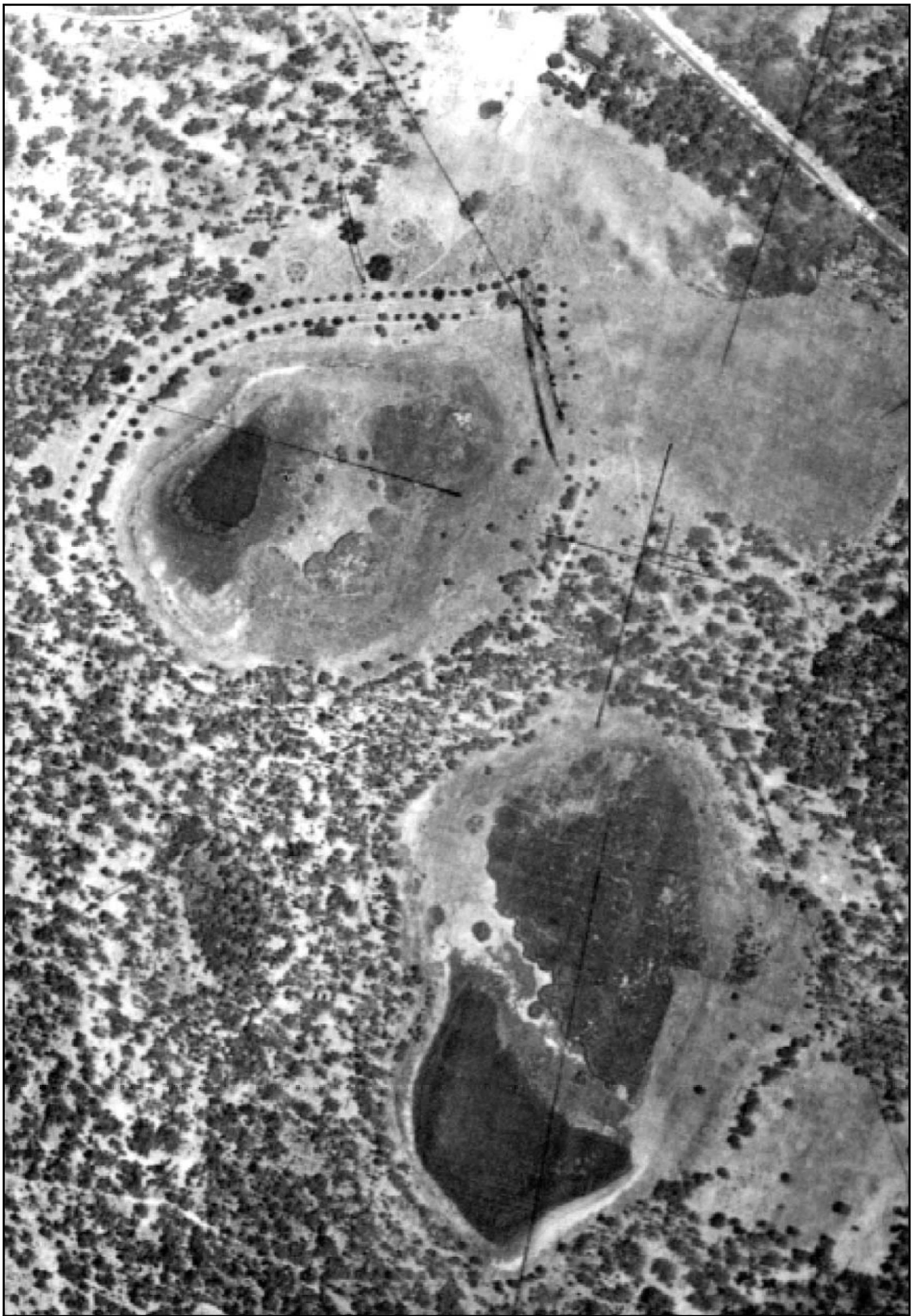


Plate 2.1 Perry Lakes, January 1942

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

Location Map

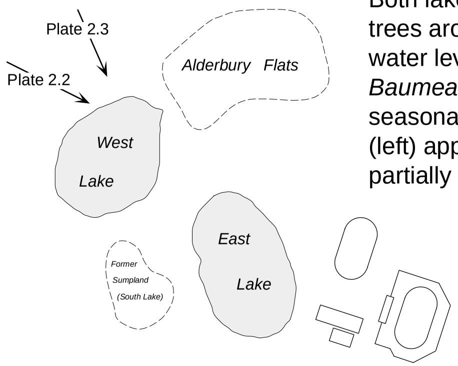


Plate 2.2 appears to have been taken in winter. Both lakes are almost fully flooded. Dead mature trees around both lakes suggest recent rise in water levels. Compared to 1942 (Plate 2.1) *Baumea* is sparcer in both lakes suggesting deep seasonally permanent innundation. Alderbury Flats (left) appear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

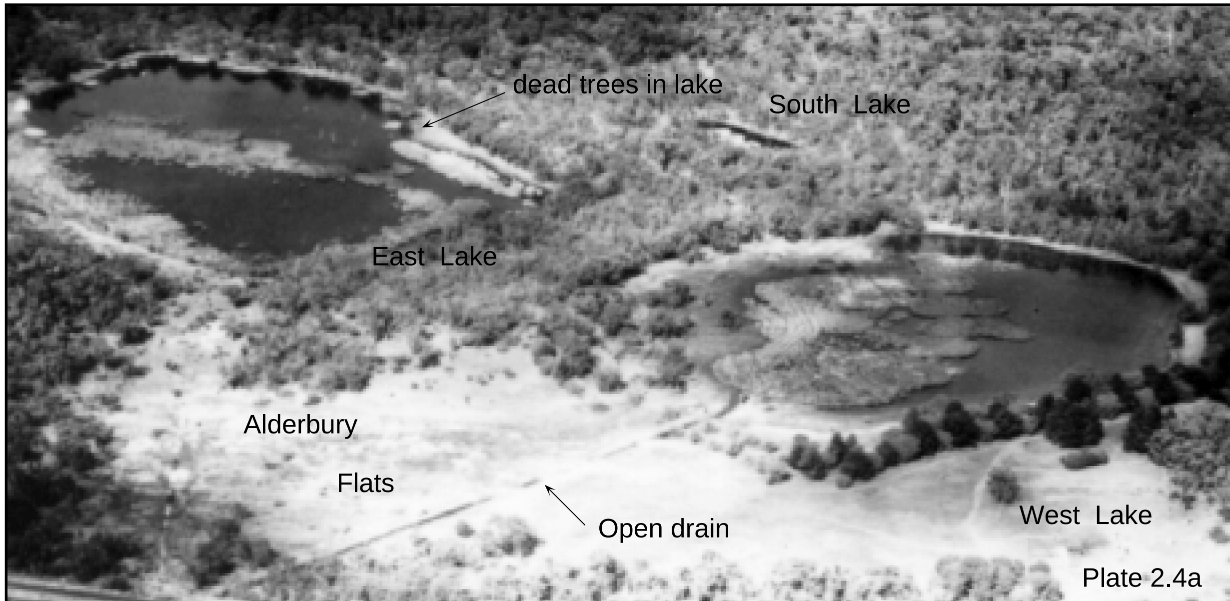


Plate 2.4a

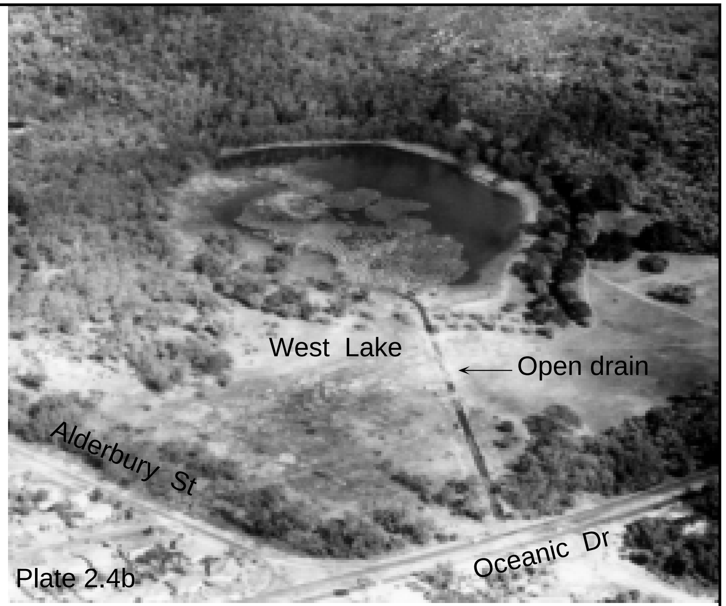


Plate 2.4b

Plate 2.5

Perry Lakes circa 1957 - 1959

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

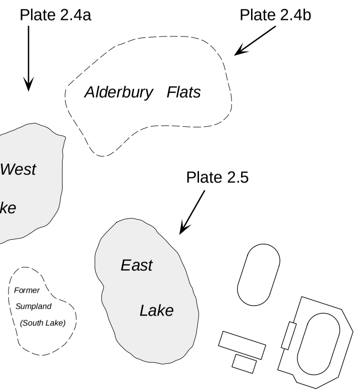


Plate 2.5 taken across East Lake 18 May 1957. Dead trees from 20-30 years of water level rise are clearly evident.

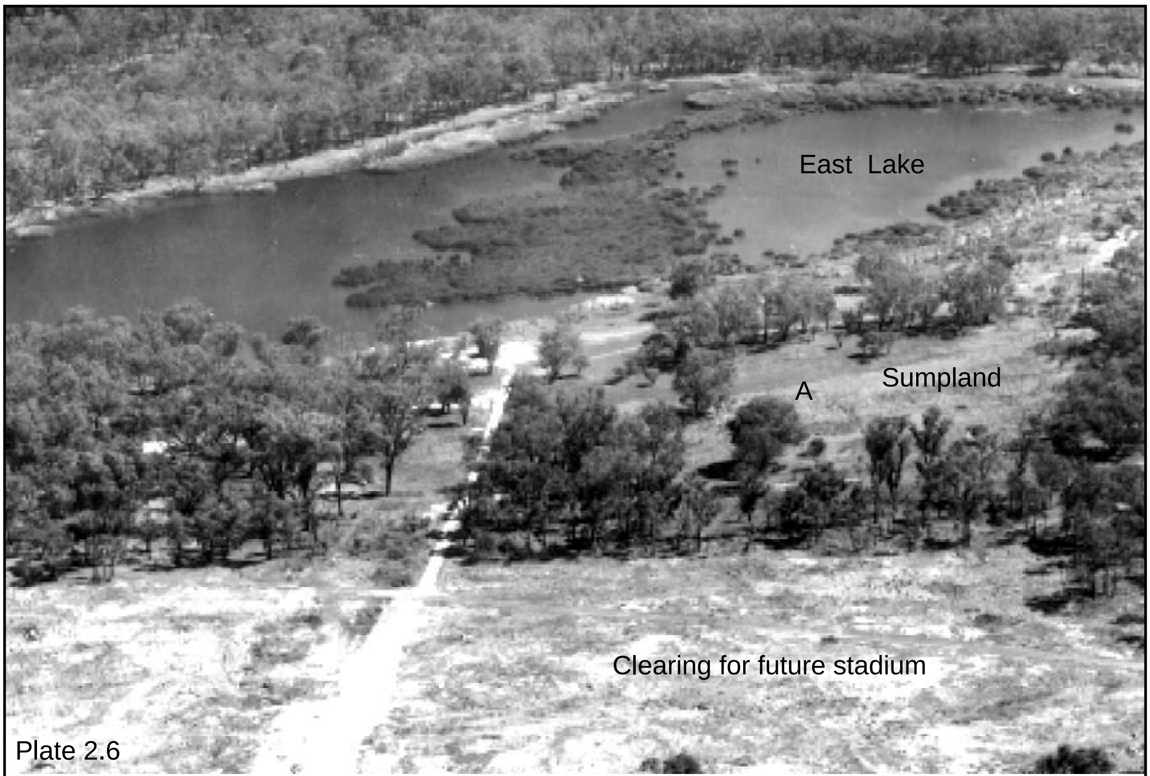
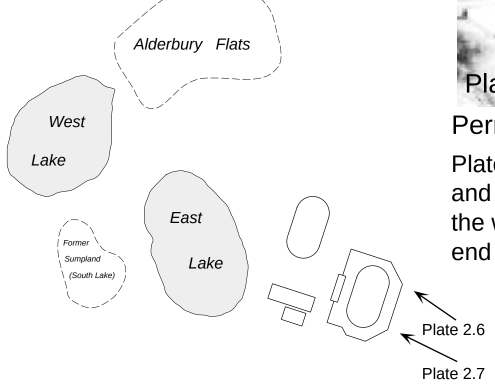


Plate 2.6

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.

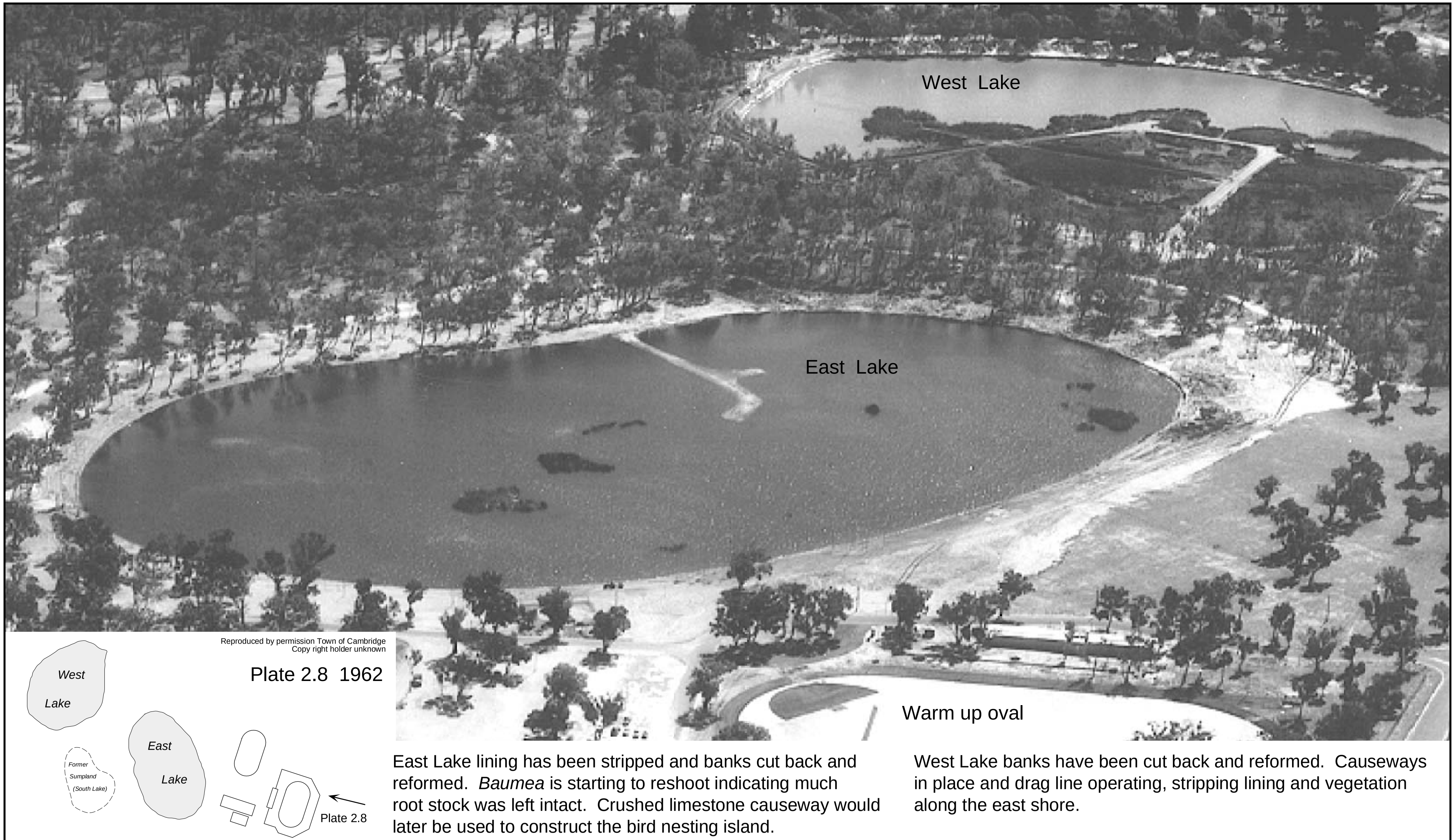


Plate 2.8 1962

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.

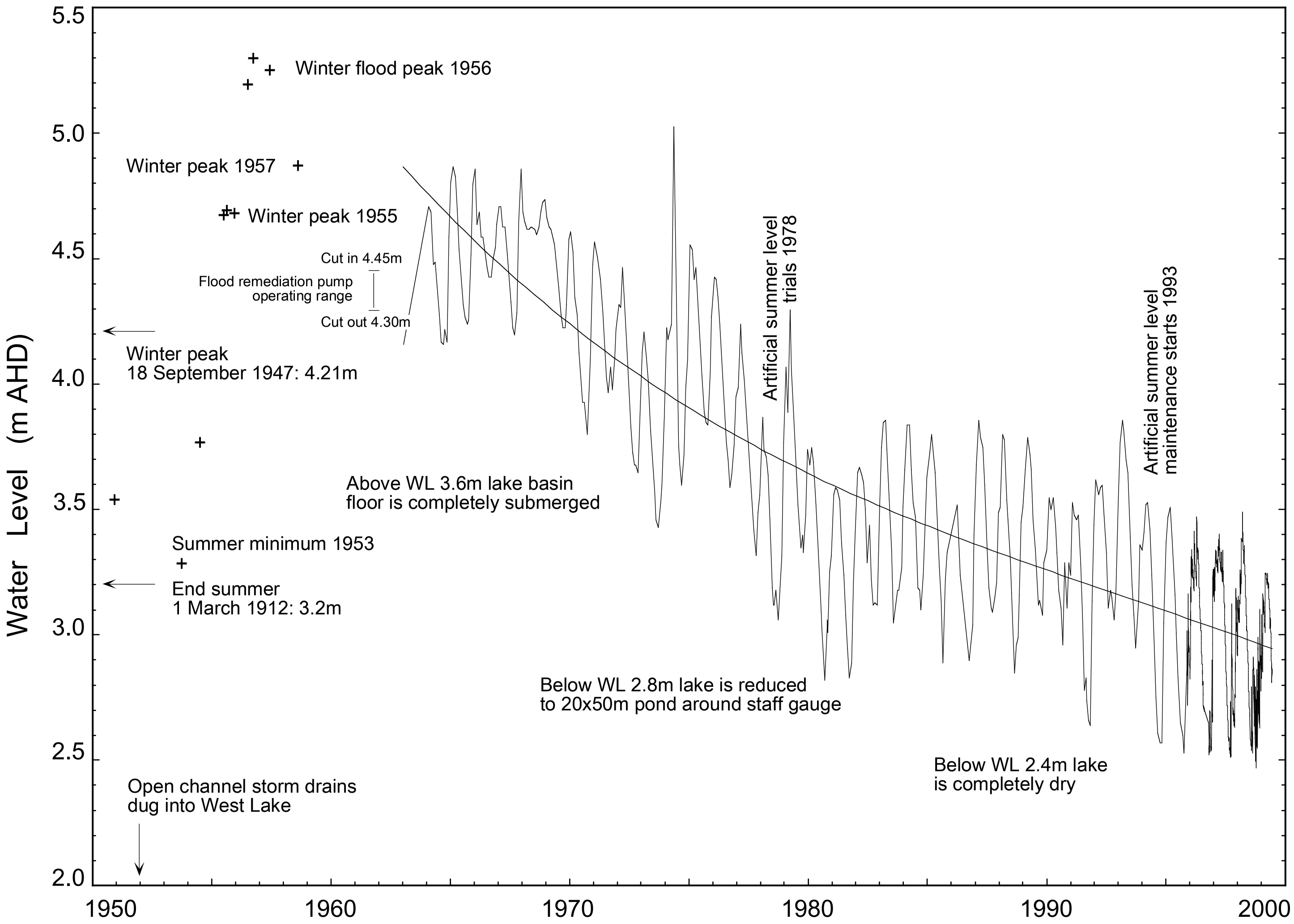
open water while a shallower northeast portion is only rimmed with *Baumea*. The two are separated by a prominent band of tall *Baumea*. Only 17 years earlier in 1942 (Plate 2.1) *Baumea* covered the entire northeast section of the lake. The photos suggest that *Baumea* proliferated in the dry spell 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

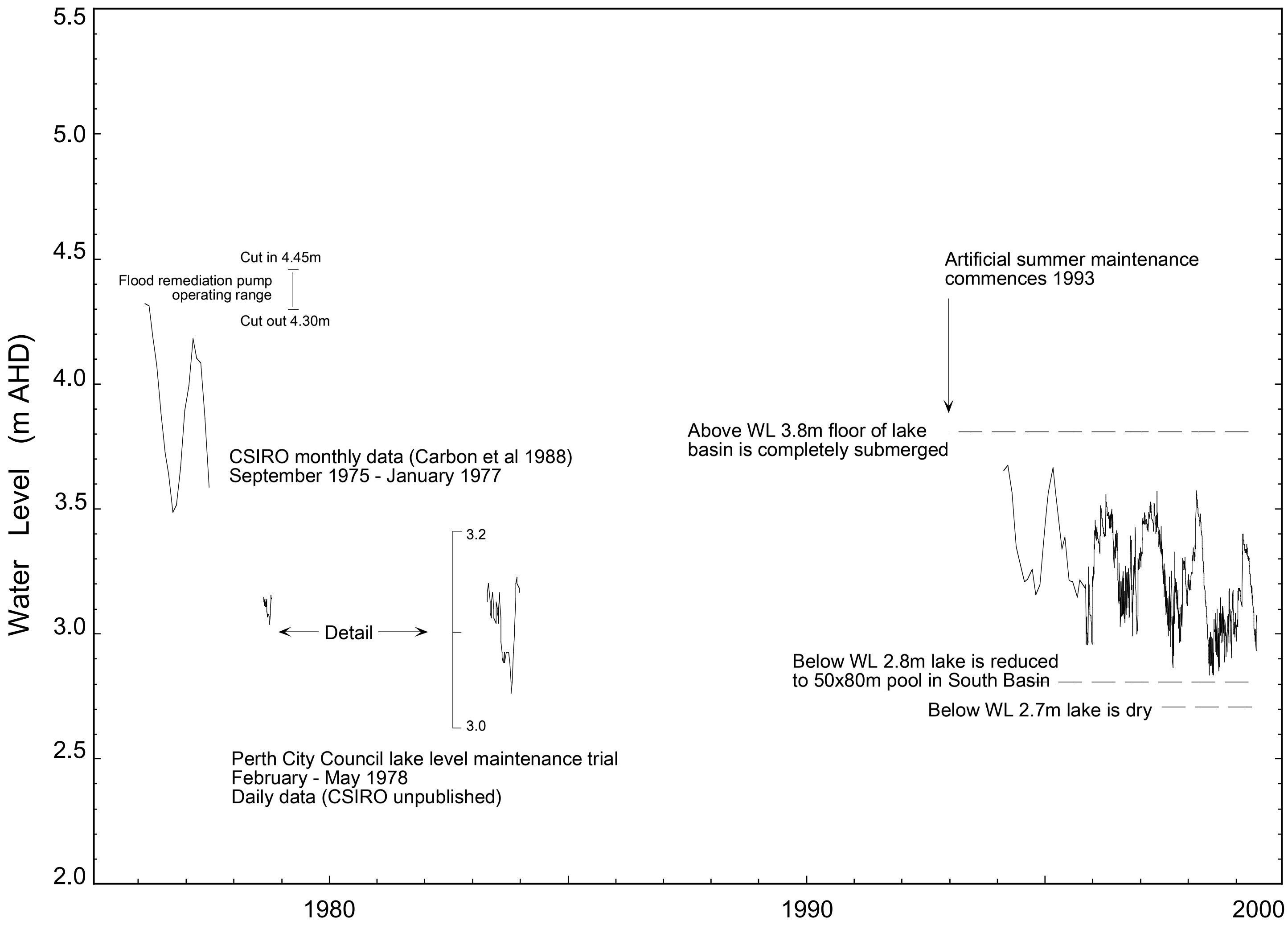
Data 1995 - 1999 data logger (hourly) and manual (daily), this study

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.

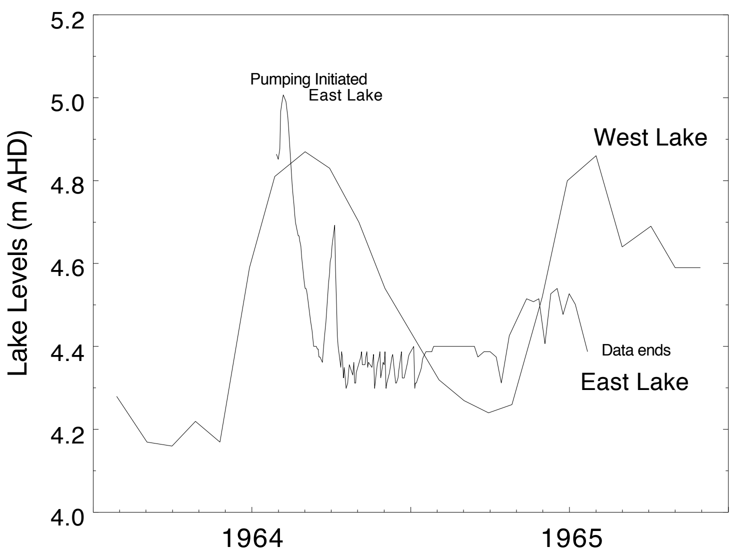


Figure 2.12 Detailed lake stage data following commissioning of flood remediation pumping station. The data suggest that the cut in and cut out levels were raised 100mm between winter 1964 and winter 1965.

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.

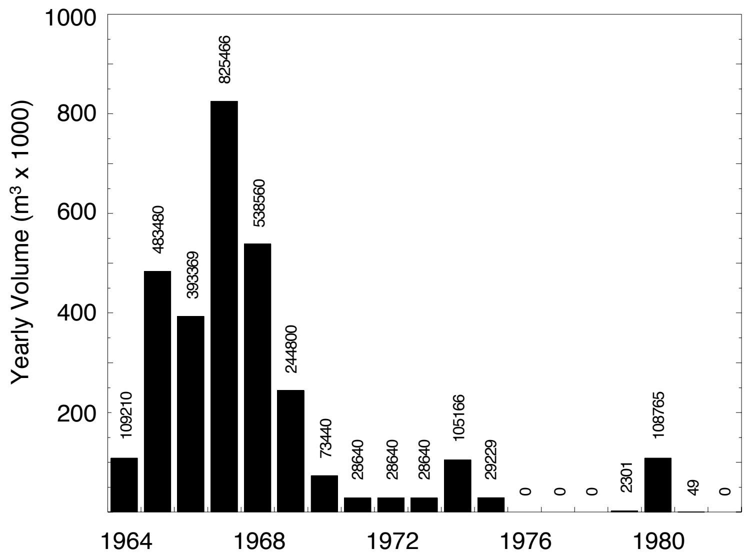


Figure 2.13 Flood remediation station, water volumes pumped 1964-1982

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).

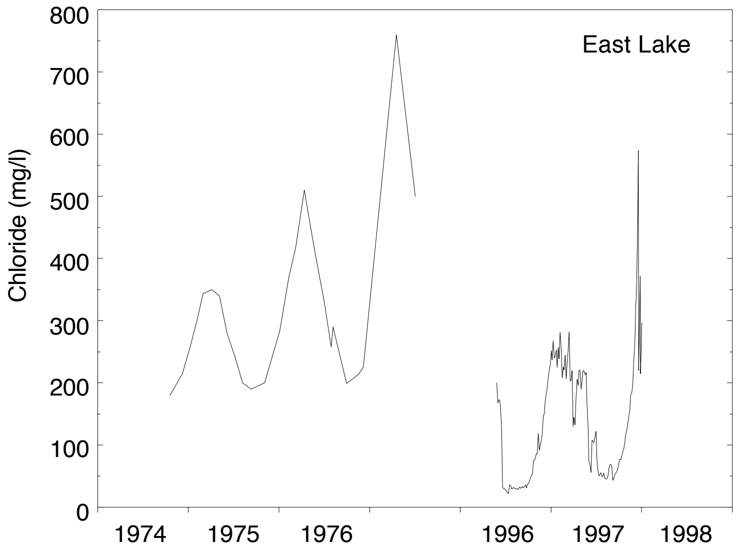


Figure 2.14 Lake chloride chemistry as a function of lake-aquifer interaction and artificial summer maintenance

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

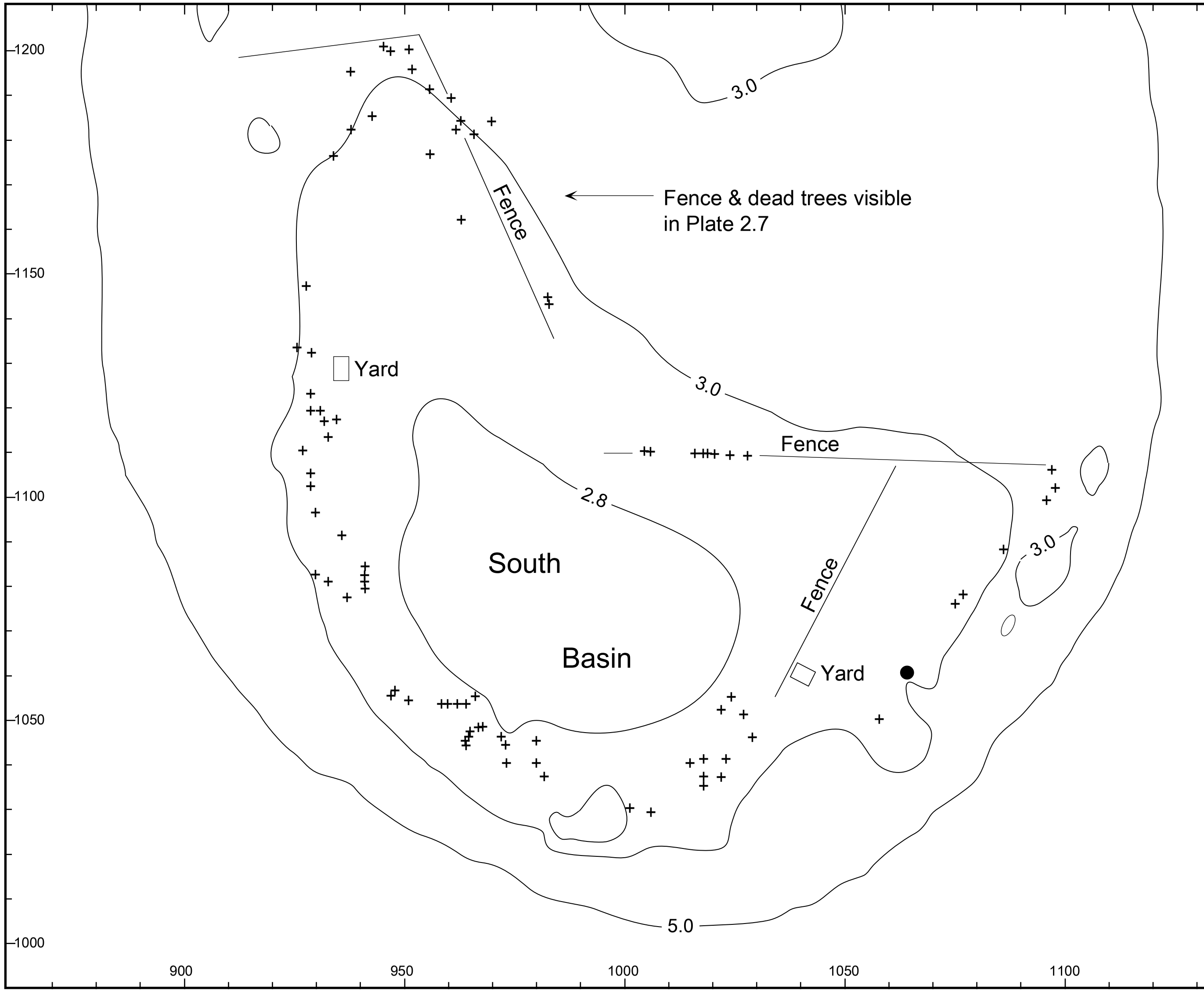
Rainfall in Perth (and by inference stormwater) has a mean chlorinity varying from about 10.7-16.5mg/l Cl (Teakle 1937, Hingston & Gailitis 1976). In winter, stormwater input during the 1970's represented a small proportion of lake volume. The lake probably functioned as a flow-through lake for most 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.