CHAPTER

5

WATER BALANCE COMPONENTS

5.1 INTRODUCTION

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

Table 5.1 Mass balance components

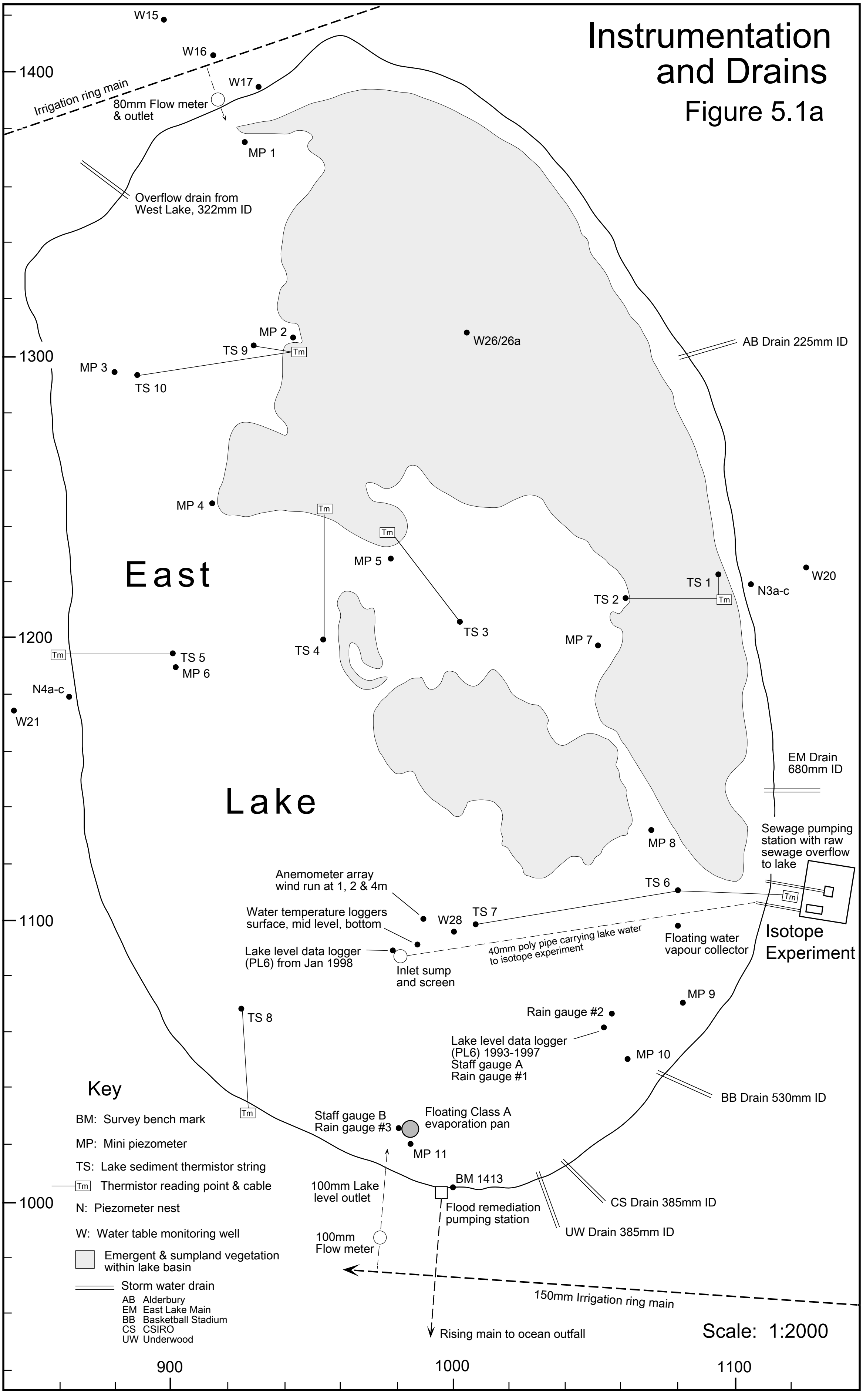
Component	Mass	Cl	^2H	Heat
Lake volume	X	X	X	X
Rainfall	X	X	X	X
Summer maintenance	X	X	X	X
Evaporation	X		X	
Transpiration	X			
Storm water	X	X	X	X
Groundwater discharge		X	X	X
Groundwater recharge		X	X	X

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

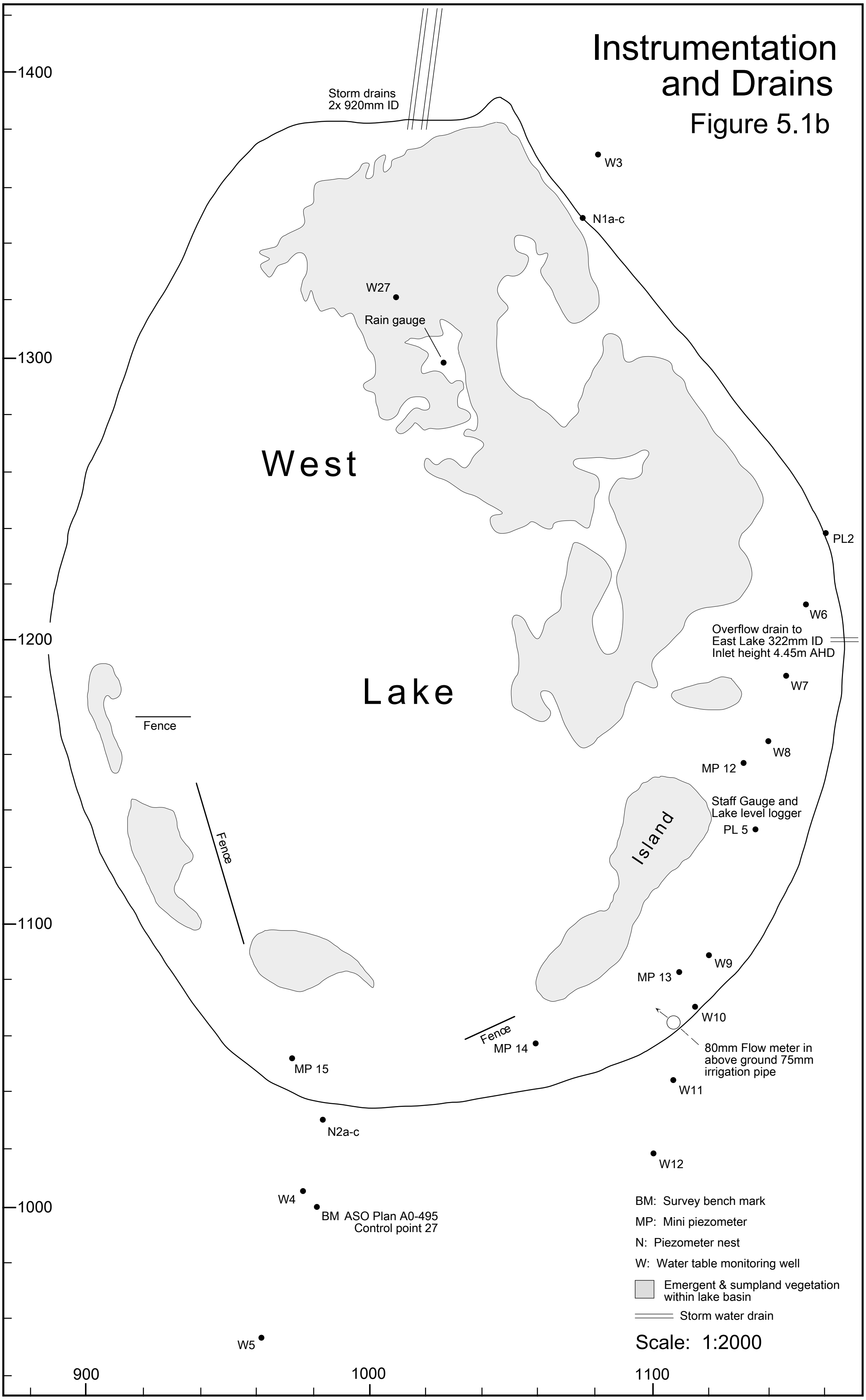
Figures 5.1a and 5.1b detail the locations of all sampling equipment and infrastructure described in this and subsequent chapters.

5.2 LAKE VOLUME

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



Instrumentation
and Drains
Figure 5.1a
W15
W16
W17
1400
Irrigation ring main
80mm Flow meter
& outlet
MP 1
Overflow drain from
West Lake, 322mm ID
MP 2
TS 9
MP 3
TS 10
1300
W26/26a
AB Drain 225mm ID
MP 4
MP 5
East
TS 1
W20
N3a-c
TS 2
TS 3
TS 4
MP 7
1200
TS 5
MP 6
N4a-c
W21
EM Drain
680mm ID
Lake
MP 8
Sewage pumping
station with raw
sewage overflow
to lake
Anemometer array
wind run at 1, 2 & 4m
TS 6
Water temperature loggers
surface, mid level, bottom
W28
TS 7
1100
Lake level data logger
(PL6) from Jan 1998
40mm poly pipe carrying lake water
to isotope experiment
Floating water
vapour collector
Isotope
Experiment
Inlet sump
and screen
TS 8
MP 9
Rain gauge #2
Lake level data logger
(PL6) 1993-1997
Staff gauge A
Rain gauge #1
MP 10
BB Drain 530mm ID
Key
BM: Survey bench mark
MP: Mini piezometer
TS: Lake sediment thermistor string
Thermistor reading point & cable
N: Piezometer nest
W: Water table monitoring well
Emergent & sumpland vegetation
within lake basin
Storm water drain
AB Alderbury
EM East Lake Main
BB Basketball Stadium
CS CSIRO
UW Underwood
Staff gauge B
Rain gauge #3
Floating Class A
evaporation pan
MP 11
BM 1413
100mm Lake
level outlet
1000
Flood remediation
pumping station
CS Drain 385mm ID
UW Drain 385mm ID
100mm
Flow meter
150mm Irrigation ring main
Rising main to ocean outfall
Scale: 1:2000
900
1000
1100
Tm


Instrumentation
and Drains
Figure 5.1b
Storm drains
2x 920mm ID
W3
N1a-c
W27
Rain gauge
West
Lake
PL2
W6
Overflow drain to
East Lake 322mm ID
Inlet height 4.45m AHD
W7
Fence
W8
MP 12
Staff Gauge and
Lake level logger
PL 5
Island
Fence
W9
MP 13
W10
Fence
MP 14
80mm Flow meter in
above ground 75mm
irrigation pipe
MP 15
W11
N2a-c
W12
W4
BM ASO Plan A0-495
Control point 27
BM: Survey bench mark
MP: Mini piezometer
N: Piezometer nest
W: Water table monitoring well
Emergent & sumpland vegetation
within lake basin
Storm water drain
Scale: 1:2000
W5
1400
1300
1200
1100
1000
900
1000
1100

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

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

5.3 RAIN

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

5.4 SUMMER LAKE LEVEL MAINTENANCE

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

5.5 EVAPORATION

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

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

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

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

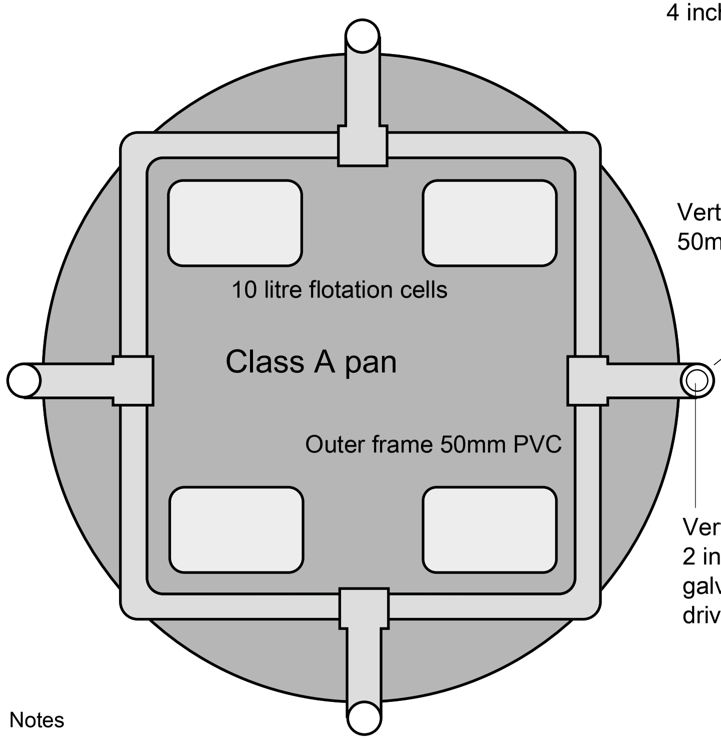
- absolutely minimal wind and solar shading
- stability without the use of rafts
- provisions to increase flotation when heavy rain is expected
- ease of levelling and stabilising pan during readings
- wave damping mechanism

Floating Evaporation Pan Detail

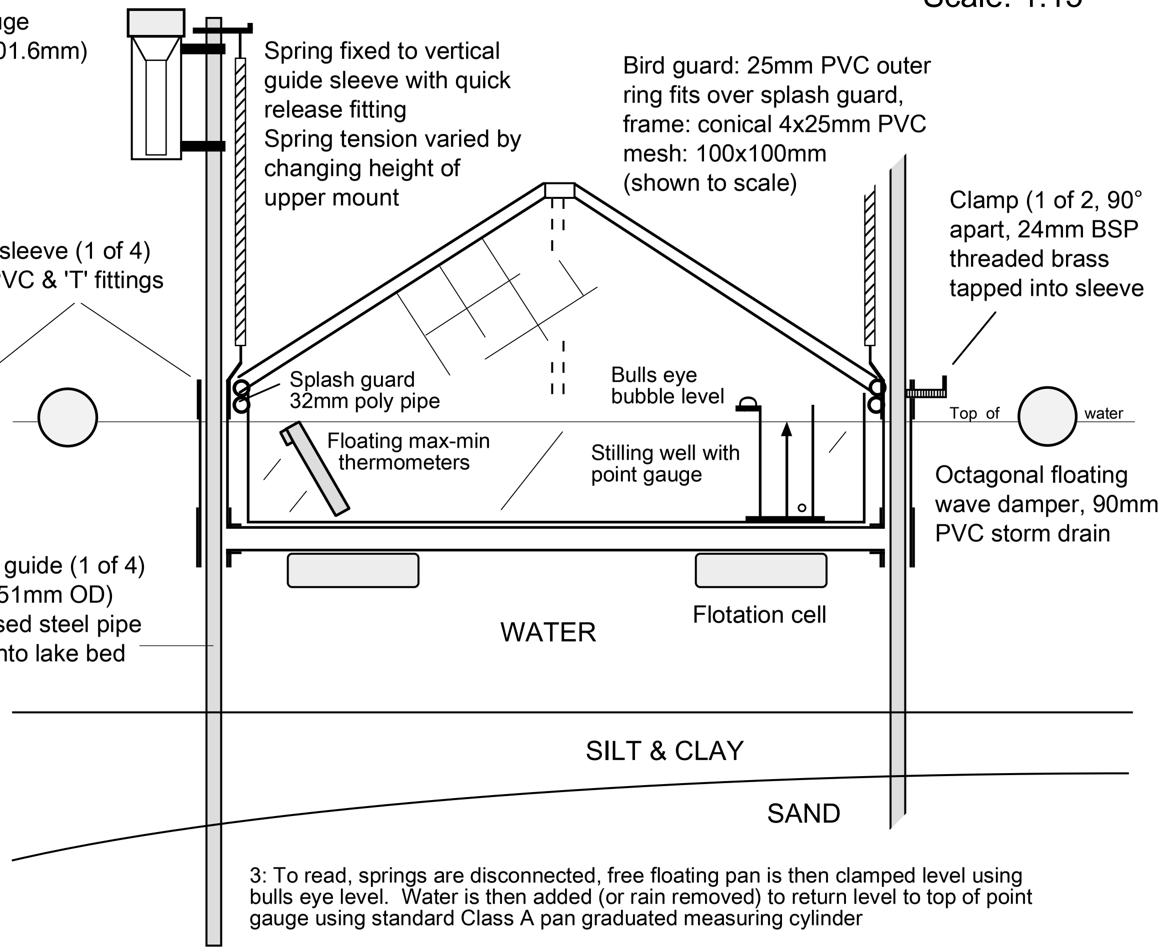
Figure 5.2

Scale: 1:15

Bottom View



Side View



Notes

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

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

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

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

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

5.6 STORM WATER

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

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

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

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

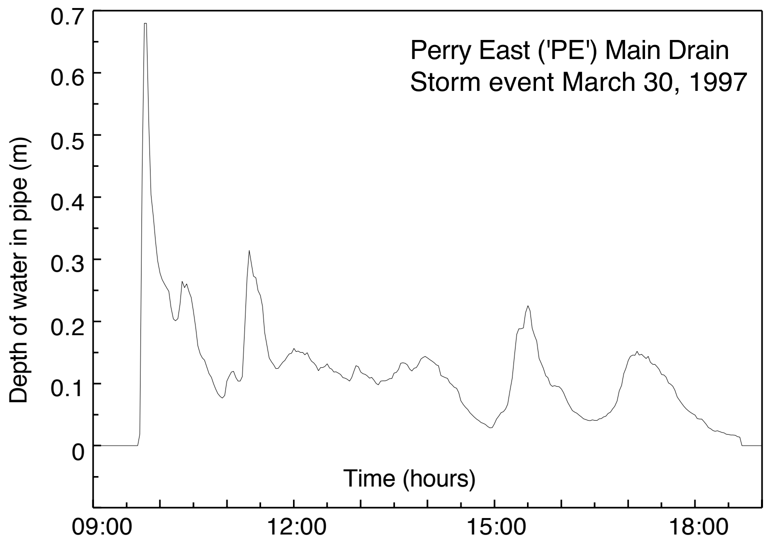


Figure 5.3 Drain response during strong frontal passage. Perry East Main Drain, data recorded every 2 minutes. In this particular case the pipe went from dry to full flow in just 4 minutes. In this event the pipe (diameter 680mm) flowed fully charged for 5 minutes. Four distinct 'events' of lessening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

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

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

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

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

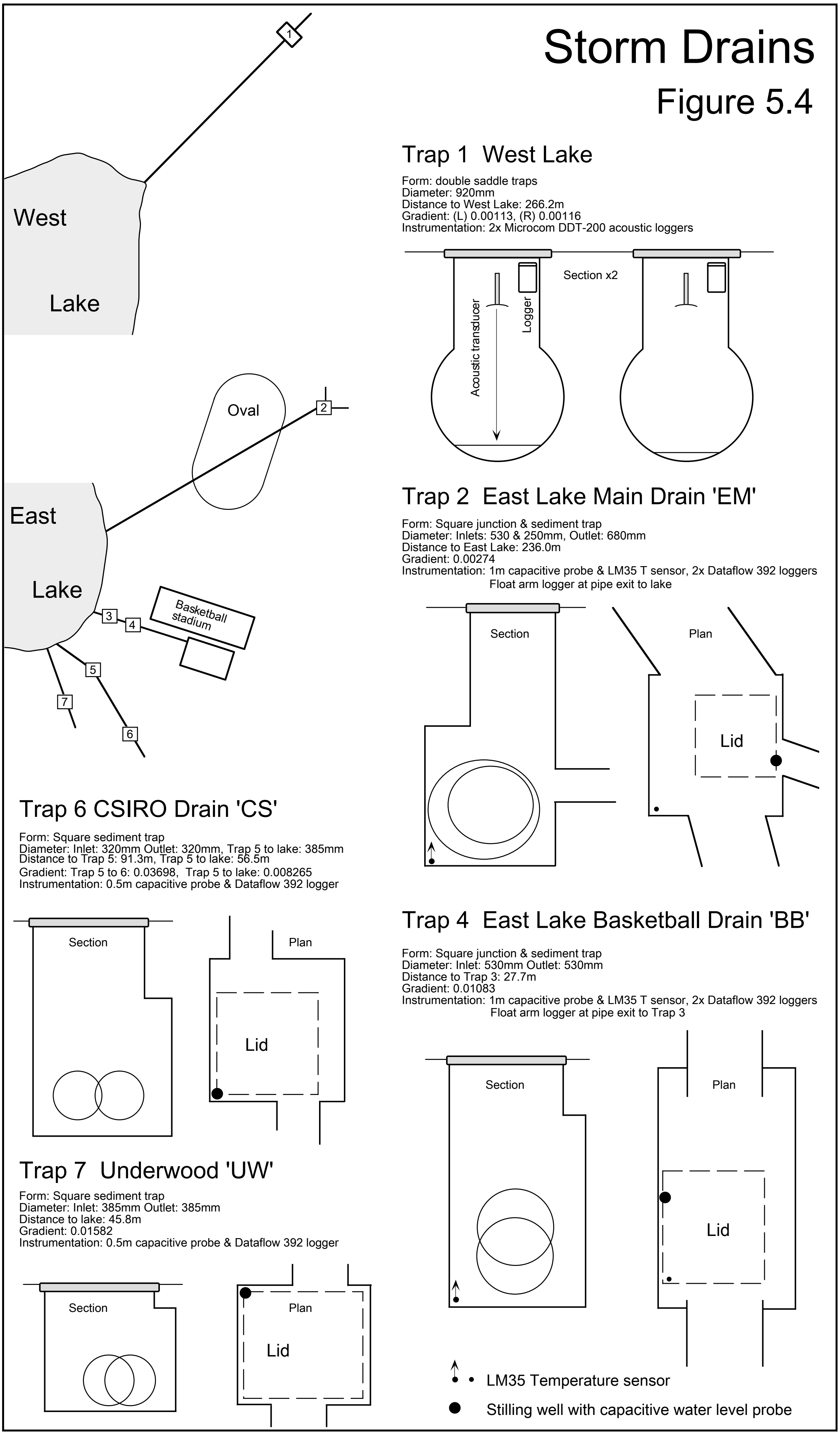
Measurement of pipe flows at Perry East was rendered extremely difficult due to the following:

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

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

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

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


Storm Drains
Figure 5.4
West
Lake
Oval
East
Lake
Basketball stadium
1
2
3
4
5
6
7
Trap 1 West Lake
Form: double saddle traps
Diameter: 920mm
Distance to West Lake: 266.2m
Gradient: (L) 0.00113, (R) 0.00116
Instrumentation: 2x Microcom DDT-200 acoustic loggers
Section x2
Acoustic transducer
Logger
Trap 2 East Lake Main Drain 'EM'
Form: Square junction & sediment trap
Diameter: Inlets: 530 & 250mm, Outlet: 680mm
Distance to East Lake: 236.0m
Gradient: 0.00274
Instrumentation: 1m capacitive probe & LM35 T sensor, 2x Dataflow 392 loggers
Float arm logger at pipe exit to lake
Section
Plan
Lid
Trap 6 CSIRO Drain 'CS'
Form: Square sediment trap
Diameter: Inlet: 320mm Outlet: 320mm, Trap 5 to lake: 385mm
Distance to Trap 5: 91.3m, Trap 5 to lake: 56.5m
Gradient: Trap 5 to 6: 0.03698, Trap 5 to lake: 0.008265
Instrumentation: 0.5m capacitive probe & Dataflow 392 logger
Section
Plan
Lid
Trap 4 East Lake Basketball Drain 'BB'
Form: Square junction & sediment trap
Diameter: Inlet: 530mm Outlet: 530mm
Distance to Trap 3: 27.7m
Gradient: 0.01083
Instrumentation: 1m capacitive probe & LM35 T sensor, 2x Dataflow 392 loggers
Float arm logger at pipe exit to Trap 3
Section
Plan
Lid
Trap 7 Underwood 'UW'
Form: Square sediment trap
Diameter: Inlet: 385mm Outlet: 385mm
Distance to lake: 45.8m
Gradient: 0.01582
Instrumentation: 0.5m capacitive probe & Dataflow 392 logger
Section
Plan
Lid
LM35 Temperature sensor
Stilling well with capacitive water level probe

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

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

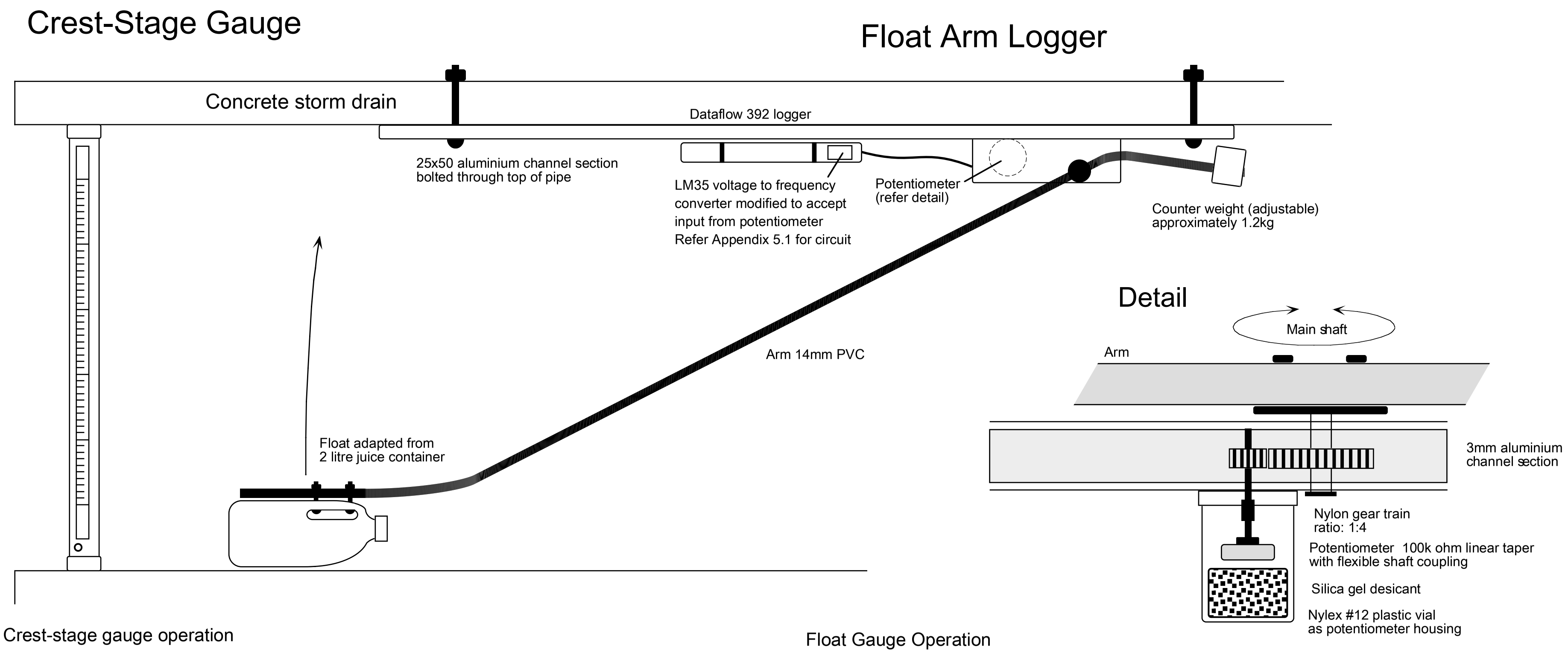
Table 5.2 Storm drain instrumentation

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

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

Drain Loggers

Figure 5.5



Crest-stage gauge operation

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

Float Gauge Operation

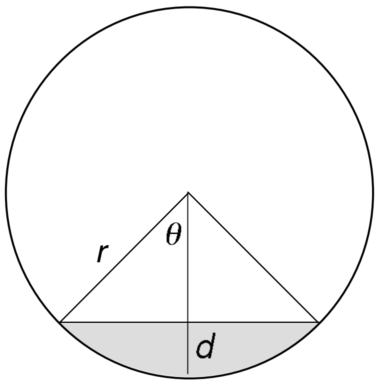
Counter weight is adjusted so float just skims top of water
Length of arm is adjusted depending on pipe diameter such that arm rotates through about 20° when pipe is half full, equivalent to 80° rotation of potentiometer shaft
Installation must be calibrated in situ
Logger typically scans every 1-2 minutes

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

Calculation of Discharge Volumes East Lake

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

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



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

Area of the wetted section *A* is

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

and length of wetted perimeter *P* is

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

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

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

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

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

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

Final Calibration East Lake

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

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

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

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

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

Table 5.3 Computation of aggregate storm drain discharge

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

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

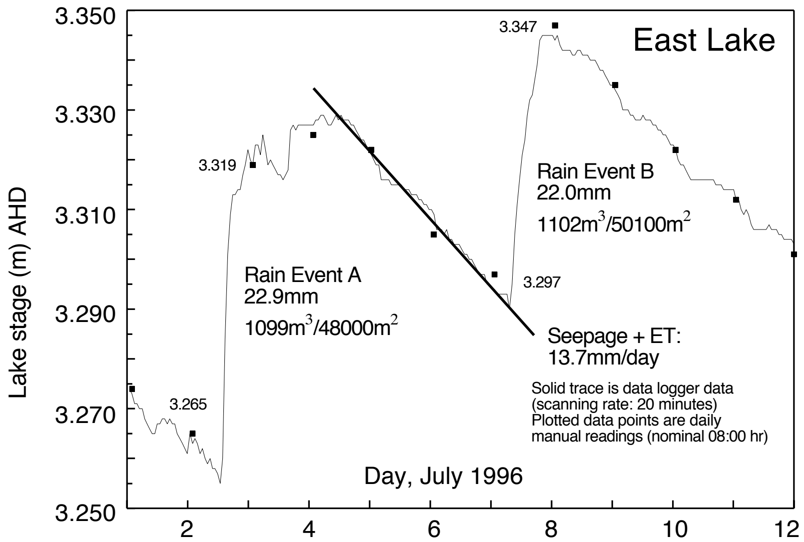


Figure 5.6 East Lake drain calibration events, July 1996. At this time during early winter, any inputs raise the lake above the surrounding water table (recharge flow conditions). Slope of the 'seepage' line represents a combination of recharge (seepage) and evapotranspirative losses. Inputs are direct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

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

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

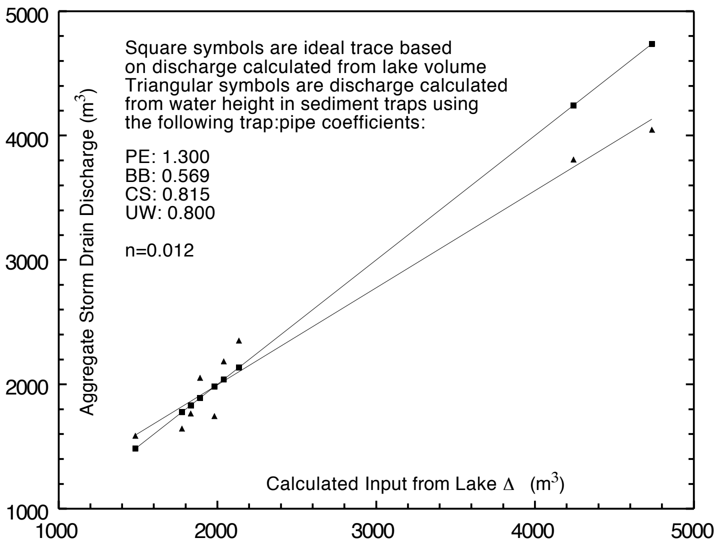


Figure 5.7 Aggregate PE, BB, CS & UW drain discharge plotted against estimates of drain discharge from lake volume change for 9 storm events. The figure includes the final trap:pipe coefficients used to compute all East Lake storm drain discharge volumes. Despite their frequent transition to supercritical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

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

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

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

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

Calculation of Flow Volumes West Lake

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

Estimation of Missing Data

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

5.7 SOLUTE AND ISOTOPIC SAMPLING

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