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

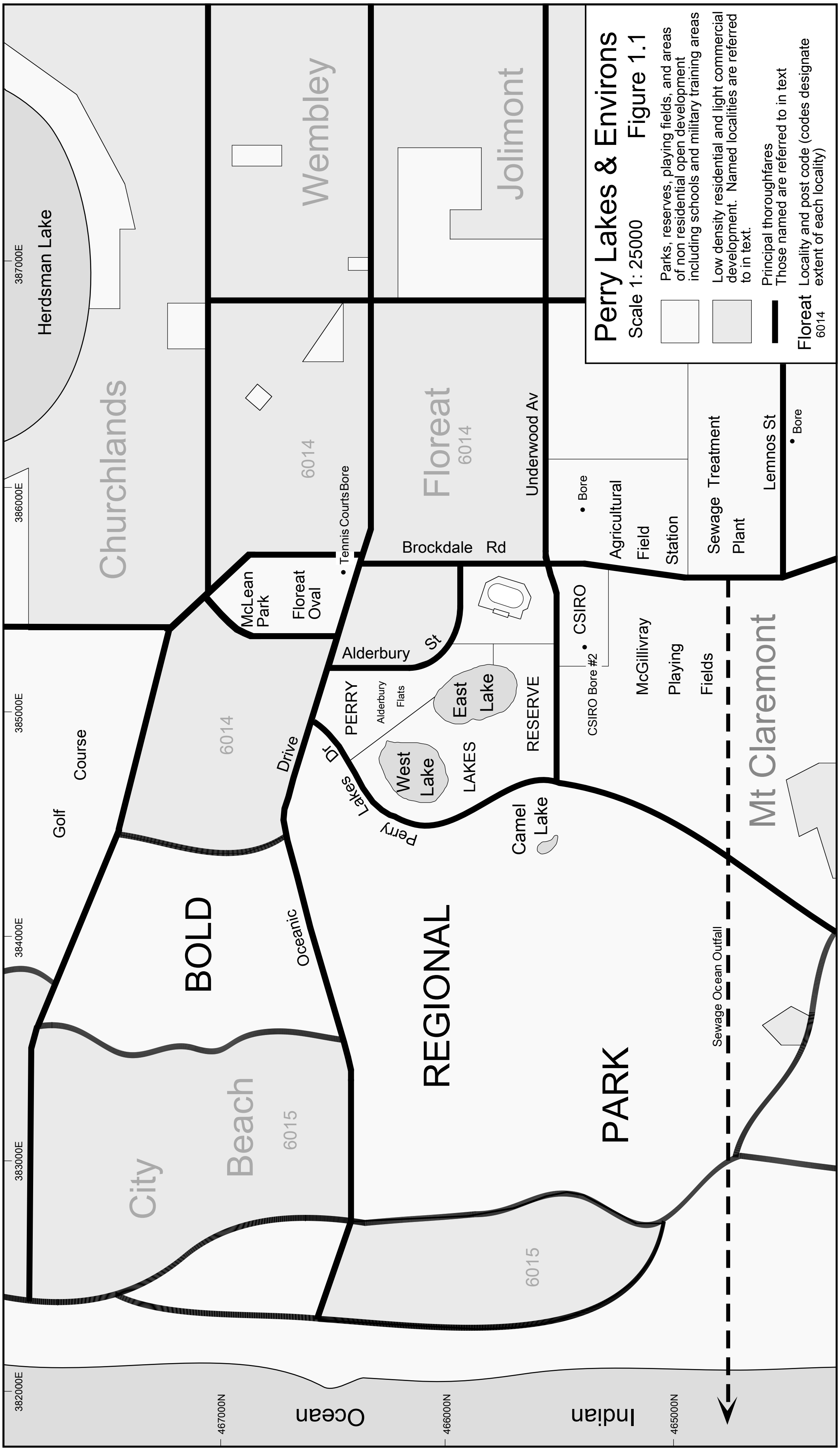
These recommendations form the basis of this thesis.

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
Figure 1.1
Scale 1: 25000
Parks, reserves, playing fields, and areas of non residential open development including schools and military training areas
Low density residential and light commercial development. Named localities are referred to in text.
Principal thoroughfares
Those named are referred to in text
Floreat 6014
Locality and post code (codes designate extent of each locality)
Herdsman Lake
Churchlands
Wembley
Jolimont
Floreat
6014
Golf Course
McLean Park
Floreat Oval
Tennis Courts Bore
Brockdale Rd
Underwood Av
Alderbury St
Alderbury Flats
Drive
Perry Lakes Dr
PERRY LAKES RESERVE
East Lake
West Lake
Camel Lake
CSIRO
CSIRO Bore #2
Bore
Agricultural Field Station
Sewage Treatment Plant
Lemnos St
McGillivray Playing Fields
Mt Claremont
BOLD PARK
REGIONAL
Oceanic
City Beach
6015
Sewage Ocean Outfall
Indian Ocean
382000E
383000E
384000E
385000E
386000E
387000E
467000N
466000N
465000N

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.

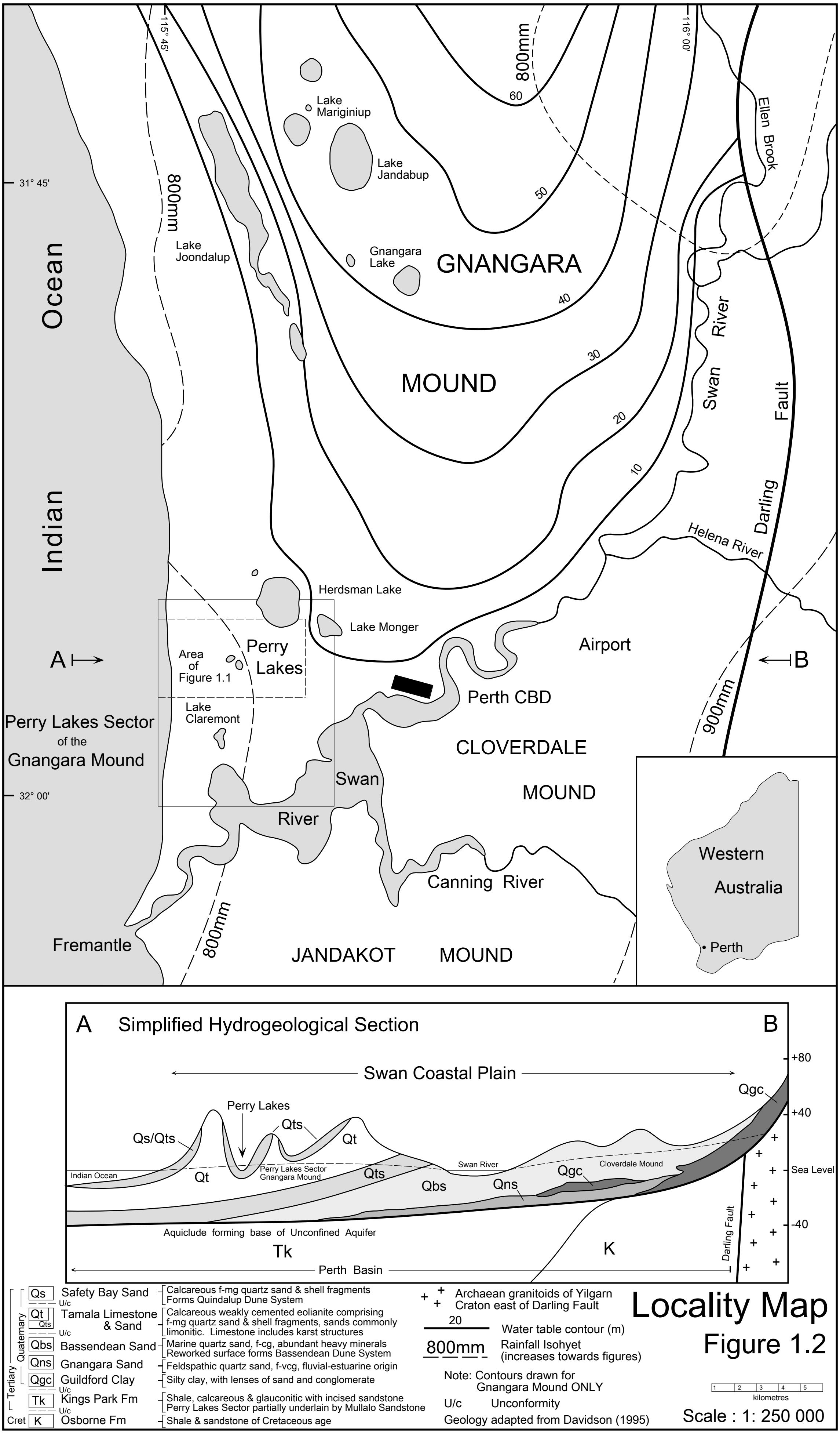
1.4 SWAN COASTAL PLAIN HYDROLOGY

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).



Locality Map

Figure 1.2

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.

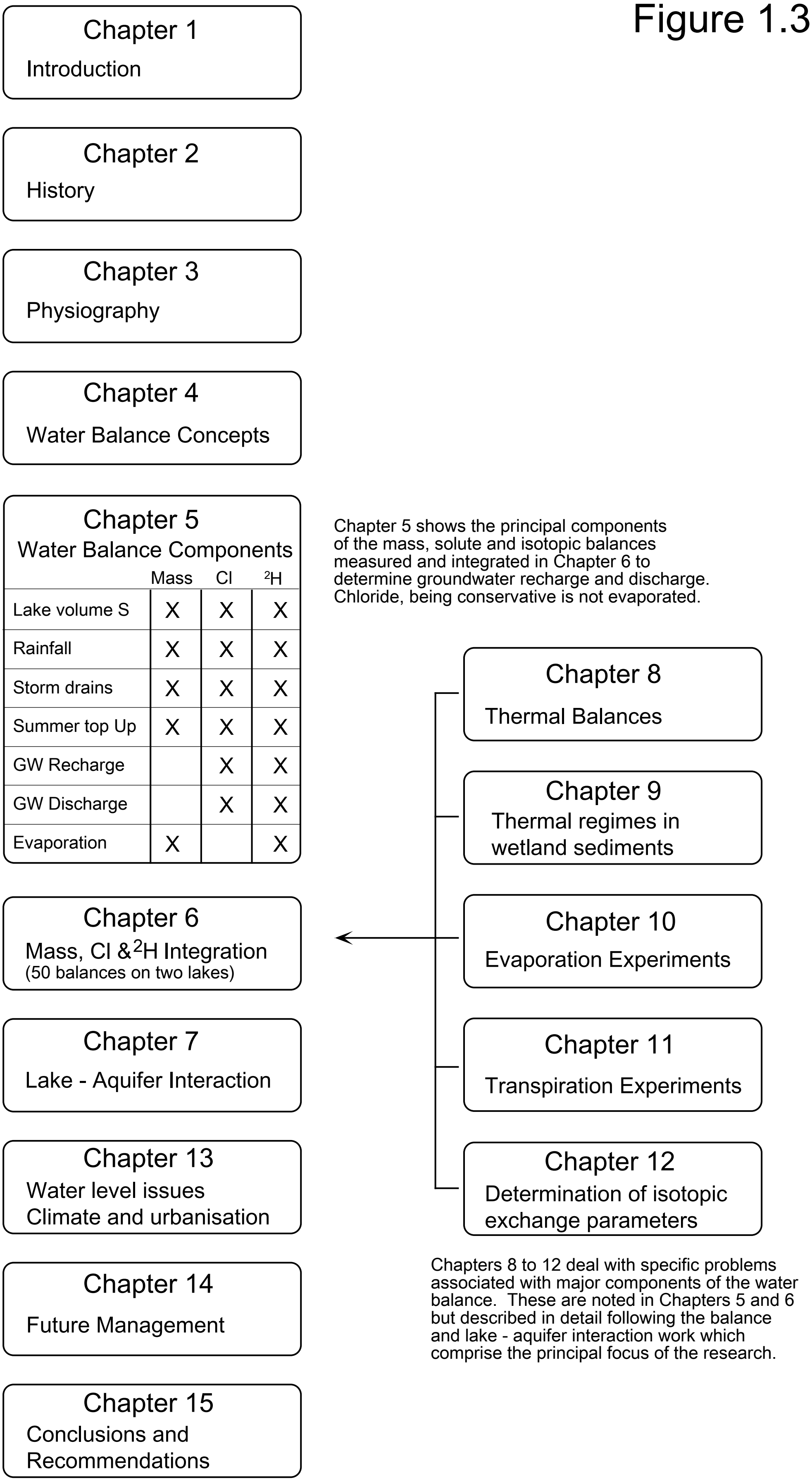
An added complexity of the isotopic balance was the requirement to quantify isotopic exchange parameters relating to evaporation and atmospheric vapour. While these could be estimated using empirically derived general equations, a more rigorous approach was proposed in which they would be experimentally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