CHAPTER
15

CONCLUDING SUMMARY

15.0 INTRODUCTION

This study has been a very detailed and holistic examination of one wetland system. The principal conclusions and observations therefore cover a wide range of topics. Some are specific to Perry Lakes while others are more general and have application to other wetlands, in particular those on the Swan Coastal Plain. Following are the principal conclusions or observations made in Chapters 6-14 followed by the principal recommendations for future study and wetland management.

15.1 CONCLUSIONS

Chapter 6 Water Balance Integration

Integrated mass, solute (chloride) and isotopic (deuterium) balances confirm that East Lake operates as a flow-through lake in late winter and a recharge lake the rest of the year when it receives substantial imported water via storm drains and artificial summer ‘top up’. Levels in the surrounding aquifer have been declining for about 40 years. West Lake is now dry for about 6 months of each year (apart from an artificially deepened ‘sump’ dug around the staff gauge). East Lake would be dry for a similar period without artificial maintenance.

In their original state such wetlands probably functioned as flow-through lakes for most if not all of the year. Under natural conditions they were maintained solely by direct rainfall and groundwater discharge. They had no riparian inputs. Most wetlands on the Swan Coastal Plain now operate as storm water infiltration basins. Groundwater discharge is reduced and replaced by ‘non natural’ inputs. The most significant result of the integrated balances was the non symmetrical nature of East Lake under flow-through conditions. It was assumed that in winter at least groundwater discharge and recharge would more or less balance each other. The storm drain inputs however are so large that even under flow-through conditions the lake always tends towards a recharge state. The dividing streamline tends towards the up gradient shore and groundwater discharge is significantly diminished. Table 15.1 shows the principal mass balance components for 1997.

Table 15.1 Mass balance components East Lake 1997

	GW Recharge	Top Up	Drains	Evaporation	Rain	GW Discharge	Total 1997
Mass (m^3)	-205,289	+155,017	+56,398	-49,299	+29,468	+11,957	507,428
Percent	40.5	30.5	11.1	9.7	5.8	2.4	100.0

Signs indicate water added to (+) or lost (-) from the lake

Non natural inputs (drains and summer top up) accounted for 41.7% of the annual mass budget. The annual ratio of groundwater discharge:recharge was 1:17, whereas under pre urban natural conditions it probably approached 1:1. In 1997 groundwater discharge comprised just 2.4% of the annual mass budget.

Chapter 7 Lake-Aquifer Interaction

Mini piezometer studies confirmed that in winter when East Lake is in flow-through status, the dividing stream line lies close to the up gradient shore. Storm water inputs constantly force the lake towards recharge status. There is an oscillation between flow-through and recharge flow states during storm events. During summer the water table now lies below the deepest point of both lakes. Allowing East Lake to shrink and approach dryness confirmed that flow-through (or potential flow-through) is maintained as the lake shrinks and becomes confined to the clay lining. Where sections of the lake became detached as separate ponds during the drying process, transitory discharge regimes become established.

In summer East Lake is maintained against a falling water table by filling it with locally derived groundwater. The lake becomes a local mound surrounded by a water table further depressed by pumping both to maintain water in East Lake and irrigate lawns. The water table gradient west of the lake steepens and the gradient east of the lake is frequently depressed to the point where significant ‘reverse flow’ zones occur with water flowing against the regional trend from a mounded East Lake into pumping depressions around the major bore fields. Despite being strongly mounded East Lake never ‘detaches’ from the aquifer. Pump spikes are evident in hydrographs throughout the summer.

When viewed over a year East and West Lake present a highly dynamic, highly modified wetland system. A typical summer pattern comprises East Lake artificially maintained as a local groundwater mound. The lake is in permanent recharge flow state. There is a steep gradient between East and West Lakes resulting in a strong flow towards West Lake. West Lake becomes a small residual pond which maintains a flow-through regime throughout the summer. The strong gradient from East Lake serves to enhance groundwater discharge into West Lake. Late summer storms can fill both lakes in a matter of hours. Both then become recharge lakes with a large shared release zone.

Flow-through is established in both lakes over winter. Initially the lakes function as separate systems however as winter progresses shared capture and release zones are established. As summer approaches the lakes shrink and separate capture and release zones re-establish. Generally in October or November the wetland managers commence pumping groundwater for summer lake maintenance and the typical summer flow pattern returns. East Lake becomes a recharge lake with local groundwater mound while West Lake shrinks almost to dryness while maintaining flow-through status.

Historic hydrograph data from the Wembley-Floreat area confirms that regionally, groundwater levels everywhere have declined in response to decreased rainfall and recharge and increased extraction. At Perry Lakes however, the absolute amount of decline has been greater. Indeed the rate of decline has increased in recent years whereas regionally it has been constant. This strongly suggests that at Perry Lakes, groundwater extraction has had a disproportionately greater effect than elsewhere.

Wetland managers are now at the limit of what is possible in terms of artificially maintaining East Lake through pumping local groundwater. The lake is the visible top of a local groundwater mound which pumping attempts to maintain against a falling regional water table, locally depressed further by irrigation extraction, increased transpiration and open water evaporation. The rate of mound decay is further enhanced by reduced water viscosity and higher effective lake lining hydraulic conductivity.

Chapter 8 Thermal Balance

As far as we are aware this represents the first thermal balance to be completed on a Swan Coastal Plain wetland. Table 15.2 shows the relative scale of all thermal terms on an annual basis. It is important to remember that seasonally some terms such as the sediment heat flux (Qse) and the heat energy stored in the lake (Qx) change sign, tending to almost cancel on an annual basis.

The sediment heat flux term (Qse), which has often been ignored in other studies, is a significant component of the thermal balance in shallow coastal wetlands. In East Lake evaporation (1997) calculated by thermal balance without considering Qse was 1468.4mm compared to the floating pan benchmark of 1378.8mm (a 6.5% over estimate). Over a year much of the error cancels out because the thermal balance both over and under estimates evaporation however within individual balance periods very large errors can occur. Greatest over estimate was 50.9% (June 1997, balance period 34). Greatest under estimate was –53.1% (August 1997, balance period 38).

Table 15.2 Thermal balance summary 1997

Term	Explanation	Heat W m^{-2}
Qbs	Long wave radiation emitted from the water	-151272
Qa	Incoming long wave radiation	124647
Qs	Incoming short wave radiation	84877
Qe	Energy used for evaporation	-39109
Qrc	Heat in lake water recharged to the aquifer	-6588
Qsr	Reflected short wave radiation	-5945
Qh	Energy conducted from the water as sensible heat	-5539
Qtu	Heat in top up water	4646
Qar	Reflected long wave radiation	-3739
Qse	Heat conducted into and out of the lake sediments	-2466
Qw	Energy advected from the water body via evaporated water	-1553
Qsd	Heat in storm water	962
Qrn	Heat in rain falling directly on the lake	441
Qx	Change in heat energy stored in the lake (T_m at final lake volume)	-283
Qdc	Heat in groundwater discharged to the lake	227

Positive terms are heat gained, negative terms are heat lost.

Chapter 9 Thermal Regimes in Wetland Sediments

When viewed seasonally the sediment heat flux term becomes much more important than might first be ascertained from Table 15.2. In extremely shallow wetlands such as East Lake, heat moves into and out of the sediments both diurnally and seasonally. In summer there is a net negative flux (heat moves from the water column into the sediments). In winter this reverses with a net flux from the sediments into the water column. The sediments act as a seasonal heat sink, storing substantial amounts of summer heat and returning it to the water column over winter. In East Lake positive winter sediment heat fluxes averaged 46.3 W m^{-2} over one 12 day period in early September.

Within the aquifer below a water table lake, heat is both conducted and advected. Close to the up gradient shore, during winter flow-through regimes heat is both advected and conducted from the sediments into the water column. In summer the situation is reversed. The lake is now in recharge and heat is both conducted and advected from the water column into the sediments. Therefore on the up gradient shore heat conduction and advection are additive both summer and winter. On the opposite shore summer heat is similarly conducted and advected into the sediments however in winter advection and conduction are opposed. Therefore flow-through lakes such as East Lake display very different thermal patterns below their up gradient and down gradient shores reflecting seasonal changes in both flow and thermal regimes.

Chapter 10 Evaporation

Class A pan coefficients were derived for Perry Lakes and the Bureau of Meteorology pan at Perth airport. Workers investigating Swan Coastal Plain wetlands within 3-4km of the coast should use the coefficients in Table 15.3.

Table 15.3 Pan coefficients for wetlands within 4km of the coast

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av
Pan	0.73	0.65	0.71	0.81	0.85	0.70	0.84	0.87	0.91	0.82	0.82	0.76	0.79
BoM	0.54	0.48	0.54	0.56	0.66	0.71	0.69	0.81	0.86	0.78	0.74	0.67	0.67

'Pan' refers to a class A pan operated adjacent to the wetland under study. 'BoM' refers to the Bureau of Meteorology pan at Perth airport.

Ten empirical equations for evaporation were calibrated against the East Lake evaporation as determined by floating Class A pan. Best performer was the Makkink equation which tracked the floating pan data closely throughout all seasons. The poorest performers were the Penman, DeBruin-Keijman, Priestley-Taylor and Brutsaert-Stricker methods all of which grossly over estimated late winter (August and September) evaporation.

Chapter 11 Transpiration

Experimental determination of annual transpiration from *Typha orientalis* was 27.6% of open water evaporation from East Lake. Typha dies back over winter. In summer (January to March) *Typha* transpiration rose to 43.2% of open water evaporation. *Baumea articulata* transpiration calculated for February through March only was 19.5% of open water evaporation. All data was calculated under non flooded conditions.

The results suggest that for East Lake the evapotranspiration from *Baumea* meadows was less than from a similar area of open water. The evaporation figures taken from the floating pan and used in the water balances are therefore slight over estimates.

Chapter 12 Isotope Experiments

Many natural water bodies undergoing evaporation, approach a limiting or isotopic steady state. This value will vary seasonally. Using pans evaporated to dryness and pans evaporated at constant volume, the limiting values can be used to determine $\delta_{E(lake)}$, the isotopic value of evaporate from the water surface. Knowing $\delta_{E(lake)}$ is a requirement for completing an isotopic balance. The meteorological conditions at the lake and pans should be similar. The most important requirement is identical thermal regimes in the pans and the lake. At Perry Lakes daily average $\delta_{E(lake)}$ was determined independently for East and West Lake using three methods:

- Equation 23 of Craig & Gordon (1965), critical parameters humidity, $\delta_{(lake)}$, δ_A with daily estimated average δ_A computed by interpolating weekly atmospheric sampling
- Equation 12 of Welhan & Fritz (1977), critical parameters humidity (as *m*), $\delta_{(lake)}$ and δ_S calculated from pans evaporated to dryness
- Equation 12 of Allison & Leaney (1982), critical parameters humidity (as *m*), $\delta_{(lake)}$ and δ_K calculated from pans evaporated at constant volume

The results obtained from all three approaches are different. The Craig and Gordon (1965) equation and the use of δ_K produced similar results although the mean daily and annual values of $\delta_{E(lake)}$ were about 40‰ greater using δ_K . The results using δ_S were much 'noisier' but with a gross similar annual pattern and difference of only about 11‰.

Isotopic balances were computed using:

- experimentally derived values of $\delta_{E(lake)}$ developed from constant volume pan δ_K
- empirically derived $\delta_{E(lake)}$ using the Craig and Gordon equation.

The resulting balances varied, on average, by less that 1%. This probably reflects the fact that in East Lake evaporation represents a small (<10%) component of the annual mass balance.

Chapter 13 Climate, Urbanization & Wetlands

The only consistent feature of climate is change. Natural variability is a normal feature of climate anywhere. Perth rainfall has exhibited extreme variability over the past 125 years and has been steadily decreasing for the past 40 years. Natural variability and anthropologically induced climate change are both operative but the relative role of each is difficult to gauge. The IOCI modelling however suggests that natural rainfall reductions of the magnitude affecting Perth over the past 40 years are rare. Greenhouse (increased atmospheric CO_2) modelling however can account for such changes. The models suggest a prolonged (possibly 100 to 150 year) decline in rainfall. Perth rainfall also exhibits well defined cyclicity with a frequency of 20 to 21 years. Suggested links with sunspot cycles remain speculative.

Simple water balance models of the Floreat, Wembley and City Beach areas suggest that groundwater extraction already exceeds recharge despite the enhanced recharge effects associated with urbanisation. Further reduced rainfall and increased extraction appear likely.

Wetland managers must take into account:

- decreasing rainfall trends over the past 40 years
- long range IOCI greenhouse modelling of further reduced rainfall
- on going urban sprawl and its increasing relative and absolute reliance on groundwater
- the likelihood that water conservation will continue to receive lip service only

These trends strongly suggest that groundwater levels in the Perry Lakes area are likely to continue declining and engineered solutions may represent the only viable option for preservation of these wetlands.

Chapter 14   Future Management

The state government needs to look seriously at reducing both the absolute and per capita amounts of groundwater it extracts in metropolitan Perth. It needs to seriously formulate and implement strategies to reduce groundwater extraction. These might include (but are not limited to) proclaiming all of metropolitan Perth as a *Groundwater Area*, capping the drilling of new domestic bores, licensing existing bores (with possible sliding scales of water usage fees), public education with a 'rural ethos' regarding water conservation, revised domestic (reticulated) water pricing which rewards 'water wise' and penalises 'water wasting' customers, better urban design which minimises European style lawn and gardens and maximises recharge, and reticulation of waste water from sewage treatment plants for toilet flushing and garden use. Possibly the single most important consideration would be serious regional planning which is proactive rather than reactive and which places a non negotiable limit on Perth's urban sprawl.

Perth appears likely to continue expanding and extracting greater absolute and per capita amounts of groundwater from the unconfined aquifer. This coupled with decreased rainfall and recharge will cause the water table to continue declining both within and outside the urban area. Wetlands which once contained permanent water will either shrink or become dry for part of each year. Permanent wetlands will become sumplands and sumplands will become damplands.

15.2 RECOMMENDATIONS

Perry Lakes

The detailed water balances provide the basis for further wetland modelling, in particular an extension of the work by Townley *et al* (1993 a&b) and Nield *et al* (1994), applying real data to the theoretical models.

The Town of Cambridge as wetland managers should initiate discussions with the state to examine the feasibility of artificially maintaining Perry Lakes using either surplus water from Herdsman Lake and/or tertiary treated waste water from the Subiaco treatment plant. The natural rejuvenation of the lakes requires a long term increase in rain. Even then potential increases in recharge may be off set by increased extraction elsewhere in the system. In other words it is highly unlikely that Perry Lakes will be rejuvenated naturally in the foreseeable future. Unlike other Perth wetlands there are two readily available sources of water nearby which could see the lakes maintained artificially indefinitely.

Further Research

The central theme of this study has been detailed water balances of two wetlands. This needs to be extended regionally to detailed balances and computer modelling of the Perry Lakes sector of the Gnangara Mound and ultimately to the entire Gnangara Mound. The simplistic modelling completed in this study suggests (but does not prove conclusively) that groundwater extraction and reduced rainfall are the principal factors in the groundwater decline at Perry Lakes. The Perry Lakes sector cannot really be treated in isolation from the remainder of the Perth metropolitan area or the Gnangara Mound. The modelling would take into account present and anticipated urban expansion and in particular look at present and anticipated extraction from public and private bores. It would also consider long term reductions in rainfall and recharge. The ultimate purpose would be to ensure that Perth’s wetlands are not sacrificed at the alter of political expediency, endless urban expansion and an insatiable public demand for water.

In Perth truly sustainable yield is possible only from that additional recharge which comes about from increased impermeable shedding surfaces within the urban landscape. Extraction beyond that amount comes with a price, in this case degradation and ultimately the disappearance of wetland systems.