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ECOSYSTEM SCIENCE PROGRAM

Hydrological response of Toolibin Lake to inundation in February 2017

Prepared for DBCA Parks and Wildlife Service's Wheatbelt Region

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Ecosystem Science

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GOVERNMENT OF WESTERN AUSTRALIA

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Disclaimer

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Cover image reference

Breach of Toolibin Lake bund, February 2017 (photograph by Peter White).

Contents

Figures

Tables

Executive summary

The Department of Biodiversity, Conservation and Attractions is undertaking research to improve the hydrological understanding of key Wheatbelt catchments and wetlands in order to develop adaptive management strategies. One of the main catchments being investigated is the Toolibin Lake Catchment where existing quantitative conceptual and numerical models are being used and improved to assess the Toolibin Lake water balance and determine the effectiveness of managing the hydrology (e.g. groundwater pumps and surface water engineering structures) to return the lake to a perched status. Models under improvement include groundwater and surface water interactions on Toolibin Lake and an opportunity to collect data to refine these models was presented when Toolibin Lake became inundated in February 2017.

In February 2017 (7th to 11th February 2017) a series of rainfall events occurred across the Great Southern District. Over a 72-hour period more than 100 mm was delivered across the catchment area of Toolibin Lake, representing a 1-5 % probability of occurrence in any given year (greater than a 20-year ARI (Annual Recurrence Interval)). On 11th February 2017, the separator diversion gates at the inlet to Toolibin Lake were closed, thereby diverting fresh (salinities less than 1,000 mg/L total dissolved solutes (TDS)) surface water to the lake. On the 12th February 2017 water levels in the lake peaked at 2.24 m, equating to about 4,094 ML, covering a surface area of 273 Ha. The lake was inundated for over twelve months, with the recession commencing in late winter 2017. Lake water levels receded at a rate of around 4.3 mm per day, until April 2018, when the lake had receded to several isolated pools.

The operation of the hydrological management infrastructure was undertaken in accordance with the Departments procedures however failure of the bund wall occurred along the lake's western boundary. The bund wall was promptly repaired by plugging with sandbags as a temporary measure to minimise surface water losses and further damage to infrastructure. The surface water diversion infrastructure was designed to carry an event of a 10-year ARI, or a 10% probability of occurrence in any given year. The height of the bund wall was found to be within the design specifications, however since its construction the bunds have eroded, which increased the risk of failure. A review of the original design specifications shows compliance apart from where modifications couldn't be implemented, or refurbishment has occurred.

Following the February 2017 rainfall event a revised hydrological (groundwater and surface water) monitoring program was developed to;

- Build upon the long-term datasets that have been acquired,
- Characterise and understand the lake water balance and
- Provide data for input to a numerical model being developed to assess the long-term effectiveness of the groundwater pumping.

The surface water monitoring program included the collection of mainly fortnightly manual lake water level measurements at the lakes' main depth gauge (Site F – see map Appendix 4) and in October 2017, following a lake water profiling study, data loggers were installed (Sites N, E & F – see map Appendix 4) to collect hourly lake level and water quality (electrical conductivity) data.

Surface water data collected were periodically imported and viewed within an analytical water and salt balance model WatBal (e.g. Peck 2000 and Hydrological 2016). This was undertaken to compare the magnitude of the 2017 inundation event with historical inundation events and assist in predicting the length of time water would remain in the lake prior to the salinity management trigger of ~5,000 mg/L TDS being exceeded, and management actions implemented.

The WatBal water balance model outputs generally show a good agreement with the observed water levels and salinity over the long-term (1978-2018) record. For the February 2017 event the model overestimates lake water levels and underestimates the rate of recession, particularly when the lake surface water level drops below around one metre. High frequency surface water level and quality data show the lake water level is around 296.6 mAHD (e.g. ~0.6 metres) when the ~5,000 mg/L TDS management trigger is reached. Rates of evaporation vary across the lake resulting in salt loads of between 560 and 920 Tonnes occupying around 27% of the lake floor.

The overestimation of lake water levels in WatBal is likely to be caused by the model not accounting for seepage to the unsaturated zone and groundwater in the initial stages of this summer inundation. Groundwater level monitoring data were collected from both the surficial (unconfined) and deeper saprolite and sedimentary (semi-confined) aquifers. Data and information on the activity and performance of pumping bores, installed in the 1990's to remove saline groundwater from aquifers beneath Toolibin Lake, was also compiled.

Monitoring results show that groundwater levels in all aquifers increase following the February 2017 rainfall event, with rates of change being variable and the average groundwater increase being around four metres. Following this rise, groundwater levels in the surficial aquifer either remained constant, until decreasing in December 2017, or displayed a seasonal response in 2017 (decline in March to May 2017 and increase in July and August 2017). Deeper aquifer's mimic these trends, with some bores showing a response to pumping in addition to seasonal rainfall (July and August 2017). The variation in the magnitude and duration of these responses appear to reflect the pumping schedule and bore location (e.g. distance of monitoring bores from pumping bores and groundwater levels displaying a rebound following a break in pumping and decreasing on the recommencement of pumping).

The complexity of the groundwater level responses makes it difficult to estimate the influence of groundwater pumping on inducing seepage of lake water into the unsaturated zone and aquifers. The WatBal model cannot easily be used for this task as it doesn't explicitly model deep drainage of soil water into aquifers, or account for groundwater pumping.

Findings from this work show that simple analytical models are useful tools when Toolibin Lake had higher lake levels (> 1 metre) and exhibited homogeneous behaviour. These models were less accurate when near-surface heterogeneity became apparent. Most notably when accounting for groundwater pumping, lake water seepage to the unsaturated zone and aquifers, and when the lake water body separated, and evaporation rates become spatially variable.

Results from the analytical models trialled here are therefore limited without both supporting observations (manual and high frequency) to identify spatial variability. This will be investigated in follow up work undertaken by DBCA in 2019, which includes the use of a numerical model to account for lake water seepage and the influence of pumping groundwater. Changes in soil water and groundwater quality beneath Toolibin Lake will also be quantified using repeat borehole geophysical logging and sampling of environmental tracers to quantify recharge, aquifer mixing and pumping induced flushing of aquifer solutes.

The Toolibin Lake inundation event of 2017 is the most significant event since 1983 and the largest since the construction of the surface water diversion channel, separator gates, controlled surface water outlet, and sump pump. The occurrence of this more significant rainfall event has provided the opportunity to;

1. Summarise and review the current surface water management infrastructure,
2. Test surface water infrastructure and produce a thorough chronological history of the event,
3. Document the process developed to alter the existing hydrological monitoring programs and collect fit for purpose data to improve our understanding of the hydrological function of Toolibin Lake and
4. Review management triggers and assess the benefits of following a scientific process where analytical predictions are proposed, monitoring recommended, data collected, and existing analytical models tested.

1 Background

Changes in the hydrology of Toolibin Lake and other Wheatbelt catchments, due to land clearing and climate change, has resulted in previously ephemeral fresh water wetlands developing a connection with deeper, saline groundwater and becoming degraded. A decline in average rainfall since the 1970s, combined with increasing summer temperatures, has seen a further decrease in wetland health as surface water flows and wetland hydroperiods decrease with respect to water quantity and quality. Robust management decisions require the main hydrological driver(s) of change to be identified and spatial and temporal fluxes (water and solutes) to be characterised.

In 2015 the Department of Biodiversity, Conservation and Attractions commenced a three-year investigation into the hydrology of key Wheatbelt catchments and wetlands (see DBCA BSC Project SPP2015-01) in order to advance understanding of hydrological behaviour of these systems. This work will be completed in 2019 and includes the updating of existing conceptual and numerical hydrological models to assess the Toolibin Lake water balance and determine the effectiveness of actively managing the hydrology (e.g. groundwater pumps and surface water engineering structures) to return the lake to a perched status. Models under improvement include groundwater and surface water interactions on Toolibin Lake and an opportunity to collect data to refine these models was presented when Toolibin Lake became inundated in February 2017.

Reductions in average annual rainfall became evident in the Wheatbelt in the 1970's. However, high intensity summer rainfall events appear to be increasing as cyclonic fronts persist inland, moving south-easterly from the north and central west Western Australia coastline (Muirden and Coleman 2014). In the Wheatbelt these events are more likely to provide low salinity surface water flows compared to winter events. This is interpreted to occur due to a reduction in summer surface water – groundwater interactions, when lower moisture content in the soil and upper regolith encourages water repellence and increased runoff (Rutherford et. al. 2015).

Due to their low salinity water the summer events are the preferred key climatic events to trigger management actions that facilitate water entering the lake (e.g. opening the separator gates) to promote bird breeding, the latter being a key criterion of Toolibin Lake maintaining its RAMSAR status (Department of Biodiversity, Conservation and Attractions 2017). However, historically most summer events are short lived and don't provide enough rainfall to produce the volume of flow required to inundate the lake for a period to allow significant bird breeding (Table 1). Toolibin Lake inflow events have decreased in flow magnitude and duration since the mid 1990's and this reflects the changes in the long-term annual average rainfall (Figure 1, Table 1). Decadal declines in average annual rainfall and for the period 2000 to 2016, are evident in data from Wickepin (BoM Station 10654), located to the north of the Toolibin Catchment (Figure 1; Appendix 1).

Rank	Event	Peak m³/s	Flow ML	Load t	Salinity mg/L
1	2017 Summer	41.50	5,737		
2	1983 Winter	34.64	15,708	8,775	559
3	1990 Summer	22.99	2,625	767	292
4	1982 Summer	9.39	1,340	485	362
5	2013 Summer	6.10	474	284	599
6	1996 Winter	4.12	1,799	2,271	1,262
7	2006 Summer	4.01	732	444	606
8	1992 Winter	3.69	2,754	4,387	1,593
9	2017 Winter	3.11	1,426		
10	1990 Winter	3.06	1,956	2,832	1,448
11	1981 Winter	2.41	2,157	2,629	1,219
12	2000 Summer	2.04	450	504	1,120
13	1993 Winter	1.78	1,401	2,981	2,128
14	1988 Winter	0.83	423	1,103	2,610
15	1994 Winter	0.78	285	631	2,212
16	2008 Winter	0.77	284	624	2,200
17	2003 Winter	0.68	336	715	2,127
18	2009 Summer	0.64	121	107	885
19	1998 Winter	0.63	308	1,292	4,200
20	1999 Winter	0.43	536	1,532	2,857
21	2009 Winter	0.32	147	477	3,244
22	2018 Winter	0.29	113		
23	2012 Summer	0.10	27	34	1,270
24	2005 Winter	0.09	92	246	2,675
25	1991 Winter	0.04	41	169	4,167
26	2001 Winter	0.03	25	73	2,969

Table 1 Toolibin Lake ranked inflow events (1979-2017) (from Muirden 2019)

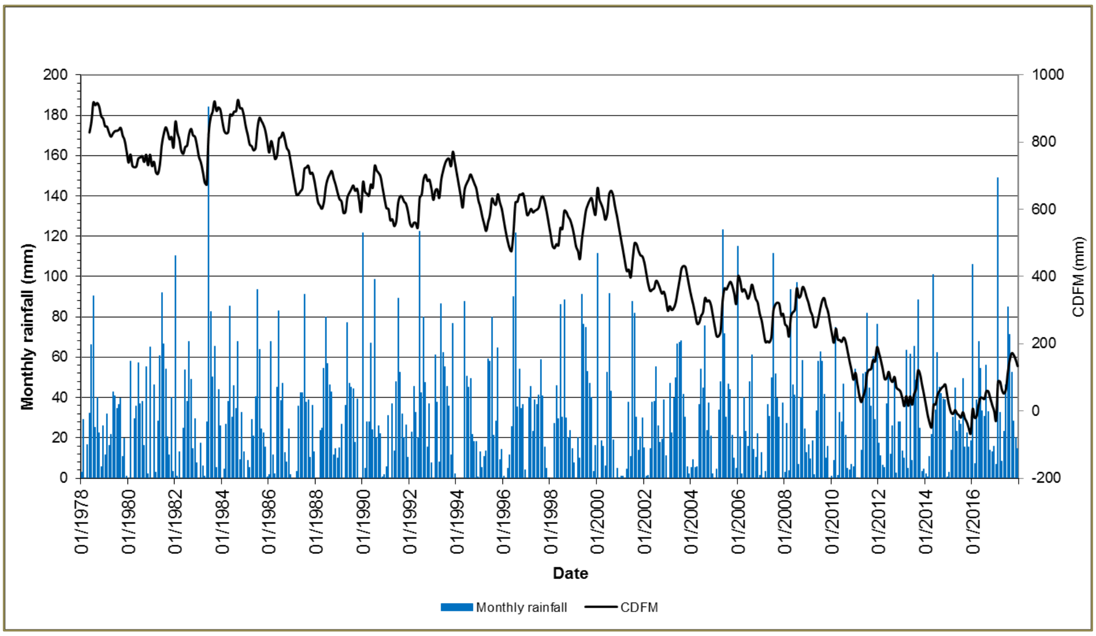


Figure 1. Monthly rainfall totals (1978 to 2017) observed at Wickepin (BoM Station 10654) (ave annual rainfall 408.5mm) and cumulative deviation from the monthly mean (CDFM) rainfall (1911 to 2017); note that decreases in average annual rainfall became evident in the 1970's and pre 1970's data are not shown in this figure.

Given the rarity of the February 2017 inundation event this provided an opportunity to review the performance of hydrological management infrastructure and collect data to assess hydrological interactions.

1.1 Report structure

The report has five sections. Section one provides background hydrological information and current research directions. Section two describes the decision making and installation of the hydrological management infrastructure and sections 3 and 4 the chronological events following the February 2017 lake inundation event, including a summary of the hydrological data collected, and quality assured between the period; February 2017 to June 2018. Section 5 presents data interpretations, conclusions and recommendations.

2 Hydrology management infrastructure

The Toolibin Lake Recovery Plan (Department of Biodiversity, Conservation and Attractions 2017) details the threatening process and associated risks to the biological elements for Toolibin Lake and the broader catchment. Management targets were set for each of the priority biological elements and these targets largely focussed on species composition.

Altered hydrology is identified as a key threatening process and is actively managed at Toolibin Lake. A summary of the major hydrological monitoring infrastructure is detailed below.

2.1 Surface water monitoring and inflow management

Surface water monitoring commenced in 1977 to fulfil objectives to understand and develop a water balance for Toolibin Lake and infrastructure installed included respective gauging stations and depth boards on ephemeral streams and lakes.

Long term continuous surface water monitoring stations are shown in Appendix 2 and include Northern Arthur River (DoW gauging station 609010), at North West Creek, now Booloo Creek, (DoW gauging station 609013), and up gradient of Toolibin Lake (DoW gauging station 609009). Data collected for 609009 and 609010 commenced in 1977. Station 609010 is still operating, while gauging station 609009 ceased to operate in 2009 for three years before data collection recommenced in 2012 (Muirden and Coleman 2014). Gauging station 609013 operated from 1982-1984 before closing due to problems including poor quality of data, few flow measurements and site location (the site is prone to flooding). Data collection recommenced from 2012 to 2013 when weekly measurements were made (Muirden and Coleman 2014).

In the early 1980s the Water Authority of Western Australia established five manual monitoring sites to measure lake water levels and water quality and to assess relative surface water contributions from different sub catchment (Stations 6091024, 6091025, 6091026, 6091027, 6091028) (Appendix 2).

In the late 1980's and early 1990's the management of surface water drainage through the Toolibin Flats and diversion of saline surface water were identified as a high priority to address the development of shallow, saline groundwater and mobilisation of saline surface water to Toolibin Lake (see summary in Rutherford et al. 2015). A number of diversion options were suggested and and assessed by state government agencies, engineering companies and community groups, with interests in the lake, prior to a collective decision being made on the final design (pers comm Richard George). In 1995 a contract was awarded to Jim Davies and Associates to construct a surface water diversion, using the inside of Toolibin Lake and separator gates to divert early winter saline surface water inflows.

This infrastructure was constructed in accordance with the design specifications and drawings developed by Jim Davies and Associates (1995). The diversion channel comprised of a waterway upgradient of Toolibin Lake designed to carry a flow of 6 m^3/s and a waterway downgradient to the south designed to carry a flow of 7 m^3/s. To minimise erosion and sedimentation the velocity of water during these design flows were less than 0.5 m/s. The lake was separated from the diversion channel by a bund formed from material excavated from the waterway (Figure 2).

The bund was designed for a 10-year ARI (Annual Recurrence Interval) (298.25 mAHD), with additional 0.3 m free-board (298.55 mAHD) above the 10-year flood level, plus an additional 0.35 m (298.9 mAHD) to allow for post construction settlement.

The bund was last surveyed in 2006 and the lowest elevation of 298.65 mAHD was observed at the location of the breach that occurred in 2017 (see cover photo) and the highest elevation of 299.46 mAHD was observed near the southern most end of the bund.

Figure 2. Southwards view of the Toolibin Lake bund wall and waterway running along its western perimeter (Photograph DBCA, Wheatbelt Region, date unknown).

The management of inflows to Toolibin Lake was achieved by construction of an inlet control structure (Figure 3). Separator gates within the waterway were constructed using steel I-beam uprights with two-metre-long Wandoo planks permanently bolted between these columns from 0.3 to 0.9 m from the bottom (Figure 4). The removal of the lower planks to a depth of 0.3 m at a total length of 14 m (or seven of the panels) would permit design flows of <3 m^3/s to continue down the diversion channel without diversion to Toolibin Lake. Although this design was not found to be optimal due to the natural variation in the boards promoting leakage and requiring the use of plastic sheeting and sand bags to form a more effective seal.

Once flows at the Wickepin-Harrismith gauging station exceeded 3 m^3/sec then a portion of the flows were diverted into Toolibin Lake. The bottom planks could be re-installed to pass all flows into the lake once water quality fell below the threshold of 2,000 µS/cm (e.g. 2 mS/cm / 200 mS/m / ~1000 mg/L total dissolved solids (TDS)) (Department of Biodiversity 2017), and it is understood that was done under the authority of the District/Regional manager. In April 2010 the diversion gates were upgraded with steel I-beam uprights and aluminium gates. By default, the gates were left in the open position (Figure 4). An upgrade and extension to the inlet weir were undertaken at the same time as repairs to the diversion gates.

Figure 3. Inlet control structure at Toolibin Lake. The photograph was taken on January 16, 2006 following about 76 mm of rainfall over the previous 72-hours (Photograph Darren Farmer/Lance Mudgway).

Figure 4. The original Toolibin Lake separator gate infrastructure. Note the lower boards were removed in two of the panels in the photograph. Photograph was taken in April 2010, prior to

the refurbishment of the diversion gates and upgrades to the inlet control structure (photograph by DBCA Wheatbelt Region).

Figure 5. Toolibin Lake refurbished separator gates. Photograph taken on December 18, 2012 (photograph by Darren Farmer)

Transects perpendicular to the waterway and along the top of the inlet weir were surveyed using 2-way spirit levelling method on 15 August 2013. On 23 November 2016 the waterway channel base depth was surveyed using RTK GPS methods across a transect from the diversion gates to a road crossing near the outlet of Toolibin Lake.

Surface water outflow management

The original design for the surface water management infrastructure included the construction of an overflow spillway at the location of the natural outlet from Toolibin Lake (Figure 6). The outlet spillway was to be set at 297.56 mAHD with a sill length of 36m and was sized to carry a 10 year ARI flow of 35 m^3/s (Jim Davies and Associates 1995). The modification of the outlet from Toolibin Lake in accordance to these specifications was not completed and instead the current outlet ceases to flow at an estimated elevation of 297.58 mAHD (based on a survey in 2013).

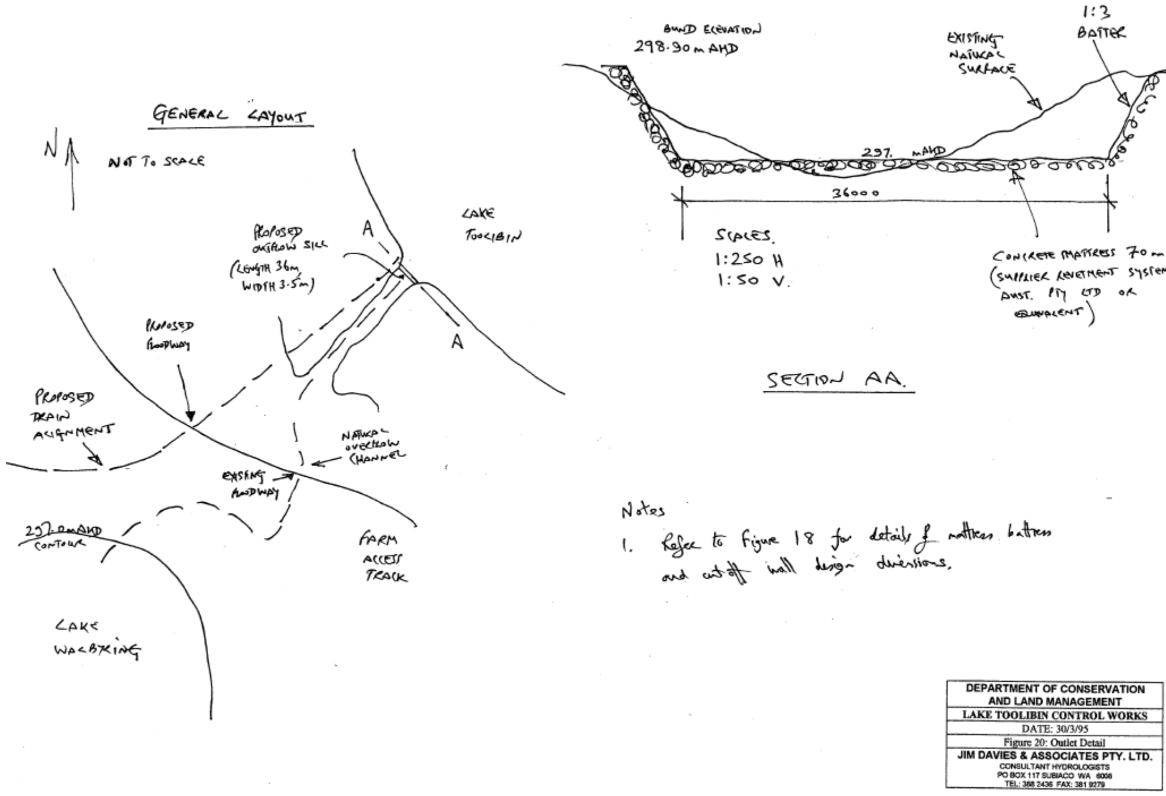


Figure 6. Original design specifications for the construction of an overflow sill at the outlet of Toolibin Lake (source: Jim Davies and Associates 1995)

An outlet control structure was numerically designed by Jim Davies and Associates (1999) in order to provide control of surface water outflows. Infrastructure was constructed in 2000 and comprised of a single 450 mm diameter culvert sited at the southern end of the constructed waterway (Muirden 2001).

Outflows were controlled with timber stop board (Figure 7). At the established cease to flow of 297.0 mAHD, the outlet was modelled to discharge 73 L/s (0.073 m^3/s) at a lake depth of 0.25 m and 424 L/s (0.424 m^3/s) at a depth of 1.0 m (Jim Davies and Associates 1999).

Figure 7. Photograph of the constructed lake outlet control

To manage residual, evaporated lake surface water in the lower lying areas of Toolibin Lake, a collector channel and sump was constructed in 2009 in accordance with specifications of Mudgway (2009). A sump was sited nearby the disused Pump 8 with the outflow pipe discharging to the diversion channel (Figure 8). The sump was later commissioned with a submersible pump with a capacity of pumping 320 kL/d (e.g. 3.7 L/s) Mudgway (Undated).

Figure 8. Sump fitted with gantry and pump (former Pump 8 and surface water monitoring site E)

Groundwater management

Details on the rationale and design of the Toolibin Lake groundwater pumping infrastructure are provided in Rutherford et al. (2015). The current configuration comprises of eight air displacement pumps located in saprolite aquifers on the western margin of Toolibin Lake and three submersible pumps sited within semi-confined palaeochannel sediments on the southern and eastern margins. The air displacement pumps discharge groundwater via a manifold, settling and transfer tank and multistage pump located at the Western Transfer Station to Taarblin Lake (URS Pty Ltd 2012). The submersible pumps discharge groundwater to Taarblin Lake via the Southern Transfer station. Groundwater pumping data is transmitted via telemetry housed at the Western Transfer Station at Toolibin Lake to the Wheatbelt Region office in Narrogin (URS Pty Ltd 2012).

Pump performance and pumping data quality are variable and are reported in numerous reports ((Dogramaci et al. 2003, URS Pty Ltd 2012, Rutherford in prep, CyMod Systems in prep).

2.2 Management guidelines

A series of management guidelines were developed for the operation of the surface water and groundwater management infrastructure. These guidelines are provided in the supporting information to the Toolibin Lake Recovery Plan (Department of Biodiversity 2017) and are therefore not detailed here.

3 Toolibin Lake inflow – February 2017

3.1 Rainfall event and catchment response

At 07:57 AM Friday 10 February 2017, a SEVERE WEATHER WARNING for HEAVY RAINFALL was issued by the Bureau of Meteorology. Heavy rainfall was observed in association with a slow, southwards moving rain band extending from southern parts of the Lower West district into eastern and northern parts of the South West district, western Great Southern district and South Coastal district. Heavy falls were reported over the previous 24-hours at Williams and Wagin, 128.8 mm and 117.8 mm respectively, and heavy falls were forecast to continue in the South West district and western parts of the South Coastal district during the morning before easing in the afternoon.

Rainfall totals observed over 5-days from Tuesday the 7th February to Saturday the 11th February at rain gauging sites within, or nearby the catchment of Toolibin Lake ranged from 159 mm at the Department of Water and Environmental Regulation (DWER) site 510254, to 117.4 mm at Wickepin (DPIRD station WI001) with an average of 138.9 mm across all sites.

The majority of rainfall occurred over a 72-hour period from the 9th February to the 11th February 2017. Analysis of the Intensity, Frequency and Duration (IFD) suggests that the 72-hr rainfall totals were equivalent of an Annual Exceedance Probability (AEP) of 0.05 to >0.01, or about a 1-5% probability of occurrence in any given year (Table 5 and Figure 9).

Table 2. Daily (midnight and 9am) rainfall totals for five rainfall stations located within, or nearby the catchment of Toolibin Lake for the period 7th February to 11th February 2017.

Date	Wickepin (10654) 9am	DWER (510254)	Wickepin (WI001)	Wickepin East (W001)	Wickepin North (WI002)
07/02/2017	1.0	9.2	8.0	27.8	8.2
08/02/2017	11.0	0.0	6.8	9.0	6.8
09/02/2017	7.0	25.2	45.8	60.8	62.4
10/02/2017	62.0	98.6	55.2	36.6	56.4
11/02/2017	68.0	26.0	1.6	0.2	1.0
5-day total	149.0	159.0	117.4	134.4	119.8

Surface water data – monitoring stations active pre-Feb 2017 event

Data from the DWER gauging station located immediately up-gradient from Toolibin Lake (site 609010 – see Appendix 2 and map Appendix 4) shows that surface water flows commenced on Friday 10th February 2017, with 194 ML being discharged that day.

Surface water flow at the DWER gauging station peaked at 17:45 hrs on the 11th February with a maximum discharge of 41.6 m^3/sec and a total discharge of 2,838 ML occurring that day. Surface water discharge continued at the DWER gauging station 609010 until 14:30 hrs on the 6th March 2017.

Table 3. Daily (midnight and 9am) 72-hour Intensity Frequency Duration (IFD) calculations, Annual Exceedance Probability (AEP) and Annual Recurrence Intervals (ARI) for five rainfall stations located within, or nearby the catchment of Toolibin Lake for the period 9th February to 11th February 2017 (Bureau of Meteorology on-line calculator).

Parameter	Wickepin (10654)	DWER (510254)	Wickepin (WI001)	Wickepin East (W001)	Wickepin North (WI002)
Duration (minutes)	4320	4320	4320	4320	4320
Rainfall total (mm)	137.0	149.8	102.6	97.6	119.8
Start date	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017
Intensity (mm/hr)	1.90	2.08	1.43	1.36	1.66
AEP	1-2%	1%	2-5%	2-5%	1-2%
ARI	50-100	>=100	20-50	20-50	50-100

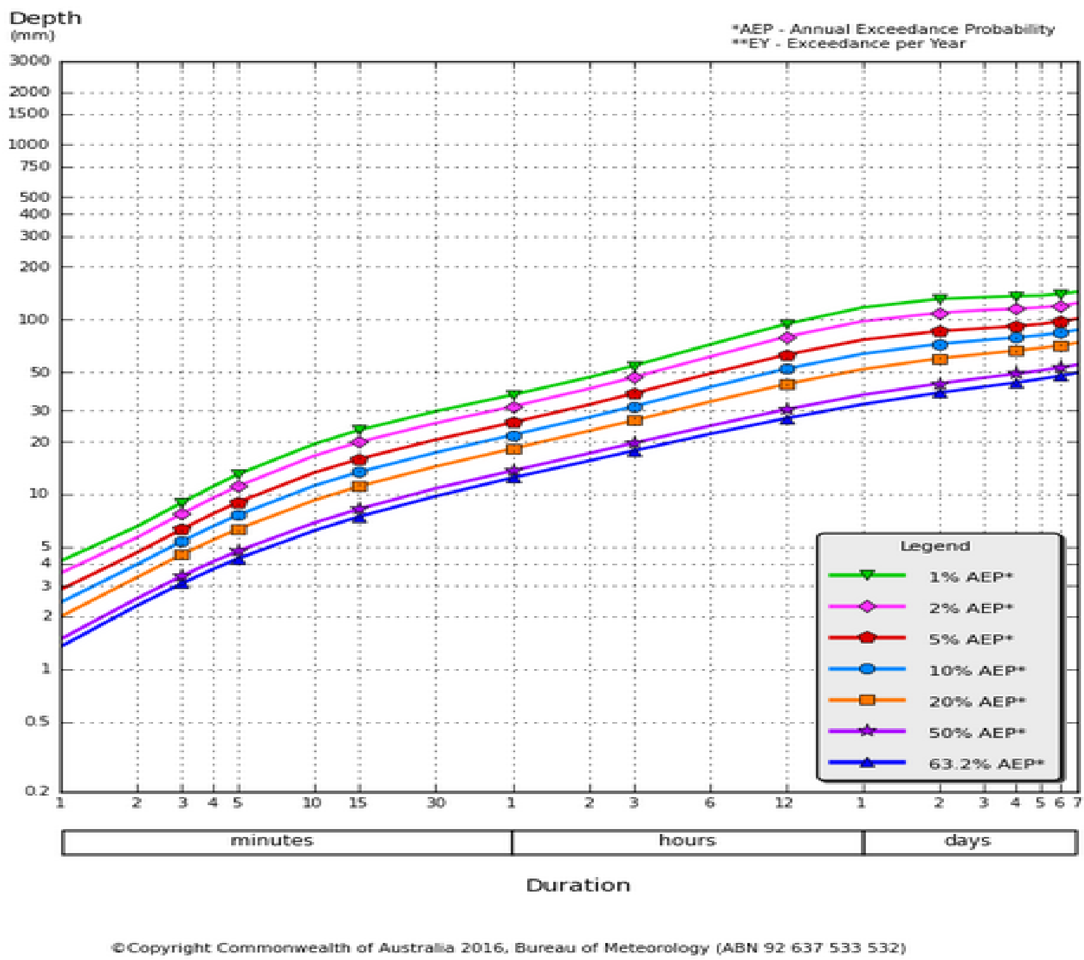


Figure 9. Rainfall depth for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP) calculated for Toolibin Lake (Zone 50, East 556820, North 6357332) (source: Bureau of Meteorology).

Analysis of the logger trace for sites located in the Dulbining waterway (Site M – see map Appendix 4) and the inlet and outlet of Toolibin Lake show a similar response with water levels rising rapidly from the 9th February to the 10th February 2017 (Figure 10). The peak water level of 0.96 m was recorded in the Dulbining waterway on 11th February 2017 at 16:30 hrs, whilst water levels in Toolibin Lake peaked the following day, on the 12th February 2017.

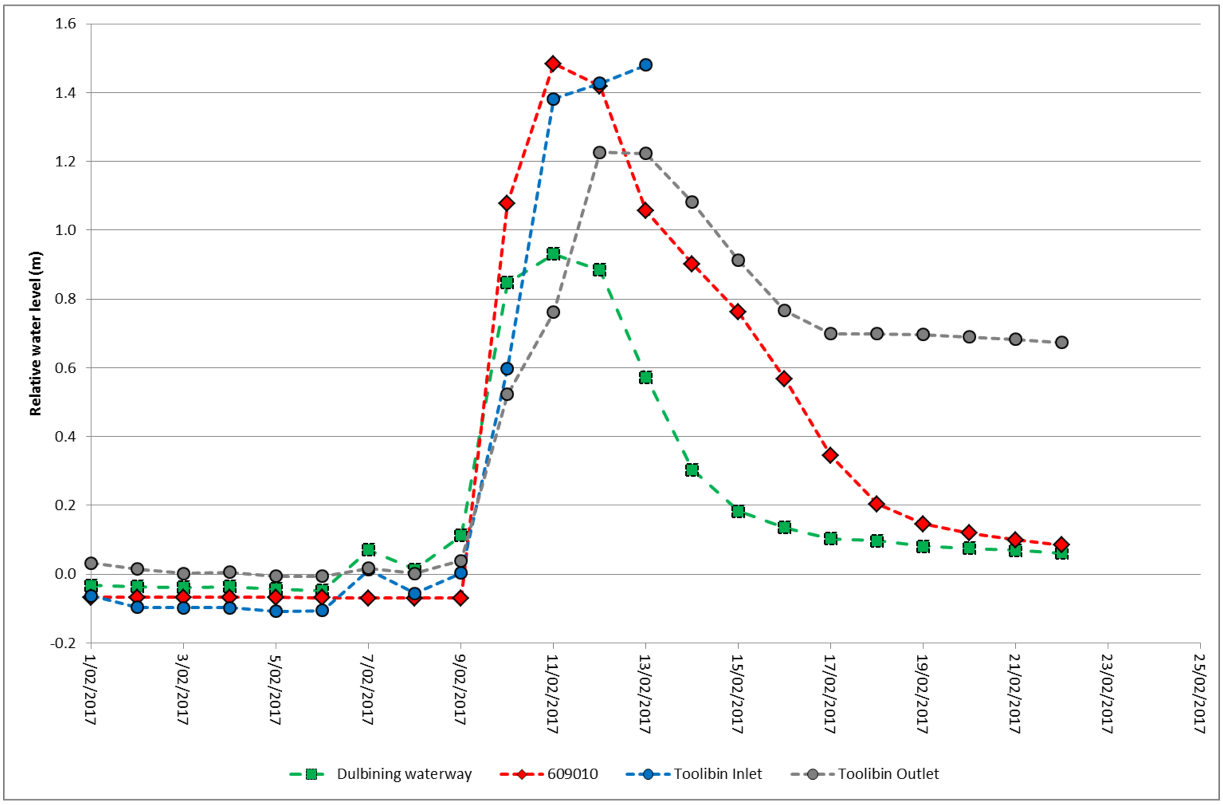


Figure 10. Maximum daily water levels from 01/02/2017 to 22/02/2017 for sites located in the Dulbining waterway (site M), Wickepin-Harrismith Road (site 609010), the inlet to Toolibin Lake (Site A – see map Appendix 4) and the Toolibin Lake outlet (Site S – see map Appendix 4).

Water level measurements at the main water body in Dulbining Nature Reserve (Lake Dulbining or Site N – see Figure 12 and map Appendix 4) (Figure 11), show that the water levels rose from 0.50 m (297.9 mAHD) on the 10th February 2017 to 1.40 m (298.8 mAHD) on the 14th February 2017. Analysis of logged water levels in the upstream and downstream areas indicates that it is likely that peak water levels in Lake Dulbining would have also occurred on the 11th February 2017.

Lake water levels in Lake Dulbining, Dulbining 2 and Dulbining 3 (sites N, O & P – see map Appendix 4) exceeded the height of monitoring infrastructure installed to record water levels. Depth-volume relationships developed from a fine-scale photogrammetric digital elevation model (DEM) quantify the total volume of water stored at the February 2017 flood peak, of around 298.8 mAHD, is approximately 292 ML of water (e.g. relative lake water volumes for Lake Dulbining, Dulbining 2 and Dulbining 3 being 158ML; 47ML and 87ML respectively).

Satellite imagery captured on 28th February 2017 (Figure 12) shows that water levels in all of the lakes in the vicinity of Toolibin Lake appear at, or close to, capacity (e.g. surface water appears black in Figure 12).

Figure 11 shows the subsequent water level response in Lake Dulbining (Site N – see map Appendix 4) to successive winter rainfall events in July and August 2017, which exceeded the cease to flow levels, resulting in surface water flows being observed downstream at the separator gates and inlet to Toolibin Lake.

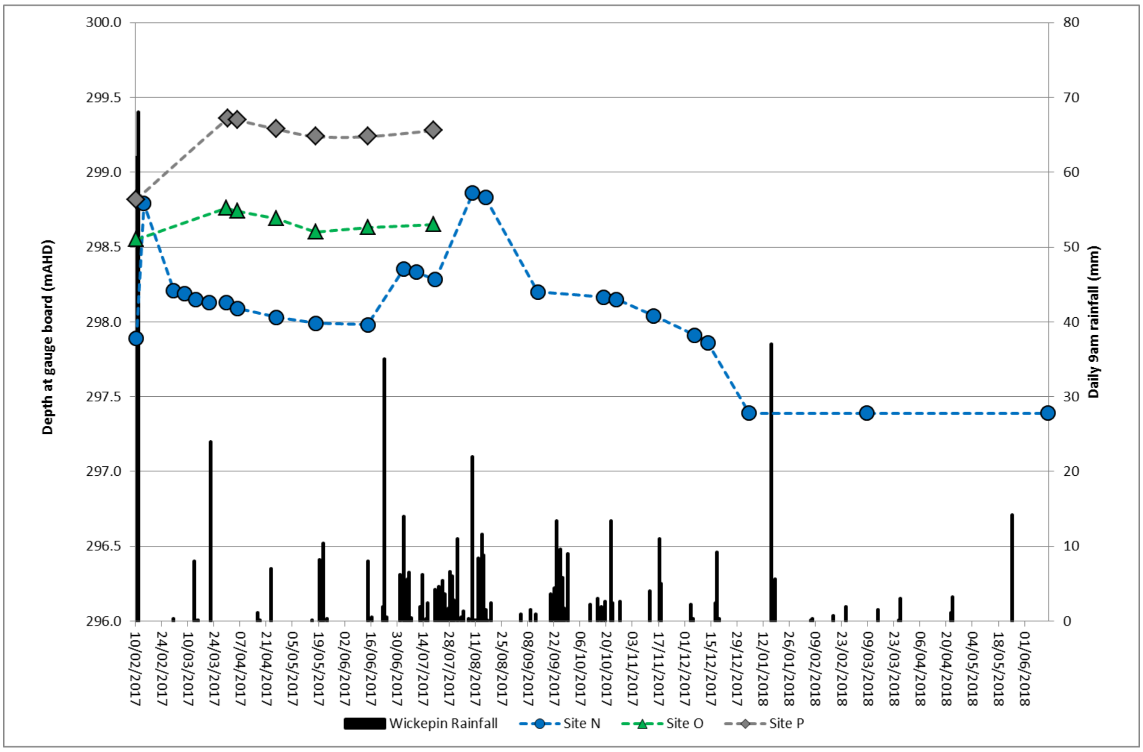


Figure 11. Daily rainfall for Wickepin (Station 10654) and water level measurements at three wetlands in the Dulbining Nature Reserve, known as Lake Dulbining (Site N), Dulbining 2 (Site O – see map Appendix 4), and Dulbining 3 (Site P – see map Appendix 4). Water levels at Lake Dulbining were made on 10th and 14th February 2017 and therefore peak levels are not known.

February 2017 Toolibin Lake management actions and inundation chronology

Approval was granted by the Wheatbelt Regional Manager on Saturday the 11th February 2017 to close the diversion gates and divert fresh surface water inflows to Toolibin Lake. The gates were closed at about 11:00 am on the 11th February 2017. Measurements of water levels at monitoring sites located within Toolibin Lake did not commence until the 17th March 2017. Observations of a trash line on the outlet gauge board (DWER site 6090126 or Site S – see map Appendix 4) on the 13th February 2017, and logger data collected from the same site, indicate that water levels in Toolibin Lake peaked at about 298.3 mAHD at 10:00 PM on Sunday evening the 12th February (e.g. a flood peak of 2.24m at SWWMP depth board on eastern bank of Toolibin Lake (Appendix 2), equating to an areal extent of around 273 Ha; approximately 4,094 ML).

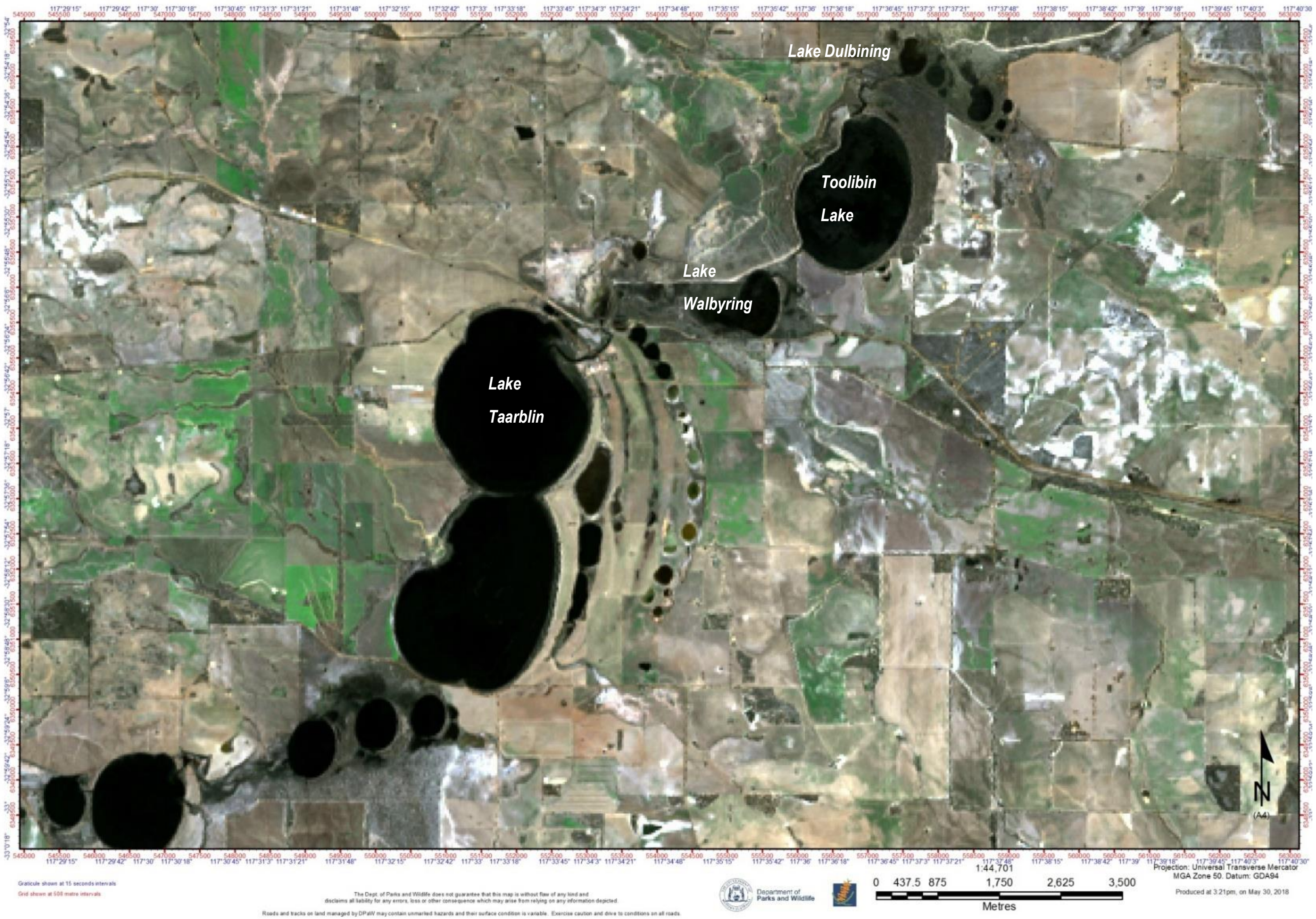


Figure 12. Landsat 8 imagery captured on 28 February 2017 showing Toolibin Lake and surrounding wetlands, including those in the Dulbining Nature Reserve, Walbyring Nature Reserve and Taarblin Lake Nature Reserve (note that areas inundated with water appear black) .

This is the highest lake level recorded since the construction of the diversion channel and separator gate, with the previous highest post-construction lake water level of 1.10m recorded in July 1996. Pre-diversion records show that prior to the construction of the diversion, in July 1983, a lake water level of 2.72 metres m was reached.

On Wednesday the 15th February 2017 staff from the DBCA Narrogin office observed a breach in the western bund wall of Toolibin Lake that led to the discharge of water from the lake into the diversion channel (image on cover page). The breach was repaired on Thursday the 16th February 2017 using sandbags and plastic liner material (Figures 13 and 14). In October 2017 the breach was surveyed and found to be 17 m wide and up to one meter deep (Appendix 3). A DEM developed from photogrammetry data acquired in 2015 indicate the top of the bund wall prior to the breach was at an elevation of about 298.42 mAHD. Following the February 2017 event, the bund eroded and at the breach was reduced to a maximum depth of approximately 297.1 mAHD, which after temporary repair was restored to a height of around 297.8 mAHD. Water storage in Toolibin Lake, between the original and eroded bund elevations (e.g. 298.42 and 297.1 mAHD) is approximately 2,700ML. Photographic evidence shows water was moving from the lake into the diversion channel, but without flow and water level elevation data from both the lake and the channel it is difficult to estimate the volume of water 'lost' from the lake during the breach. The temporary bund repair was effective as around the same time as the completion of the bund repair, around noon on the 16th February, time-series lake water level data from the outlet of Toolibin Lake shows a decrease in the rate of Lake water level decline.

The occurrence of a number of consecutive rainfall events between June and July 2017, in combination with about 20 mm of rainfall in August, led to further generation of surface water flows in the Toolibin Catchment (Figure 15). In spite of the separator gates being in the open position (i.e. diverting water around the lake) water was observed to overtop the inlet apron and an additional 0.07 m, or 184 ML, of combined incident rainfall and surface water entered the lake. Over 221 days from the 16th August 2018 to the 15th March 2018 lake surface water levels receded by one metre, at an average rate of about 4.3 mm/day. By the 12th April 2018 the majority of the lake floor was dry (Figure 16). On the 12th April 2018 the decision was made to remove residual evaporated lake water using the sump pump. The sump pump was in operation until the 26th April 2018 and over this 14-day period a total of 5,265.75 kL (5.3 ML) of lake water was removed at an average rate of 376 kL/day, or about 4.3 L/s. Given the average surface water salinity measured at this time was 5,579 mg/L the removal of this lake water equates to the removal of about 29.4 tonnes of salt.

Figure 13. Repair of the Toolibin Lake bund wall breach being undertaken by DBCA staff and volunteers on Thursday 16 February 2017. Photograph by Maria Lee.

Figure 14. Northwards photograph of the repaired bund wall breach. Photograph taken on 18 October 2017 by Lindsay Bourke.

Figure 15. Northwards photograph of surface water flows overtopping Wickepin-Harrismith road at DWER station 609010. Photograph taken by Maria Lee on 16 August 2017.

Figure 16. Northwards view of the area nearby the sump pump on the lake bed of Toolibin Lake. Photograph by Maria Lee on 12 April, 2018.

4 Toolibin Lake inflow - monitoring

Stakeholders and hydrological consultants currently working on Toolibin Lake, including DPIRD and CyMod Systems, were consulted regarding modifying the existing hydrology monitoring programs to ensure post–inundation event data were suitable for making both short- and long-term management decisions (e.g. activation of groundwater and sump pumps and input for the numerical model under development).

4.1 Hydrology management triggers

The key components of a lake water balance quantify the change in lake water inputs and outputs over time. Of particular importance for the lake ecology is the frequency and length of time water remains in the lake, which requires an understanding of the rate lake water levels and volumes change over time and how this affects water quality.

Empirically this can be described by the equation below:

$$Qin - Qout = dV/dt = A\ dh/dt$$

where; Qin = input water; Qout = output water, V = Lake water volume (m^3); dV/dt = rate of volume change (m^3/d); A = Lake water area (m^2) and h = water depth (m).

The input and output balances can be expanded and described empirically:

$$Pin + Sin + Din - (E + Sout + Gout) = dV/dt = A\ dh/dt$$

where; Qin = input (Pin + Sin + Din) and Qout = output (E + Sout + Gout); Pin = precipitation (rainfall on surface of the Lake); Sin = streamflow into the Lake; Din = drainage flow into the Lake; E= evapotranspiration; Sout = streamflow out of the Lake and Gout = groundwater outflow.

This study focused on the collection and interpretation of lake surface water level data and derived rates of water volume and salinity changes in the above equations. Lake depth and volume relationships were calculated from a fine scale aerial photogrammetric DEM developed from data acquired in 2015 to develop a conceptual hydrological model (Rutherford in prep) and update an existing lake spreadsheet model (e.g. WatBal; see Appendix 5) and input into a saturated flow model under development (Hydrologia 2016 and CyMod Systems in prep).

Based on previous summer inundations in Toolibin Lake it was anticipated that the lake would store in excess of 0.5 metres of water for more than twelve months. The length of inundation dependent on rates of open water evaporation, transpiration and subsequent winter 2017 incident rainfall and surface water inflows. It is common knowledge that evaporation would be the major water balance output and lake water was estimated to reach the 10,000 µS/cm (10mS/cm, 1,000 mS/m and ~5,000 mg/L TDS) maximum water quality sump pump activation trigger in March 2018.

The volume of water left in the lake when this threshold was reached, and how it could be managed to minimise increasing salt storage in the lake substrate was unknown, and of concern.

To address this question surface water level and salinity monitoring data collected were periodically imported, modelled and interpreted in simple spreadsheet models as well as a spreadsheet-based water and salt balance model previously used in Toolibin Lake called WatBal.

These tools were used to provide regular predictions on the length of time water would remain in the lake and how the average lake water salinity would change over this period.

The WatBal model was developed in the late 1990's to assess water balances for Toolibin Lake and other Wheatbelt wetlands (e.g. Peck 2000) and was updated in 2016 as part of the Department's Wheatbelt hydrology research (see DBCA SPP 2015-001, Hydrologia 2016; see Appendix 5 for a description of the WatBal model). The WatBal model includes and uses existing long-term data series for precipitation, surface water inflows and evapotranspiration. Hydrologia (2016) updated the WatBal model to include an interpolated rainfall dataset and at the request of DBCA different pre-1995 and post-1995 diversion lake volumes and streamflow. The latter accounting for the changes in catchment area before and after the construction of the diversion. In this study data from the February 2017 event were uploaded and in order to make timely predictions the model time step was changed from weekly to daily.

The WatBal model has potential to include parameters to calculate a complete water and salt balance (e.g. surface water and groundwater interactions). However, as it provides spatially averaged estimates for the whole lake it is limited as a tool to model the spatial variability that occurs in Toolibin Lake.

As a spatially discretised saturated flow model is under development for the Toolibin Lake and catchment, the WatBal model in this study was used as a tool to identify and interpret trends rather than report a water and salt balance.

4.1 Hydrology data collection and processing

Table 3 provides a summary of pre and post February 2017 hydrological datasets assessed in this study. Note that direct measurements of transpiration and lake open water body evaporation were beyond the scope of the work undertaken in this project.

Surface water levels

Following the lake inflow, the DBCA Wheatbelt Region surface water monitoring program (Appendix 4) was implemented, with the frequency of monitoring increasing to weekly, or fortnightly depending on accessibility and presence of water. Manual measurements for the period Feb 2017 to April 2018 were collected by DBCA staff based in the Wheatbelt Region.

In March 2017, data was retrieved from an existing network of data loggers distributed throughout the Toolibin Lake Catchment (Bourke 2017). With the exception of three data logging sites there was insufficient field data to calibrate or validate retrieved data.

Table 4. Summary of hydrological datasets collected, compiled, quality assured and assessed for this study

Site type	Data type	Data period	#sites total	#total points	#sites 2017-18	#points 2017-18	Data custodian	Comment
Groundwater	Water level	2017-2018	485	24,844			DBCA – Wheatbelt Region	
Groundwater	Water level/temperature	2017-2018	2	9,072	2	9,072	DBCA – Wetlands Conservation Program	Data loggers installed 6/12/2017, removed 13/06/2018
Surface water	Water level	2017-2018	23	396			DBCA – Wheatbelt Region	Further work required to compile other historical data. Data quantity in 2017 not typical due to high rainfall events, February 2017
Surface water	Electrical conductivity	2017-2018	23	198			DBCA – Wheatbelt Region	As above
Surface water	Temperature	2017-2018	23	198			DBCA – Wheatbelt Region/WCP	As above
Surface water	Water level/EC/temperature	2017-2018	3	17,193	3	17,193	DBCA – Wetlands Conservation Program	Loggers installed 17/10/2017, removed 13/06/2018
Surface water (SWWMP)	Water level	1979-2018	1	110			DBCA – Wheatbelt Region	Data for Toolibin only – Custodian Jim Lane, however copy of this data to be stored in database for QA/graphing purposes
Surface water (SWWMP)	pH	1982-2018	1	30			DBCA – SWWMP program	As above
Surface water (SWWMP)	EC	1997-2018	1	3			DBCA – SWWMP program	As above
Surface water (SWWMP)	Salinity (mg/L TDS)	1981-2018	1	41			DBCA – SWWMP program	As above
Surface water (SWWMP)	Other WQ	1984-2018	1	36			DBCA – SWWMP program	Total of TN, TP etc
Surface water pumping	Volume	2018	1	0	1		DBCA – Wheatbelt Region	Sump pump was turned on 12 April, 2018, then off on 26/04/2018. Total of 5265.75KL over 14 days.
Groundwater pumping	Volume	2016-2018	13	426,903			DBCA - Wheatbelt Region	Data extends to 1997, however data available before 2016 not included in summary
Subtotal 1				**456,790**				
<u>Other agency data</u>								
Site type	**Data type**	**Data period**	**#sites total**	**#total points**	**#sites 2017-18**	**#points 2017-18**	**Data custodian**	**Comment**
Surface water	Daily Water level-Flow TS archive	1978-2018	1	14,235	1		Department of Water and Environmental Regulation (DWER)	Only for Wickepin-Harrismith Rd gauging station
Surface water	Water levels discrete	1980-2012	0	201	0		DWER	Only for Wickepin-Harrismith Rd gauging station
Surface water	Daily Water quality - TS archive	1978-2018	0	14,235	0		DWER	Only for Wickepin-Harrismith Rd gauging station
Surface water	Water quality - discrete	1980-2012	0	1,667	0		DWER	Only for Wickepin-Harrismith Rd gauging station
Rainfall	Daily 9am rainfall	1911-2018	1	39,083	1		Bureau of Meteorology	Daily rainfall data used for hydrographs.
Subtotal 2				**69,421**	**2**			
<u>Total</u>				**<u>526,211</u>**	**<u>272</u>**			

Data from one site located at the outlet of Toolibin Lake was found to be of acceptable quality and was applied in this study.

As the lake dried, access to monitoring sites became increasingly difficult. To combat this problem DBCA Wetlands Conservation Program staff installed and collected data from data loggers (Eijkelkamp CDT – Diver DI271) that were deployed on 17th and 18th October 2017 at two sites; Toolibin Lake (Site F and Site E – see map Appendix 4) and Dulbining Lake (Site N – see map Appendix 4).

Data loggers were set up to record hourly water level, temperature and electrical conductivity and continuous data were collected until they were decommissioned in June 2018.

The longest time-series surface water dataset for Toolibin Lake was collected by DBCA staff in the South West Wetlands Monitoring Program (SWWMP) (e.g. Lane et al. 2017). To enable comparison with the long-term records all surface water levels collected from the various monitoring locations are presented in metres relative to the height of the long-term SWWMP monitoring gauge board (TOOL). Water levels are also reported to Australian Height Datum (mAHD) (Appendix 6).

Surface water quality

The DBCA Wheatbelt Region enacted their surface water monitoring program (Appendix 4) which includes the collection of manual water quality data (e.g. electrical conductivity, temperature and conversion to TDS (mg/L)). The frequency of data collection being weekly, or fortnightly depending on accessibility and presence of water.

Lake depth profile measurements of surface water quality (salinity, EC, pH, temperature, redox potential, turbidity and dissolved oxygen) were collected on the 9th May 2017 by dinghy. Measurements were taken at 0.10 m to 0.20 m intervals from the surface to the benthic interface to assess if salinity in the lake water body was stratified and varied with depth. If this was the case, regular water sampling at different depths may have been required. Initial profiling indicated the lake surface water was well mixed and this was confirmed by repeat EC, pH and temperature depth profile measurements on the 17th October 2017, and EC and temperature measurements on the 6th December 2017 (see Section 4.2.1, Appendix 7).

Following the profiling results DBCA Wetlands Conservation Program staff installed and collected temperature and electrical conductivity data from data loggers (Eijkelkamp CDT – Diver DI271) deployed on 17th and 18th October 2017 at Toolibin Lake (Site F and Site E – see map Appendix 4) and Dulbining Lake (Site N – see map Appendix 4). Data loggers recorded measurements hourly and continuous data were collected until they were decommissioned in June 2018.

Surface water flow

Surface water inflows to Toolibin Lake or flows within the diversion channel were not measured or quantified. Similarly, outflows from Toolibin Lake via the main outlet and the bund breach were not measured or quantified, although hydraulic modelling across two sections of the diversion channel using a 1D HEC-RAS model has provided estimates of flow, predicting they may have reached 20 and 25 m^3/s (Muirden 2019).

Quantitative surface water flow data is limited to that recorded at DWER gauging station 609010 (Appendix 2), located at the outlet of the Dubining Nature Reserve on Wickepin-Harrismith Road. The stage to discharge rating table for this station was revised by DWER in February 2018. For this study it was assumed that gauging at site 609010 was representative of that at the separator gates and other localised contributions, for example runoff from roadside drains, are negligible.

This approach is consistent with previous water balance studies undertaken in Toolibin Lake (see Rutherford et. al. 2015) and the setup of the existing WatBal spreadsheet model.

Sump pump flow

Outflows from the sump pump were considered negligible in comparison to other water balance components (e.g. 5.3ML is less than one percent of the peak lake volume) and therefore excluded from the water balance analysis.

Constructed outlet outflow

The constructed surface water outlet, which is operable by the removal of stop boards, remained closed and therefore surface water outflows via this location were considered negligible.

Groundwater levels, water quality and pumping

The frequency of the existing monthly and biannual groundwater monitoring program outlined in Rutherford et. al. (2017), was increased to weekly measurements following the February 2017 lake inflow. DBCA staff based in the Wheatbelt Region monitored groundwater levels in 38 bores following the February 2017 lake inflow and this was reduced to 28 bores in March 2017 (Appendix 8). Monitoring frequency was further reduced to monthly measurements in May 2017 as access became more difficult and rates of groundwater level change slowed (Appendix 8).

To ensure a continuous record of groundwater levels for the lake recession the DBCA Wetlands Conservation Program installed two data loggers (Eijkelkamp Cera-Diver DI701) in bores TL20 and TL28 on the 5th December 2017. Water levels and temperature were recorded at hourly intervals from the 5th December 2017 until they were decommissioned on the 13 June 2018.

Groundwater pumping data for individual pumps and the two transfer stations was quality assured and reprocessed to a daily time-step. Manual records collected by DBCA staff in the Wheatbelt Region were collated and used to assist with data quality assurance. Several problems were encountered with respect to reconciling cumulative pumping totals against those recorded at each of the transfer stations.

This problem has been previously identified in the development of the pumping time series for numerical model under development. Pump downtime occurred at several sites and on a number of occasions during the period the lake contained water.

The DBCA Wheatbelt Region surface water monitoring program (Appendix 4) includes the collection of manual water quality data (e.g. electrical conductivity, temperature) and conversion to TDS (mg/L)) from the Southern and Western pumping transfer stations to compare and assess the salinity of lake surface water with groundwater being pumped from aquifers beneath the lake.

Climate

The WatBal model was updated with precipitation data sourced from Bureau of Meteorology Site at Wickepin (BoM site 10654), as it represented the longest precipitation time-series dataset.

Pan evaporation data in the WatBal model are provided by SILO data between 01/01/1978 to 30/11/2016, using an interpolated datapoint located at the centre of Toolibin Lake (Latitude -32.90, Longitude 117.60) (Appendix 5). From the period 1/12/2016 to the 31/5/2018 the model data series uses average evaporation data for thee DPIRD operated weather stations (https://dpird.wa.gov.au/ ASWWSTNEW001, ASWWSTNWI001, and ASWWSTNWI002), located less than 25 km to the north and east of Toolibin Lake.

4.2 Data interpretation

Surface water levels and quality

Surface water depth profiling was undertaken at three locations on three separate occasions in 2017 (Appendix 7).

Results indicated that both salinity (halocline) and temperature (thermocline) showed little spatial variation, either laterally or with depth. Therefore for the purpose of monitoring surface water electrical conductivity variation it was reasonable assumption to consider the lake as being well mixed. However, data collected for dissolved oxygen (DO) and redox potential (ORP) in May 2017 indicate that the lake is stratified, oxygen levels at the surface were low (36% to 15%) and declined appreciably with depth (Appendix 7). Repeat profiling in December 2017 show reducing conditions were dominant throughout the surface water body, with the most negative redox potentials (i.e. anaerobic) near the benthic zone.

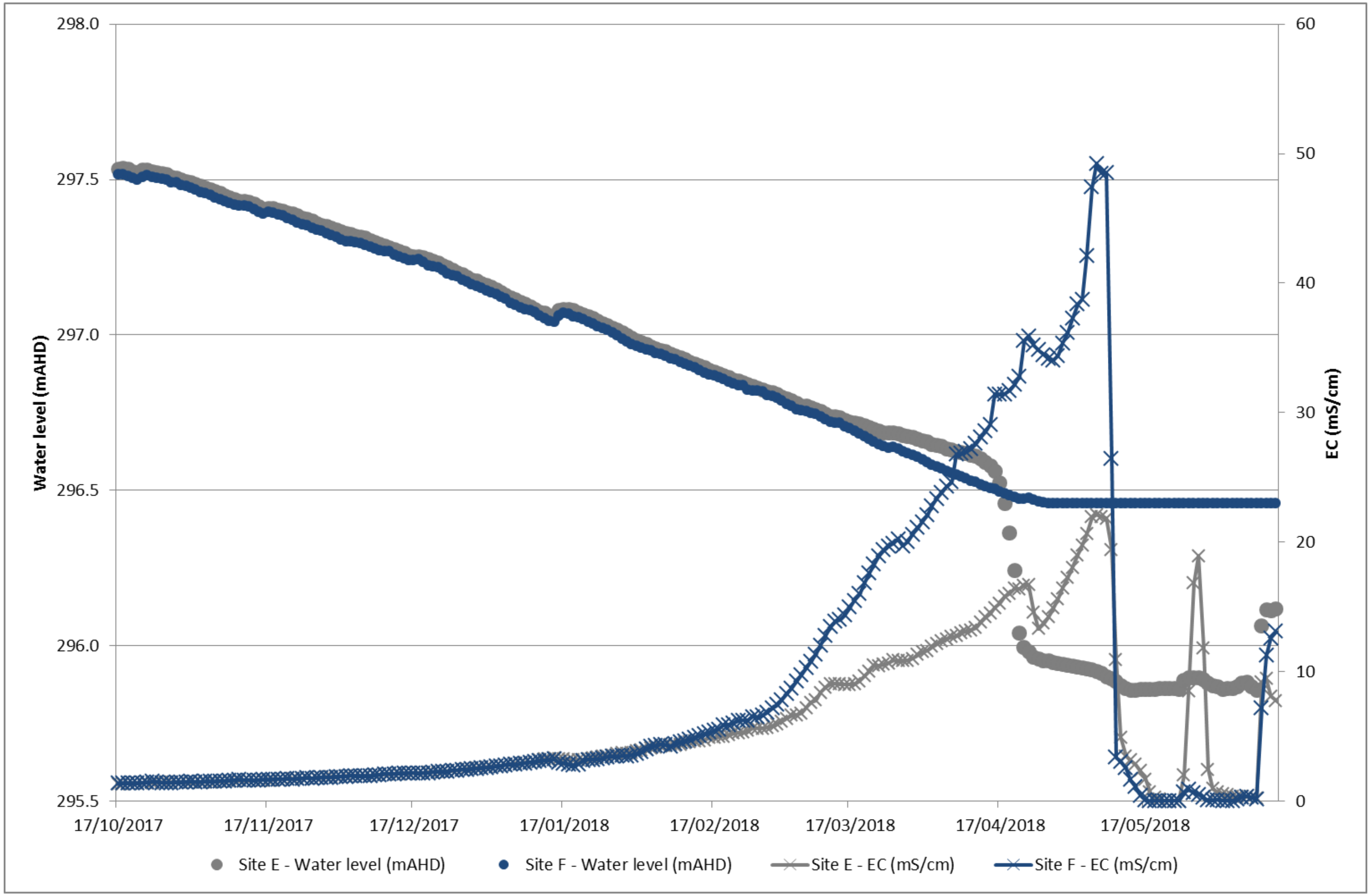
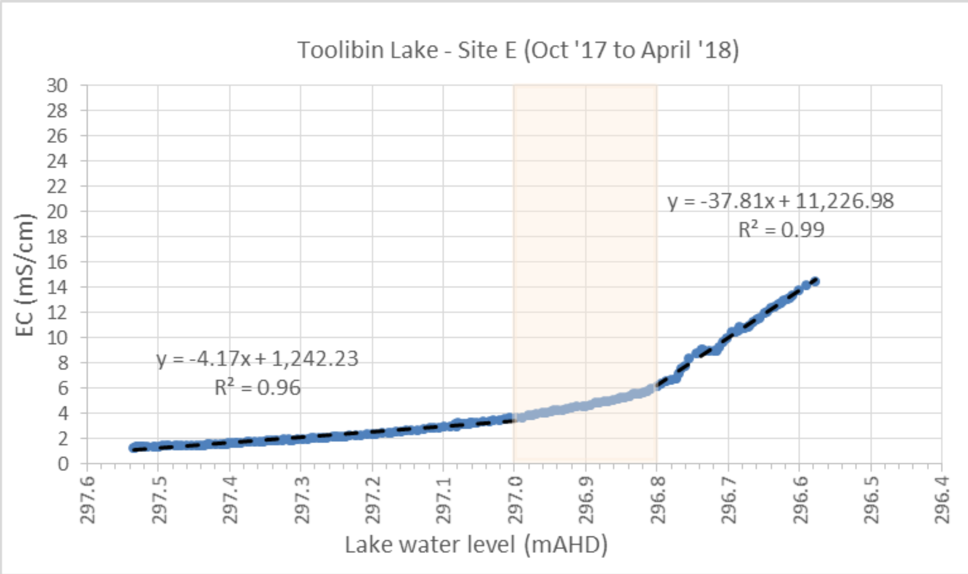
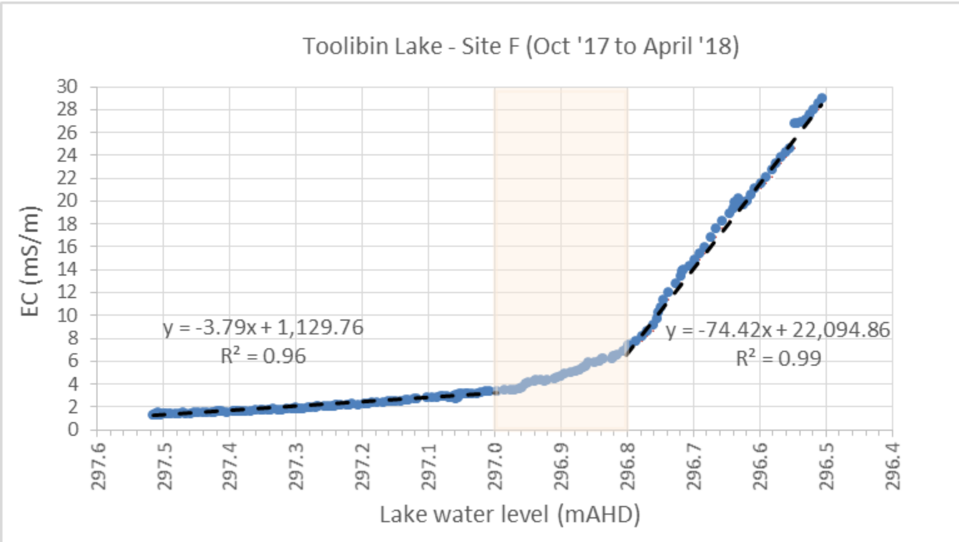


Figure 17 Trends in water level (blue and grey solid dots) and electrical conductivity (blue and grey crosses) logged at hourly intervals from October 2017 to May 2018 at Site E (sump pump) and Site F (DWER station 609009).





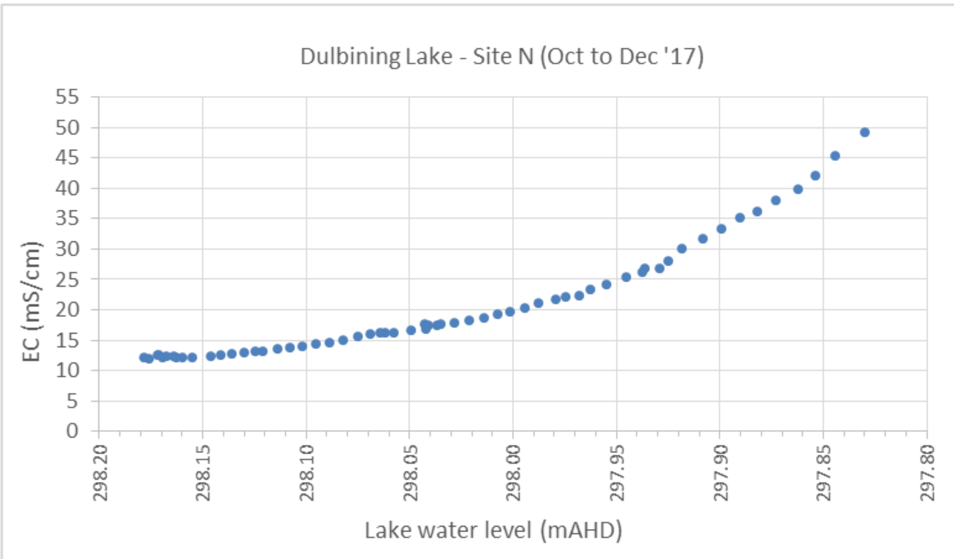


Figure 18 Surface water data logger electrical conductivity data collected at depth gauge sites; Site E (sump pump), Site F (DWER station 609009) and Site N (Lake Dulbining); see map Appendix 4). Note area shaded in orange represents data collected in Jan and Feb 2018.

Electrical conductivity (EC) data collected from lake surface water data loggers installed to measure the lake recession show salinity increases as water evaporates and lake surface water levels decline (Figure 17). The relationship between water depth and salinity in Toolibin Lake are distinctly linear, but with a transition in slope between January 2018 and March 2018, with trend lines and correlation coefficients overlying data graphed in Figure 18. Higher rates of salinity with depth are observed in March and April 2018 at Site F, (DWER station 609009 – see map Appendix 4) compared with the sump pump (Site E – see map Appendix 4) (Figure 18).

The higher rate of change is anticipated at Site F, where the slightly elevated lake bathymetry encourages development of a broad shallow surface water body, which appears to disconnect with the deeper, excavated and spatially discrete sump pump Site E. The relationships observed in Toolibin Lake are distinctly linear, with trend lines and correlation coefficients overlying data graphed in Figure 18.

Salinity levels are higher in Dulbining Lake and relationship with depth is different (Figure 18). Although data in this lake were collected for a shorter period (October to December 2017) and monitoring ceased when approximately 97% of the February 2017 inundation water, and 'top-up' winter 2017 flows, had evaporated.

The relationships for the recession lake water level and salinity at Toolibin Lake (Figure 18) were applied to predicted surface water salinity where no data were collected. These data are plotted at 0.2-meter depth increments for Site E and F in Figure 19 and show similar relationships until salinity of around 5,000 mg/L is reached.

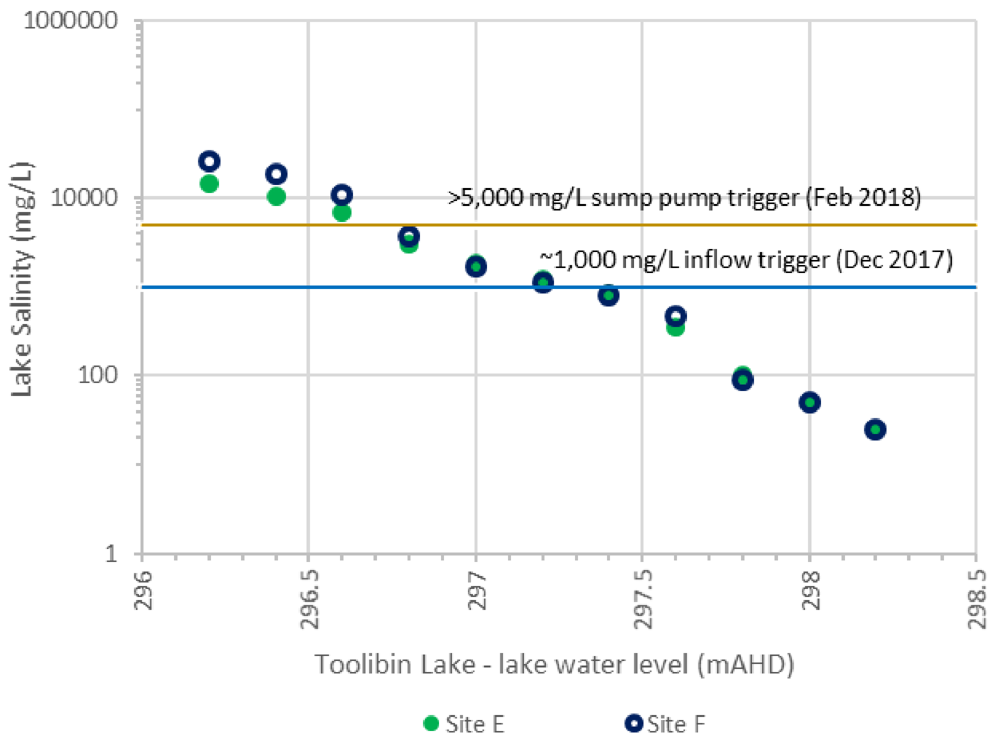


Figure 19 Graph of lake water level (mAHD) versus lake salinity (mg/L) for Toolibin Lake Site E and F (see Figure 18); Note relationships from Figure 18 are used to predict data for elevations >297.6 mAHD and lower than 296.4 mAHD: Note that 296 mAHD is ave base of lake.

Relationships between Toolibin Lake water level and salinity persist until mid-April when lower salinity rainfall mixes with the remaining evaporated water body. This occurs when surface water salinity exceeds 5,000 mg/L and approximately 98% of the February 2017 inundation water, and 'top-up' winter flows, have evaporated. Although at this stage in the lake hydroperiod there is still approximately half a meter of water, which equates to around 90ML of water covering around 27% percent of the lake floor (Figure 20).

Lake depth-volume relationships were applied to convert lake water salinity to salt load (Tonnes) and these data are graphed in Figure 20 and show between 590 and 950 Tonnes of salt (Site E and F respective relationships) remain in the lake when the ~5,000 mg/L trigger is reached. Noting that tonnages reduce to 560 and 920 respectively when accounting for the sump pumping (~30 Tonnes of salt removed; see Section 3.1).

Figure 20 indicates higher volumes of salt exist in January and February 2018 lake water, with up to 1400 Tonnes covering over 60% of the lake floor. However, it is important to note that at this time some of the lake water may have been either taken up by vegetation through transpiration rather than evaporated on the lake substrate.

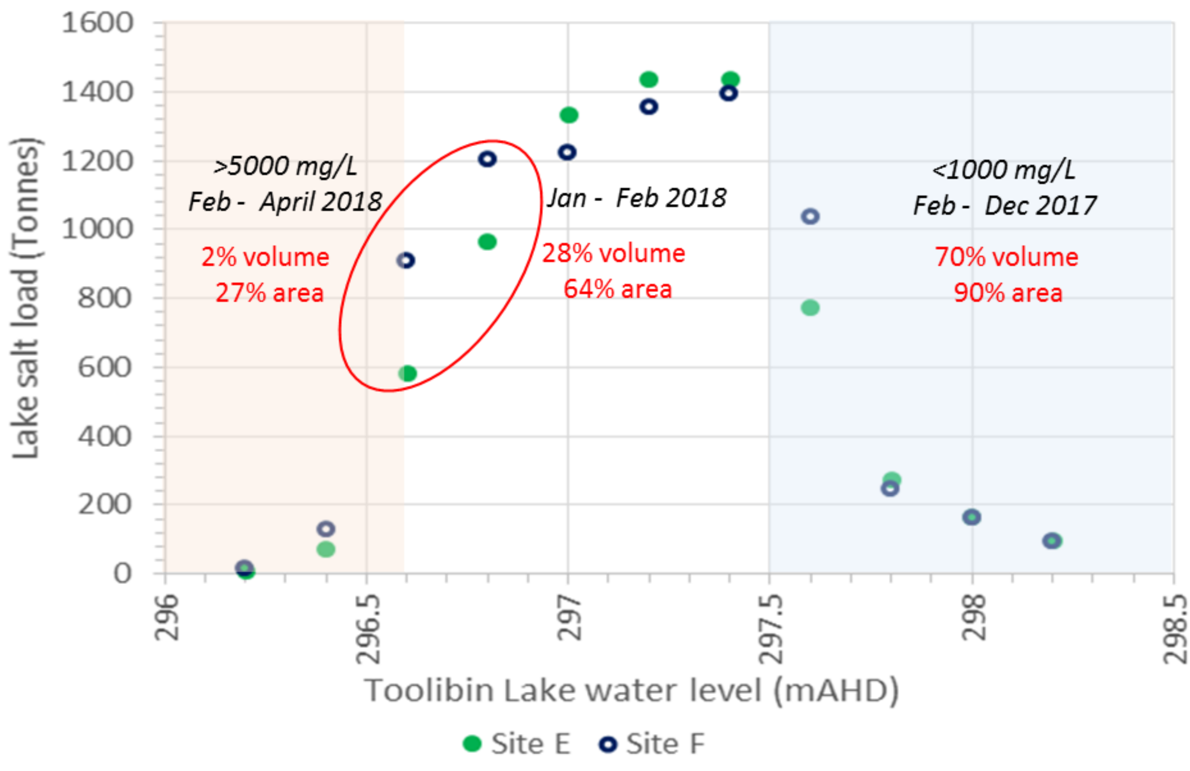


Figure 20 Graph of lake water level (mAHD) versus lake salt load (Tonnes) for Toolibin Lake Site E and F (see Figures 18 and 19); Note relationships from Figure 18 are used to predict data for elevations >297.6 mAHD and lower than 296.4 mAHD; Note that 296 mAHD is average base of lake and departure of Site E and F relationship is circled in red.

Groundwater levels and pumping

Groundwater monitoring included the collection of groundwater level data from both surficial (unconfined) and deeper saprolite and sedimentary (semi-confined) aquifers, as well as information on the activity and performance of pumping bores that were installed in the 1990's to remove saline groundwater from aquifers beneath Toolibin Lake.

Monitoring results show that groundwater levels in all aquifers increase following the February 2017 rainfall event, with rates of change being variable and the average groundwater increase being around four metres (Appendix 8 and 9).

Following this rise, groundwater levels in the surficial aquifer either remain constant, until decreasing in December 2017, or display a seasonal response in 2017 (decline in March to May 2017 and increase in July and August 2017) (Appendix 9).

Deeper aquifer's exhibit similar trends, with some bores show a response to pumping in addition to seasonal rainfall (July and August 2017). The variation in the magnitude and duration of these responses are most likely to reflect the pumping schedule and bore location (e.g. distance of monitoring bores from pumping bores and groundwater levels displaying a rebound following a break in pumping and decreasing on the recommencement of pumping). This was discussed in Rutherford et. al. (2015), with bores located within a few metres of active pumping bores located in the palaeochannel show more rapid rates of change (rise and fall) compared with bores located at greater distance, which are likely to be more representative of broader groundwater levels.

As an example of the influence of pumping bores, groundwater levels at TL34, located adjacent to pump E15, was 5.49 meters below ground level (mbgl) on 23rd January 2017, and following the inundation event rose to 1.45 mbgl on the 23rd February 2017. This four-metre rise in groundwater level occurred whilst pump E15 was not operating. Water levels at TL34 then fell nearly three metres to 4.26 mbgl on 1 March 2017 soon after pumping recommenced (Appendix 9). The influence of pump breakdown was also evident in high-resolution groundwater level data at bore TL28, located about 200m to the west of Pump E11 (Appendix 9).

When fully operational the groundwater pumping network in 2017 had a slightly reduced performance rate to that recorded in 2003 and 2004 (Table 5) and that reported by George et al. (2004). A significant investment in a maintenance program however had resulted in much improved pumping performance to that recorded in 2014 and that reported by URS Pty Ltd (2012). Recent differences in performance achieved at the submersible pumps at locations Pump E13 and Pump E15 are due to the replacement of pumps with different pumping capacity than that originally installed (Gary Mills, pers comm 22nd March 2018).

Table 5. Summary of average daily pump rates for the submersible (E11 to E15), air displacement pumps (P01 to P14) and the associated southern (SPS) and western (WPS) transfer stations in Toolibin Lake from 1997 to 2017 (1997 to 2016 data from Rutherford in prep)

YEAR	E11 (kL/s)	E13 (kL/s)	E15 (kL/s)	P01 (kL/s)	P02 (kL/s)	P03 (kL/s)	P04 (kL/s)	P07 (kL/s)	P09 (kL/s)	P10 (kL/s)	P14 (kL/s)	SPS (kL/s)	WPS (kL/s)
1997	3.47	3.47	0.81	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.75	4.44
2003	2.89	1.74	0.93	0.22	0.19	0.23	0.35	0.31	0.10	0.46	0.28		
2004	2.70	1.79	0.60	0.21	0.18	0.24	0.36	0.33	0.10	0.47	0.30		
2014	0.64	0.54	0.72	0.14	0.07	0.08	0.23	0.28	0.05	0.47	0.16		
2015	1.08	1.35	1.21	0.09	0.08	0.02	0.14	0.11	0.03	0.49	0.17		
2016	1.65	1.08	1.23	0.23	0.19	0.17	0.26	0.25	0.05	0.56	0.20	4.73	2.11
2017	2.66	1.26	1.24	0.22	0.14	0.25	0.33	0.26	0.08	0.71	0.18	3.52	2.05

Throughout 2017 there were extended periods where individual pumps, or problems with the infrastructure were encountered (Table 6). Electrical noise at the Southern Transfer station was a particular problem that resulted in the collection of erroneous data until rectification of the fault on 7 August 2017 (Figure 21).

Consequently, daily pump volume totals from the submersible pumps cannot be reconciled for the preceding period. Submersible pumps E11, E13 and E15 all failed prior to the inundation event on 3rd February 2017. Pumps E11 and E13 were restored on 11th February 2017 whilst pump E15 was not operational until 23rd February 2017. Pump E11 again failed on 28th February 2017 and was restored on 23rd March 2017.

Table 6. Summary of the number of days and percentage of time that groundwater pumps were operational in 2017

Pump ID	# days where pumping >0	Pumps operational or data available (%)
E11	277	75.9
E13	296	81.1
E15	285	78.1
P01	272	74.5
P02	70	19.2
P03	287	78.6
P04	288	78.9
P07	287	78.6
P09	50	13.7
P10	290	79.5
P14	259	71.0

Problems with the air displacement pumps also occurred. Leaking airlines were observed at pumps P02 and P09 and in the case of P02 it was evident that surface water was being removed. Pumps P02 and P09 were subsequently shut down on the 17th March and the 1st March 2017 respectively and they were not repaired until January 2018 when the infrastructure could be safely accessed.

On the 1st March 2017 an airline was replaced on P14. Faults with the flow meter at P01 gave the appearance of pump failure from the 2nd June to the 15th June 2017.

The telemetry system failed on the 3rd November 2017 and was not restored until the 3rd January 2018. This resulted in a loss of the daily values, although a cumulative total for each of the pumps was retrievable (Appendix 10). A power outage at the Southern Transfer station from the 20th May 2018 to the 24th May 2018 meant that all three pumps were inoperable. The error associated with the accounting of pumping volumes is unknown, but it may be in the order of ±20%.

At the time of writing this report all pumping infrastructure was fully operational and groundwater levels now reflect this and are in decline (Appendix 9).

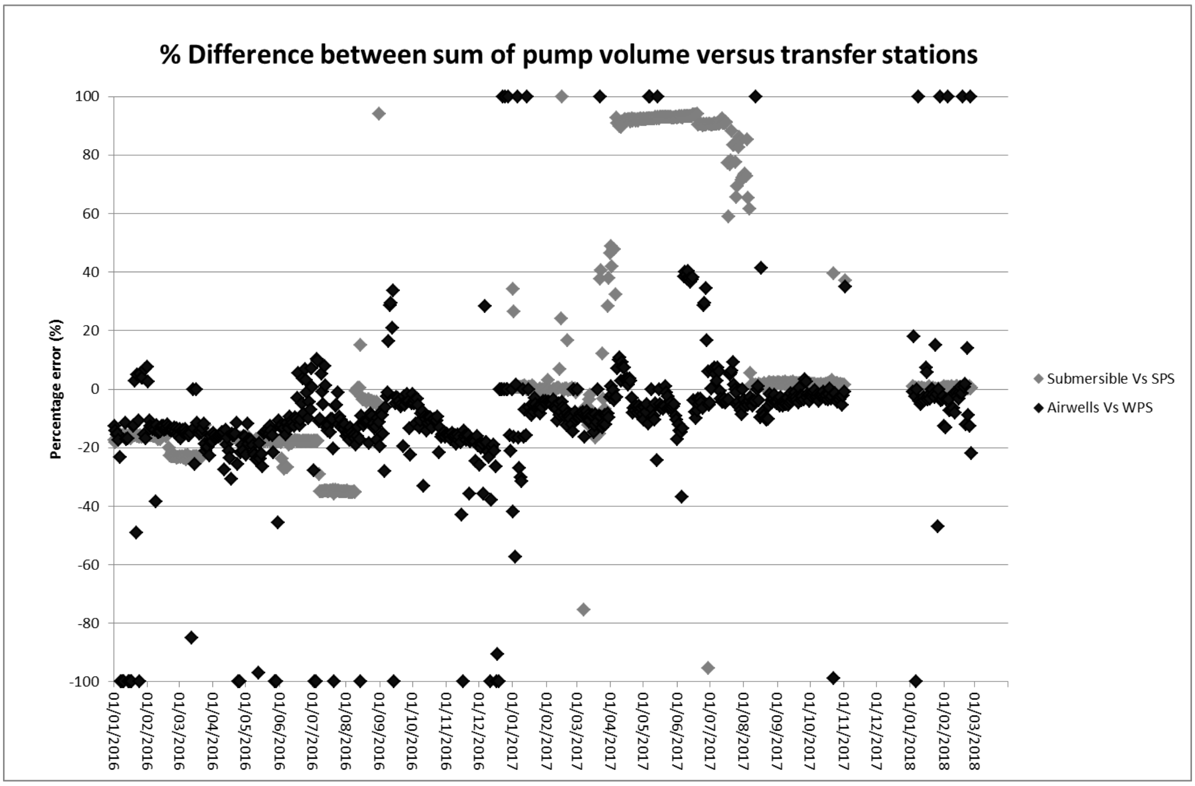


Figure 21. Reconciled performance (expressed as percentage error) of the sum of the air displacement pumps and submersible pumping network versus that observed at their respective western and southern transfer stations.

Measurements of the electrical conductivity of pumped groundwater from the Southern and Western pumping transfer stations show a similar range of values over the monitoring period, with both sites averaging about 62,000 µS/cm (62 mS/cm, 6,200 mS/m, ~31,000 mg/L TDS), which is similar to that previously reported (see Rutherford et al. 2015). Some temporal variability was evident, particularly with the lower range of salinity levels observed at the Western Transfer station in February and March 2017 (Figure 22).

These lower values are coincident with the period that pump P02 was operational and pumping lines were observed to be pumping lake water, which may have diluted salinities measured at the Western Transfer Station (see Section 4.2.2).

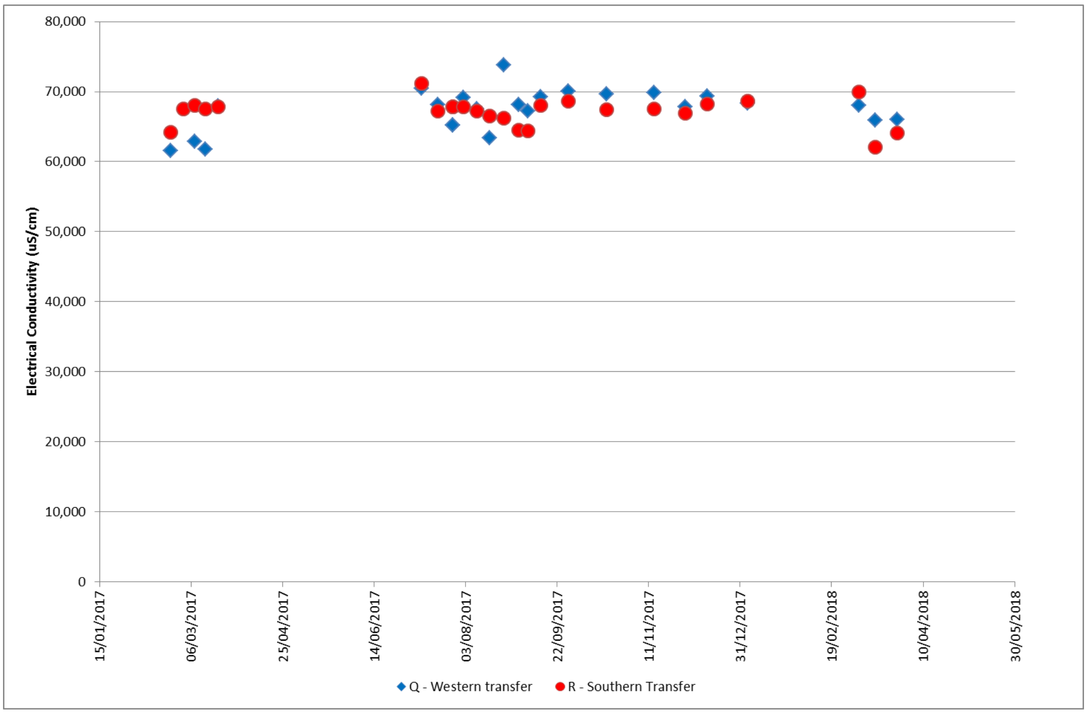


Figure 22 Electrical conductivity of groundwater discharge measured at the Southern (red dots) and Western (blue diamonds) Transfer stations.

The aquifers beneath Toolibin Lake having complex geometry and variable physical properties (e.g. storages, specific yields and hydraulic conductivities). Integrating the monitoring and pumping data presented here is therefore difficult to assess outside a numerical model. This is discussed further in Section 5.

WatBal model

The WatBal water balance model outputs generally show a good agreement with the observed water levels over the long-term (1978-2018) record (Appendix 11), although for both the 2017 and 1981-1982 events the model overestimates lake water levels and underestimates the rate of recession, particularly when the lake surface water level drops below around one metre (Appendix 11).

The overestimation of lake water levels is likely to be caused by the antecedent conditions prior to the lake inundation. The inundation occurred in summer when pumping had reduced groundwater levels to around 4 meters below ground level and soil moisture was likely to be low. During the first week of inundation groundwater monitoirng levels in all aquifers increase, confirming there is recharge, which is likely to be combined with a hydraulic loading effect induced by the volume of overlying lake water. Seepage and deep drainage of lake water therefore occurs in the unsaturated zone and recharges groundwater and these water losses are not accounted for in WatBal.

Monitoirng and modelled data trends are different with respect to the rate of lake water level decline. This is most pronounced when lake levels fall below the natural outlet and may be caused by different rates of evaporation occuring across the lake (Figures 18, 19 and 20) and recharge to groundwater induced by pumping, both of which cannot be modelled in WatBal.

Considering these limitations outlined above, WatBal was updated with event data and the model run at a daily time-step to assess the broad scale water balance parameters. WatBal outputs indicating that from January 2017 to May 2018, surface water inflows via the main inlet dominated inputs to the water balance at 4,809 ML (83%). Incident rainfall was estimated to contribute 970 ML (13%).

The relative contributions of rainfall and surface water inflows to Toolibin Lake have remained relatively constant over the 1978 to 2018 period analysed, which are similar to those reported by Dogramaci et al. (2003) using the same model. It is estimated that about 2,356 ML (33%) of flows measured at the gauging station 609010 bypassed the lake and were diverted downstream to Lake Taarblin.

From January 2017 to May 2018 the water balance outputs were dominated by evapotranspiration losses at 4,030 ML (70%) and the remainder (1,741 ML (30%)) accounted by surface water outflow. Surface water losses via the natural outlet accounted for the majority of outflows (1,469 ML (84%)) and outflows via the bund breach were estimated to be 272 ML (16%).

Applying WatBal to model a lake inundation scenario without the bund breach indicates that the lake level would have peaked at about 0.13 m higher, or 2.41 m (298.47 mAHD). This difference in peak levels equates to 525 ML in additional storage in the lake. This approach indicates that outflow losses via the bund breach, as estimated by WatBal, are significantly less than initially estimated (see File Note: Department of Parks and Wildlife 2017). However, losses via the bund breach and damage to the diversion channel and bund would have been more substantial if DBCA Wheatbelt Region staff had not promptly responded to the situation and completed the repairs.

The WatBal results here need to be treated with caution and the full value of the data collected and analysed here will be reviewed within a numerical model in 2019. It is important to note that observations between modelled and manual data are only possible due to comparisons with the long term manual surface water measurements collected by the DBCA SWWMP program, which are critical in verifying the WatBal model historical outputs. The 33 DBCA Wheatbelt Regional office measurements from Site F, collected between February 2017 and April 2018, were essential in assessing model performance for the inundation reported here (Appendix 4 and 5).

5 Discussion

The February 2017 Toolibin Lake inflow event has provided the opportunity to;

1. Summarise and review the current surface water management infrastructure,
2. Test surface water infrastructure and produce a thorough chronological history of the event,
3. Document the process developed to alter the existing hydrological monitoring programs and collect fit for purpose rainfall event and inundation data to improve our understanding of the hydrological function of Toolibin Lake and
4. Review management triggers and assess the benefits of following a scientific process where analytical predictions are proposed, monitoring recommended, data collected, and existing analytical models tested.

Although there have been in excess of 20 inflow events (Table 1) there is little documentation that summarises the surface water management infrastructure and inundation event chronology. This is mainly due to few events taking place since the installation of the diversion and separator gates. This report is the first to document the hydrological significance of a rainfall and inundation event, and cover the collaborative effort, both within and between government agencies, to troubleshoot problems as they arose, and develop solutions and processes to ensure hydrological data were collected to analyse and improve the understanding of Toolibin Lake's hydrology.

The scientific process adopted for the February 2017 inundation event focused on how and when the hydrology salinity management triggers would be met. Results show the initial DBCA spreadsheet predictions underestimated the length of time for lake surface water to recede but produce relatively accurate temporal estimates of the time to reach the 10,000 µS/cm (10 mS/cm, 1,000 mS/m and ~5,000 mg/L TDS) water quality sump pump activation trigger. Figure 23A (see Appendix 12) estimates this will occur in March 2018, when lake water levels are around 0.2 metres.

The collection of high frequency surface water level data shows the lake recession is slower than predicted in Figure 23A, with the ~5,000 mg/L management trigger being reached when lake water levels are around 296.6 mAHD (e.g. ~0.6 metres) (Figure 23B). Comparing linear-log plots of actual and modelled data (Figures 23B and 23C) shows salinities and trends are similar. However, as noted in the previous section, the WatBal model tends to overestimate water levels and underestimate the rate of recession that occurs when lake levels decrease below one metre. This may occur due to losses to groundwater, which is an important knowledge gap.

Groundwater levels in all aquifers increased following the February 2017 rainfall event, with rates of change being variable and the average groundwater increase being around four metres. Following this rise, groundwater levels in the surficial aquifer either remained constant, until decreasing in December 2017, or displayed a seasonal response in 2017 (decline in March to May 2017 and increase in July and August 2017).

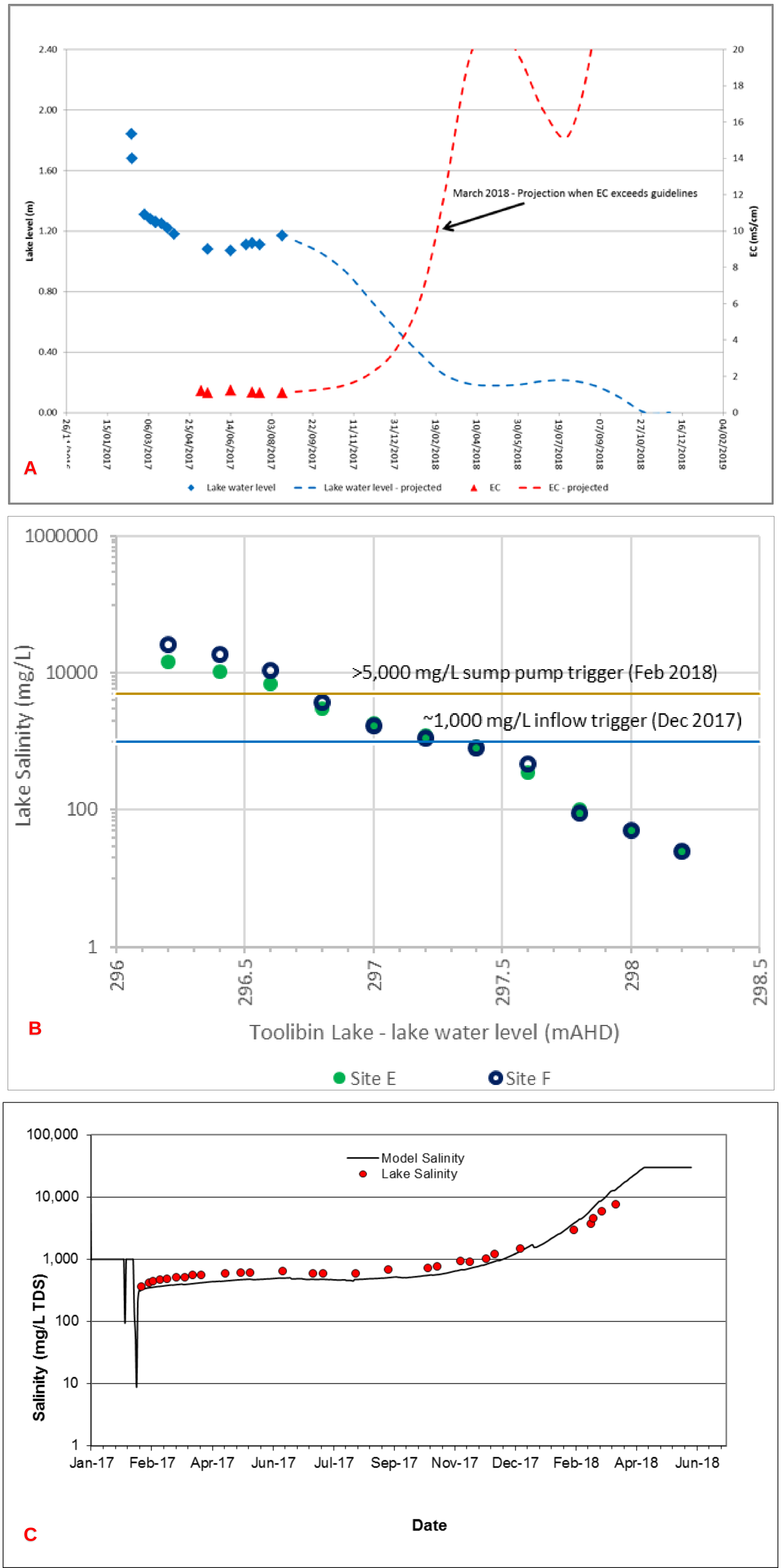


Figure 23 A. DBCA plot of observed and predicted water levels and salinity in Toolibin Lake, B. Data logger EC data collected in Toolibin Lake and converted to mg/L TDS (Note 296 mAHD is average base of lake and C. WatBal modelled and observed salinity concentrations for the period 01/01/2017 to 31/05/2018

Deeper aquifer's mimic these trends, with some bores showing a response to pumping in addition to seasonal rainfall (July and August 2017). The variation in the magnitude and duration of these responses appear to reflect the pumping schedule and bore location (e.g. distance of monitoring bores from pumping bores and groundwater levels displaying a rebound following a break in pumping and decreasing on the recommencement of pumping).

The complexity of the groundwater level responses makes it difficult to estimate the influence of groundwater pumping on inducing the seepage of lake water into the unsaturated zone and aquifers. The WatBal model cannot be easily used for this task as it doesn't explicitly model deep drainage of soil water into aquifers or account for groundwater pumping. This will be undertaken using a numerical model in 2019 (CyMod Systems in prep.).

The collection of high frequency lake level and salinity data over a number of sites demonstrate that the lake behaves as a homogeneous entity until water levels reach around 296.8 mAHD (approximately 0.8 metres). At this stage relationships between lake level and rates of salinity increase change, with some areas receiving more salt loads than others (Figure 23B).

Findings from this work show that simple analytical models used in this study were useful tools when Toolibin Lake had higher lake levels (> 1 metre) and exhibited homogeneous behaviour. These models were less accurate when near-surface heterogeneity became apparent. Most notably accounting for groundwater pumping, lake water seepage to the unsaturated zone and groundwater, and when the lake water body separated and evaporation rates across the lake become spatially variable (Figure 23C).

5.1 Limitations and further work

As outlined in Section 4 and 5 the simple analytical models used in this study are designed for homogeneous systems that show a common behaviour. They provide spatially averaged estimates for the lake and are therefore limited as a tool to predict water and salt balance changes in Toolibin Lake.

WatBal may be able to provide improved results if data can be collected to calibrate and verify losses of lake water to groundwater. However, if this is induced by pumping the likelihood is this will be spatially variable, which cannot be modelled with WatBal.

Consequently, the results from analytical models trialled here are limited without both supporting observations (manual and high frequency) and an understanding of spatial variability. The full value of post February 2017 hydrology data collected at Toolibin Lake will be realized on the completion of the saturated flow model for the Toolibin Lake and catchment. This model is to be completed in early 2019 (CyMod Systems in prep).

The February 2017 event has delivered more salt and water to Toolibin Lake. Data collected and interpreted here indicate that 560 to 1400 Tonnes of salt may have been deposited over 27 to 60% of the lake floor. Follow up work to be undertaken by DBCA in 2019 includes quantifying changes in soil water and groundwater quality beneath Toolibin Lake using repeat borehole geophysical logging and environmental tracers to quantify recharge, aquifer mixing and pumping induced flushing of aquifer solutes. The outcomes of this work will include the collection and development of an independent dataset to assess;

- The relative effectiveness of groundwater pumping across the lake (in the absence of a continuous pumping data series).
- An understanding of the time and climatic events needed to assist the flushing of salt stored in the lake substrate and
- A dataset/map to help develop revegetation strategies (e.g. dynamics of salt stored in the root zone).

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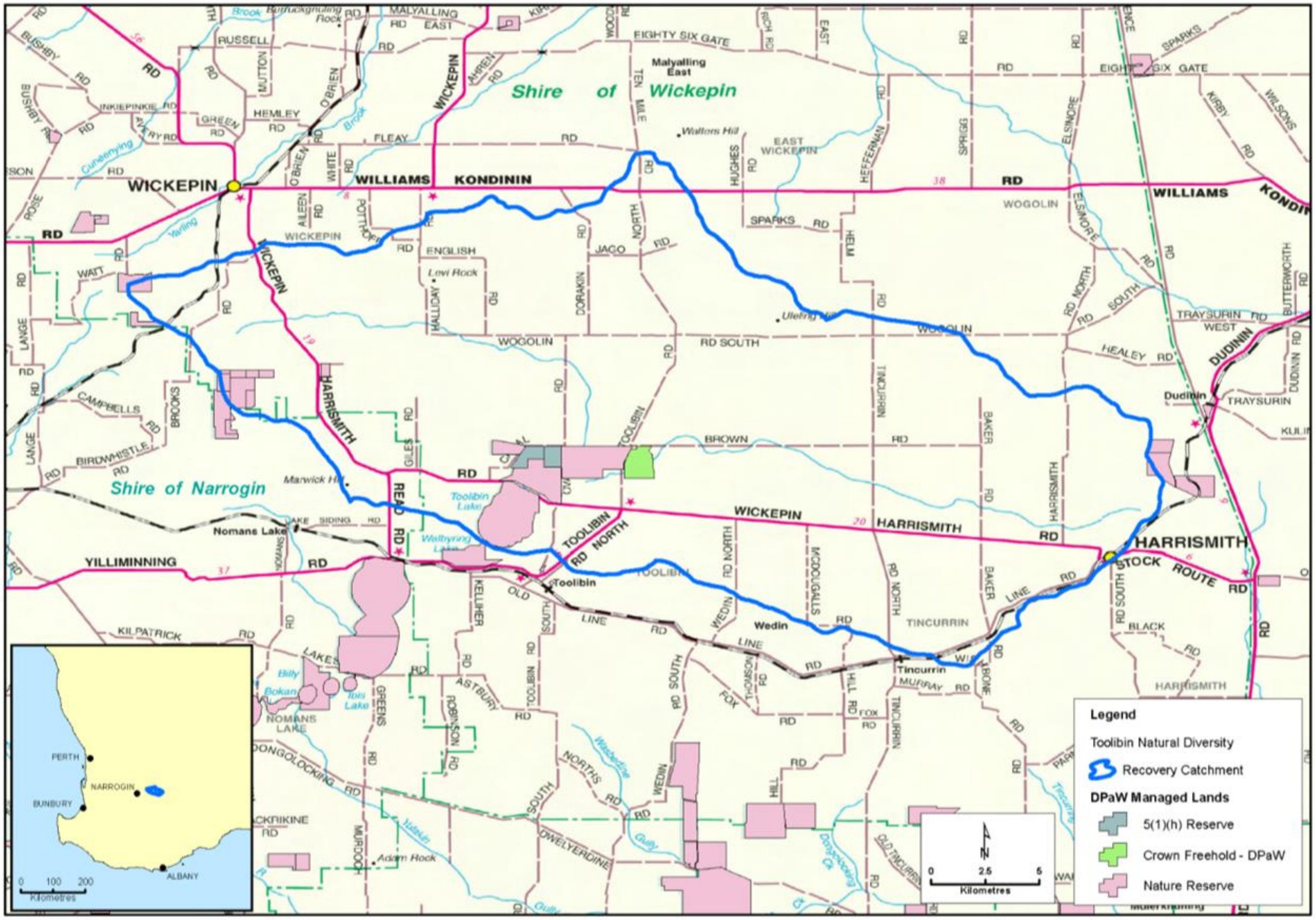
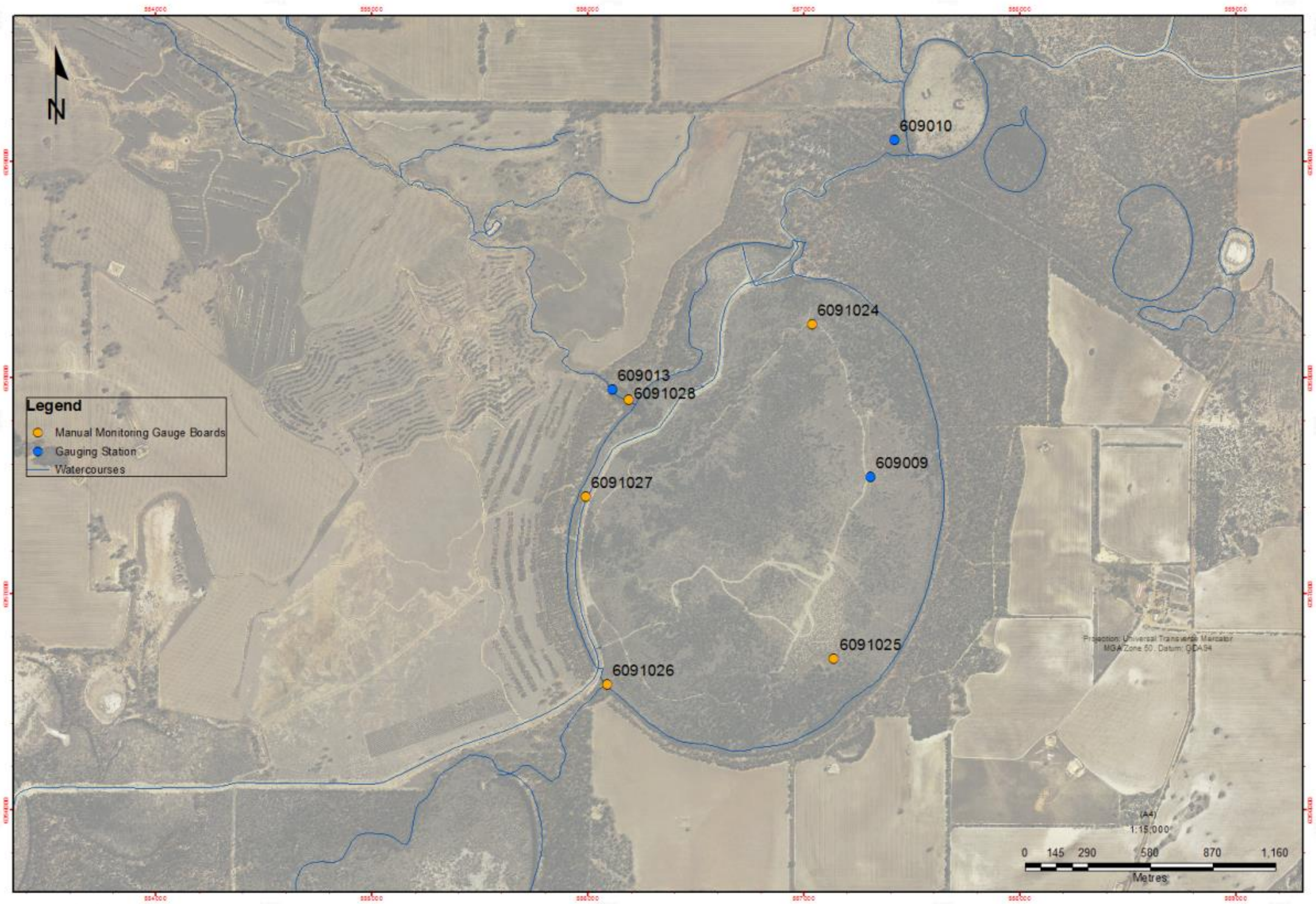
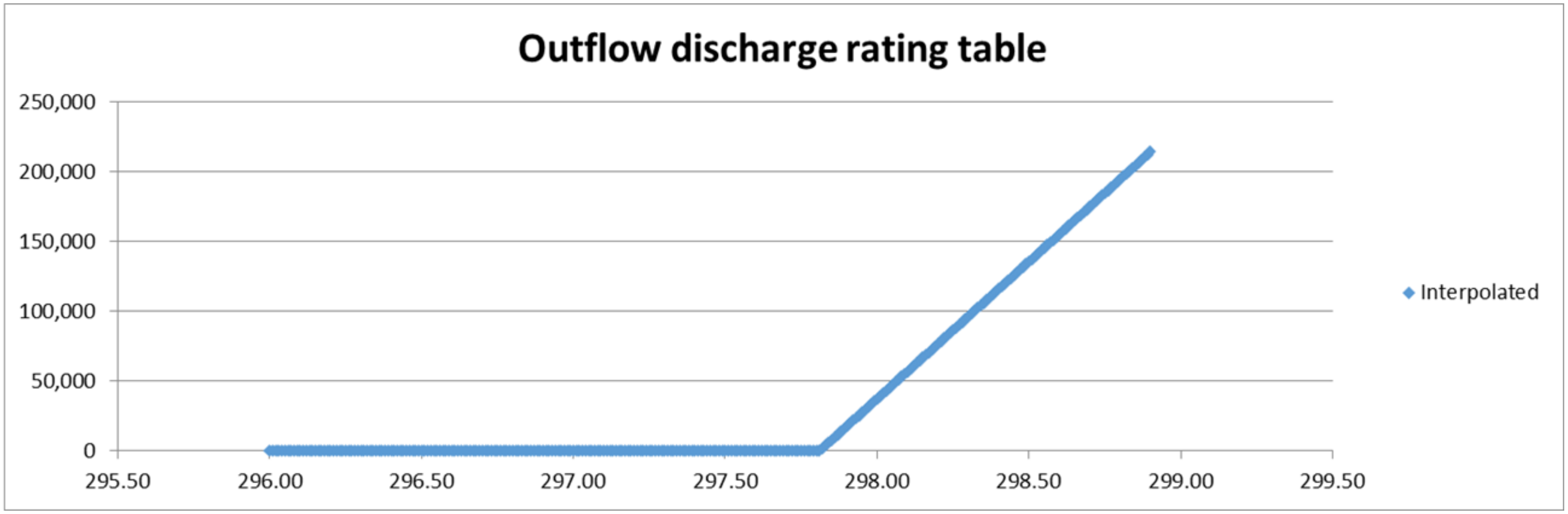
Appendix 1 Site location



Appendix 2 Surface water monitoring stations (1977-1989) - Toolibin Lake



Appendix 3 Toolibin Lake bund breach cross-section survey



The cross-sectional area of the breach in the bund wall was surveyed on 20 October 2017 by Lindsay Bourke with a laser level. Survey with differential GPS (Sokkia Stratus 12-channel L1 GPS) reduced the surveyed cross-section to Australian Height Datum relative to a survey bench mark (Zone 50, E 557378.424, N 6359066.537, Z 297.51mAHD) located adjacent to the Department of Water and Environmental Regulation (DWER) gauging site 609010. Elevation accuracy of the bund breach survey is expected to be better than ±0.2 m.

Appendix 4 Toolibin Lake – surface water monitoring operating procedures

TOOLIBIN LAKE

STANDARD OPERATING PROCEDURES

SURFACE WATER MONITORING

Responsible Officer: Conservation Officer, Toolibin Lake

INTRODUCTION:

SW monitoring is undertaken at the above sites during inundation events, which can occur during winter, or at other times due to thunderstorms or cyclonic rainfall events.

The key SW metrics include:

- Direct observations of water properties at SW sites including:
  - Water depth – on the depth gauge;
  - Electrical conductivity (EC) of water samples; and
  - Temperature of water samples.
- Derived values include:
  - The total dissolved solids (TDS) estimated from the EC measurements;
  - The wetland volume derived from bathymetric analysis; and
  - Salt load, derived from wetland volume and TDS .

Past monitoring has generated considerable data of questionable quality and value. Contributory factors include:

- A lack of documentation on the equipment used and how it was set-up and calibrated;
- Use of non-standard techniques
- Use of non-standard data recording sheets;
- Absence of key observations, which prevent derived values being calculated; and
- Collection of data at non-standard sample points.

To address these problems

- Standardised recording forms have been developed which now capture key information that was missing from early documentation;
- Standard equipmentset-up and calibration procedures have been documented.

The following sites (listed and tabled below) are to be monitored. All waypoints are captured in the Conservation Officer's GPS and are identified as A, B, C etc, a map is located in the TL Surface Water Monitoring folder.

Toolibin Nature Reserve

A. Diversion Gate upstream of weir
B. Booloo (west) creek downstream of culvert
C. Diversion channel/boundary track crossing in south-west corner
D. TL25 GB (gauge board)
E. Sump GB
F. DOW gauging station GB – levels only

Catchment

G. Wickepin-Harrismith Road downstream of culvert
H. Toolibin Road North culvert (road side drain from Brown Rd)
I. Toolibin Road and Brown Rd intersection NE corner upstream
K. East drain downstream Brown Rd
L. West drain downstream Brown Rd

Dulbinings

M. Dulbining waterway at Oval Road
N. Dulbining Lake GB (2 gauge boards)
O. Dulbining 2 GB
P. Dulbining 3 GB

Pumping Sheds

Q. Western Pumping Station
R. Southern Pumping Station

Toolibin outlet

S. Muirden old gauge board
T. Muirden new gauge board

These procedures cover surface water depth measurement technique, water sampling technique and surface water EC and temperature analysis.

SITE ID	EASTING_MGA50	NORTHING_MGA50	SITE_DESCRIPTION	Sampled By (Initials)	SiteVisited Yes/No	DATE	TIME	EC_microS/cm	Temp_ ^{0} C	TDS_mg/L	Flow Observations (including no or recent flow information)	Water_level (mLD)	Photo_Record Yes/No	General Comments
A	556750.3	6358462.4	Diversion Gate upstream of weir											
B	556047.0	6357995.9	Booloo (west) creek downstream of culvert											
C	555998.5	6356563.9	Diversion channel/boundary track crossing in south-west corner											
D	557389.5	6357286.6	TL25 GB (gauge board)											
E	556405.7	6357005.5	Sump GB											
F	557295.8	6357661.4	DOW gauging station GB – levels only											
G	557507.3	6359035.4	Wickepin-Harrismith Road downstream of culvert											
H	561556.7	6360255.7	Toolibin Road North culvert (road side drain from Brown Rd)											
I	561822.5	6360899.8	Toolibin Road and Brown Rd intersection NE corner upstream											
K	559935.0	6360842.1	East drain downstream Brown Rd											
L	558993.3	6360870.3	West drain downstream Brown Rd											
M	558987.9	6359376.0	Dulbining waterway at Oval Road											
N	557629.6	6359178.1	Dulbining Lake GB											
O	557992.7	6358990.7	Dulbining 2 GB											
P			Dulbining 3 GB											
Q			Western Pumping Station											
R			Southern Pumping Station											
S			Outlet (Muirden old gauge board)											
T			Outlet (Muirden new gauge board)											
Electrical conductivity metre calibrated by (Initials) with standard solution														

SW Water Depth Measurement Technique

A gauge board. The alternating black and white bars are 1 cm wide with the measure commencing at the bottom of each bar. The water level at this gauge board is 1.37 m.

EQUIPMENT REQUIRED

- TL Surface Water Monitoring folder which contains:
  - Maps
  - SW monitoring sheet (or waterproof notepad if conditions are wet)
  - Clipboard and pens
- GPS
- Camera
- Extendable water sampler/walking/measuring stick
- Scourer
- Waders or rubber boots

Extendable water sampler/walking/measuring stick

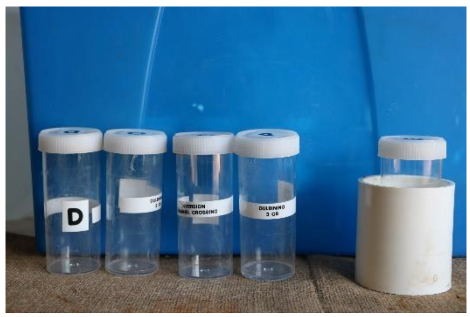
WORK REQUIRED

1. On the *SW monitoring sheet* (or waterproof note pad) note the officer's name, and the date and time of reading.
2. Navigate to the gauge board.
3. Use the tape measure or measuring rod to determine if the depth board is indicating an accurate water depth.
4. If the error is more than 1cm, record the error (as a +, or – value), in metres to 2 decimal places, in the *Depth Board Correction* field.
5. Observe the water depth indicated on the depth gauge
6. Record this in the *Water_level_mLD* column (Note: Record measurements in metres to 2 decimal places). It is likely many old gauge boards are stained from the tannins and debris in the water. A scourer can be used to remove any muck to ensure an accurate reading.
7. Capture a photograph of the gauge board , showing the water depth and gauge board identification (if there is one).
8. Record the photo number on the *SW monitoring sheet* or notepad.

Water Sampling Technique

EQUIPMENT REQUIRED

- TL Surface Water Monitoring folder which contains:
  - Maps
  - SW monitoring sheet (or waterproof notepad if conditions are wet)
  - Clipboard and pens
- GPS
- Waders or rubber boots
- Labelled water sample container with lid
- Depth sample collector for the tanks at the pumping station
- Extendable water sampler/walking/measuring stick



Labelled water sample container with lid

WORK REQUIRED

Water samples are collected using the guidelines from *Field sampling guidelines: A guideline for field sampling for surface water quality monitoring programs* (Department of Water 2009) below. Labelled containers are stored in a blue plastic box in the Toolibin shed:

9. Ensure that label on the container is correct to the site you are sampling and the *SW monitoring sheet.*
10. Take the sample within a 10 m radius of the gauge board you may need to wade into the water in waders or wellington boots, minimising disturbance as much as possible. Use the walking/measuring stick to support yourself.
11. Don't uncap the bottle until just before the sample is to be taken.
12. When inundationing the bottle (both for rinsing and for the final sample) take the sample upstream and to the side of you.
13. For rinsing immerse the bottle in the water to your elbow (to a depth of ~40cm) lying it flat with its mouth towards the flow of the water, then slowly move the bottle forwards into the flowing water. Allow approximately 20 mL of water to enter the bottle. Cap, shake well and pour the rinsate downstream of yourself. As water level becomes shallower the depth at which you sample will decrease, it is important to note in the *General Comments* column if your technique changes.

14. For sampling immerse the bottle in the water to your elbow (to a depth of ~40cm) lying it flat with its mouth towards the flow of the water, then slowly move the bottle forwards into the flowing water.
15. Where there is no flow cover the opening of the container with your hand and lower into the water to the desired depth, remove hand and allow the water to enter the container and when full bring it to the surface.
16. Cap, and store the sample container as required for transport.
17. Collect water samples from all sites.

<u>Return to Shed</u>

18. Analyse the water sample with the TPS WP-81 meter. See *Surface Water EC and Temperature Analysis*, see below.
19. If necessary, transfer observations from the waterproof notepad to the *SW monitoring sheet*.

<u>Return to the office</u>

20. Data from the monitoring sheet is entered into the TL Surface Water Monitoring spreadsheet located in T:\465-Operations (Region)\Shared Data\SCIENCE AND CONSERVATION\CONSERVATION\TOOLIBIN\HYDRO - SURFACE WATER\EVENTS.
21. Copy a *field blank input sheet* to a new tab and rename it with the date YYYY_MONTHDAY and input data from the monitoring sheet.
22. Open the *calculator sheet.* Firstly, you will need to enter the temperature and convert microsiemens/cm (µS/cm) to millisiemens/cm (mS/m) in the table.

ID	SITE_DESCRIPTION	ELECTRICAL_CONDUCTIVITY_microS/cm	Temp_°C	EC_mS/m
A	Diversion Gate upstream of weir			0
B	Booloo (west) creek downstream of culvert	5030	16.7	503
C	Diversion channel/boundary track crossing in south-west corner	156	17.3	15.6
D	TL25 GB (gauge board)			0
E	Sump GB			0
F	DOW gauging station GB – levels only			0
G	Wickepin-Harrismith Road downstream of culvert	533	16.5	53.3
H	Toolibin Road North culvert (road side drain from Brown Rd)	190.9	16.7	19.09
I	Toolibin Road and Brown Rd intersection NE corner upstream	196.1	16.6	19.61
J				0
K	East drain downstream Brown Rd			0
L	West drain downstream Brown Rd	151	16.9	15.1
M	Dulbining waterway at Oval Road	765	16.9	76.5
N	Dulbining Lake GB	9960	17.2	27
O	Dulbining 2 GB			0
P	Dulbining 3 GB			0

23. Move to the INPUT table and enter the temperature and mS/cm into the table to give you the TDS mg/L and then enter into the details into the spreadsheet.

INPUT

Temperature	17.2	°C				
UnCompensated Conductivity	27	mS/m		**SALINITY - TDS**	172	mg/L
Compensated Conductivity	31.9	mS/m		Salinity - Farmer	12	gr/gal
UnCompensate a SpecCond	23	mS/m	--->	----- Comp ---------	> 147	mg/L

24. The saved spreadsheet is then emailed to Senior Hydrologist, WCP and any other interested parties. Research scientists for birds and invertebrates would also be interested in this spreadsheet.

Surface Water EC and Temperature Analysis

EQUIPMENT REQUIRED

- SW monitoring sheet
- Clipboard and pens
- Hand-held TPS WPS-81 EC and temperature meter, probes, charger and manual
- 2 L distilled water
- Water samples from each site
- Container to clean probes
- Container holder

WORK REQUIRED

25. Before analysis ensure the TPS WPS-81 EC is calibrated see *TL Procedures - Calibration and Use of TPS-WPS-81 EC, pH and Temperature Met*er
26. Record on the *SW monitoring sheet* at the site the sample was taken:
    a. Depth from which the sample was taken;
    b. Time the sample was collected; and
27. If not already done, inundation a clean and empty container with distilled water and thoroughly rinse the sensors and then blot dry, do not blot the sensor wires.
28. Connect the sensors to the TPS WP-81 Meter and switch the meter on.

29. Ensure that the meter is set to read EC, see *TL Procedure- Calibration of WPS81 Conductivity, pH and Temperature Meter*.
30. Place a water sample container into the holder and carefully place the EC/temp sensor in the water sample.
31. Observe the EC and Temperature readings obtained for the sample.
32. When these stabilise, record on the *SW monitoring sheet*:
    a. EC value obtained from the sample,
    b. EC units of the sample (either µS/cm or mS/cm),
    c. Temperature of the sample.
33. Add in any additional comments about the water sample, the SW site or other relevant matters.
34. After each analysis the water sample can be disposed and container and lid rinsed with distilled water.
35. The sensor probe needs to be rinsed in fresh distilled water and blot dry, do not blot the sensor wires.
36. Process additional samples collected.
37. When analysis is completed, thoroughly rinse the sensors in distilled water and then dry, and pack up the equipment.

REFERENCES

- TL Procedures - Calibration and Use of WPS-81 EC, pH and Temperature Meter Procedures
- Field Sampling Guidelines: A guideline for field sampling for surface water quality monitoring programs (Department of Water 2009)
- JSA - Use of Dinghy In and Around Toolibin Lake
- JSA – Surface Water Monitoring

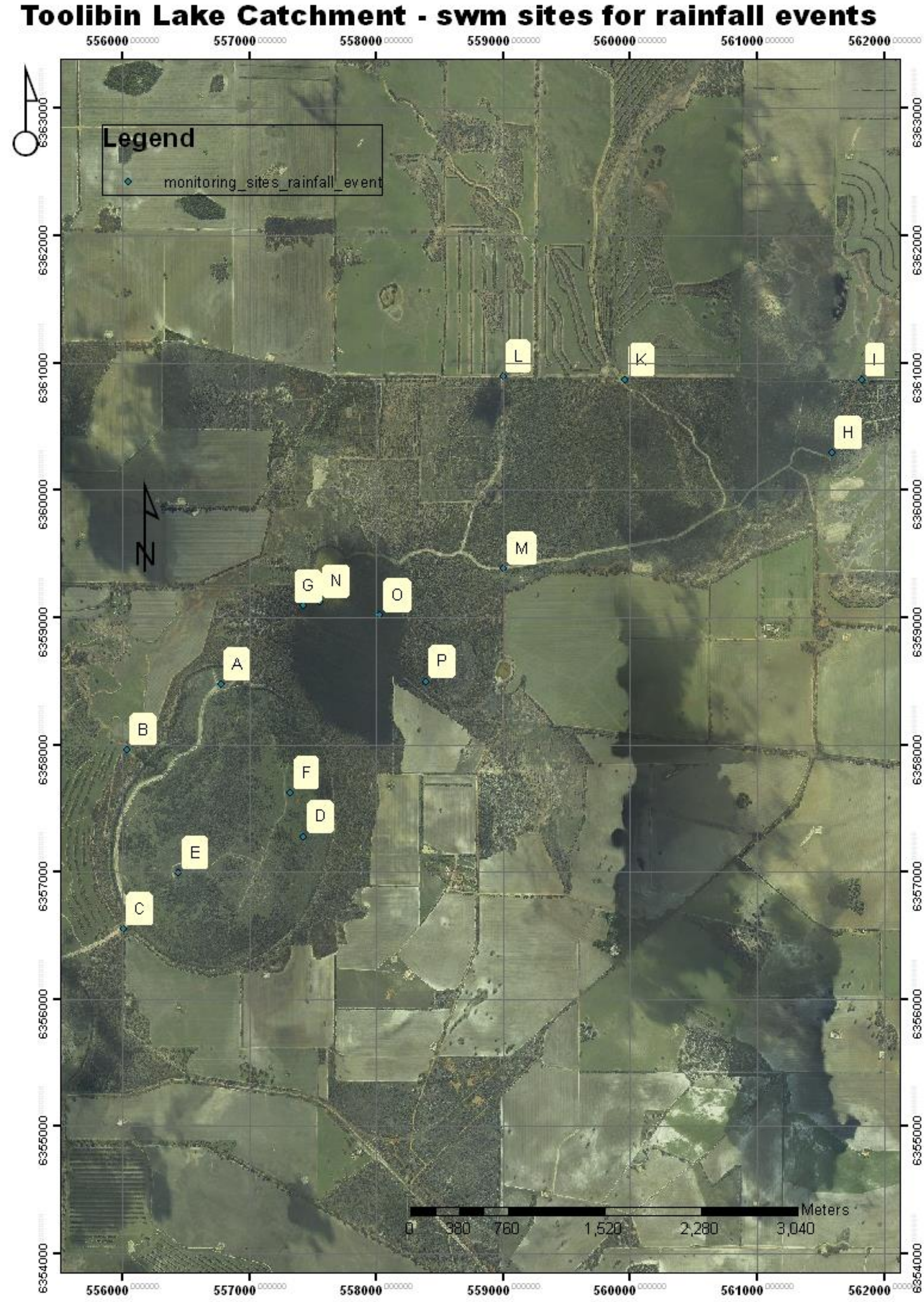
APPROVED:

CONSERVATION OFFICER

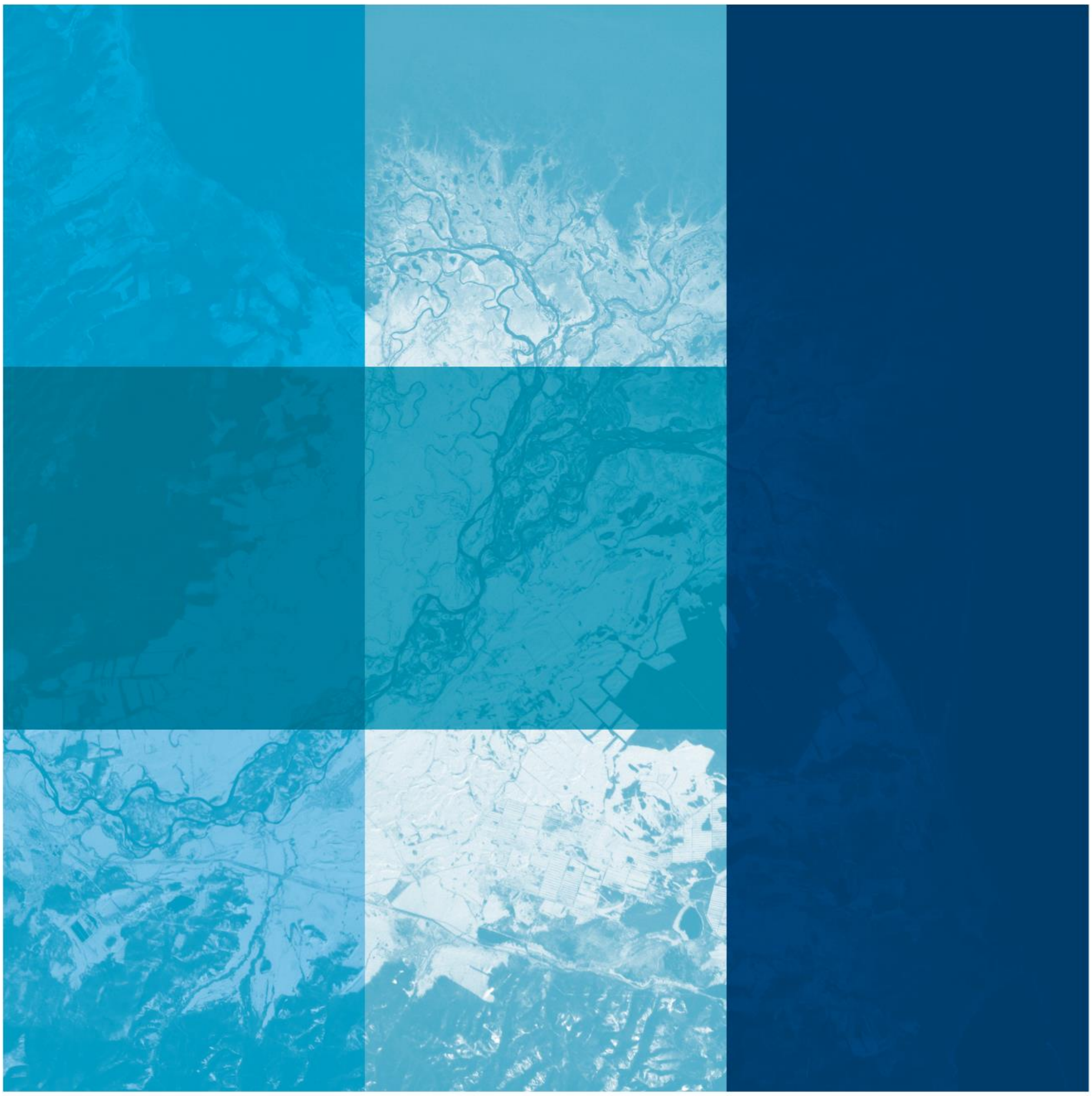
(TOOLIBIN LAKE)

Version: 2 May 2017

Attachment B



Appendix 5 WatBal user manual



Report: WatBal user manual

Client: Department of Parks & Wildlife

Job number: 010 0007

Date: 11 April 2016

Contents

Figures

Tables

1. Introduction and background

1.1 Purpose of this document

In January 2016 Hydrologia were contracted by the Department of Parks and Wildlife (DPaW) to update an existing Lake water balance model for Toolibin Lake and write a user manual. This project was developed following an internal review of hydrological work undertaken in the Toolibin Lake Natural Diversity Recovery Catchment (TLNDRC) (Rutherford et al. 2015).

This document presents a user manual for the programme WatBal.

WatBal is a water and salt balance model for Toolibin Lake, developed originally by Adrian Peck (Peck 2000). The model is coded into a Microsoft Excel spreadsheet and predicts the Lake water level and salinity using a monthly time step.

The Toolibin Lake model was developed in the early 2000's for the Water and Rivers Commission (Dogramaci *et al.* 2003, Bari 2004) and was used to simulate the monthly Lake water and salt balance for the period 1978 to 2000.

The scope of this project was to:

- Extend the model period (1978-2015);
- Update the model with new lake depth-volume relationships (pre and post diversion) derived from fine-scale photogrammetric data (see Appendix A) and change the monthly time step to weekly; and
- Develop a user manual.

This document is the user manual and is structured to provide a brief background on the rationale for developing the model, the model set up (data input files and empirical relationships), operation and the model outputs. The model and supporting data files are presented as Microsoft Excel spreadsheets.

1.2 Background

Toolibin Lake is one in a chain of lakes in the Northern Arthur River system in the upper Blackwood River Catchment, a semi-arid area characterised by low rainfall and high evaporation.

Figure shows the location of Toolibin Lake in relation to the Recovery Catchment boundary, which is also the main surface water catchment boundary.

The Lake and surrounding reserves form an important breeding site for native flora and fauna. The site has been listed under the Ramsar convention as a wetland of International Importance (RAMSAR 2016).

Toolibin Lake is classified as ephemeral and can be dry for extended periods of time. The Lake and catchment are affected by dryland salinity associated with imbalances in both the water and salt balance caused by the clearing of native vegetation for agriculture. These processes have increased the frequency and duration of surface water flows as well as stream salt loads to the Lake, which has resulted in rises in groundwater levels and salinity.

To help manage this problem, a diversion channel was installed in 1995.

Figure shows the main engineering structures built between 1990 and 1999. Table 2 details the works undertaken.

The catchment for the Lake covers approximately 480 km^2 (Figure and Table). Streamflow into the Lake is variable and intermittent and a small outlet allows flows when water when the Lake water depth is at about 2 meters (6091026, Figure).

Table 1 Catchment details

Name	**Area (km^2)**	**Description**
Upper Arthur River	440.0	Catchment to station 609010 (Figures 1 and 3).
Booloo Creek	41.2	Catchment to 609013 (west of Toolibin Lake, see Figure 3).
Lake Toolibin	4.3	The Lake itself (Figures 2 and 3).
To Toolibin outlet, pre-diversion	484.5	Entire catchment before the Booloo Creek diversion in 1995 (Figure 1).
To Toolibin outlet, post diversion	444.3	Entire catchment after the Booloo Creek diversion.

The original infrastructure to measure flow and Lake Level was installed by the Water and Rivers Commission (now Department of Water) in the late 1970's and this has been supplemented with additional sites to measure the performance of engineering infrastructure, such as the diversion channel.

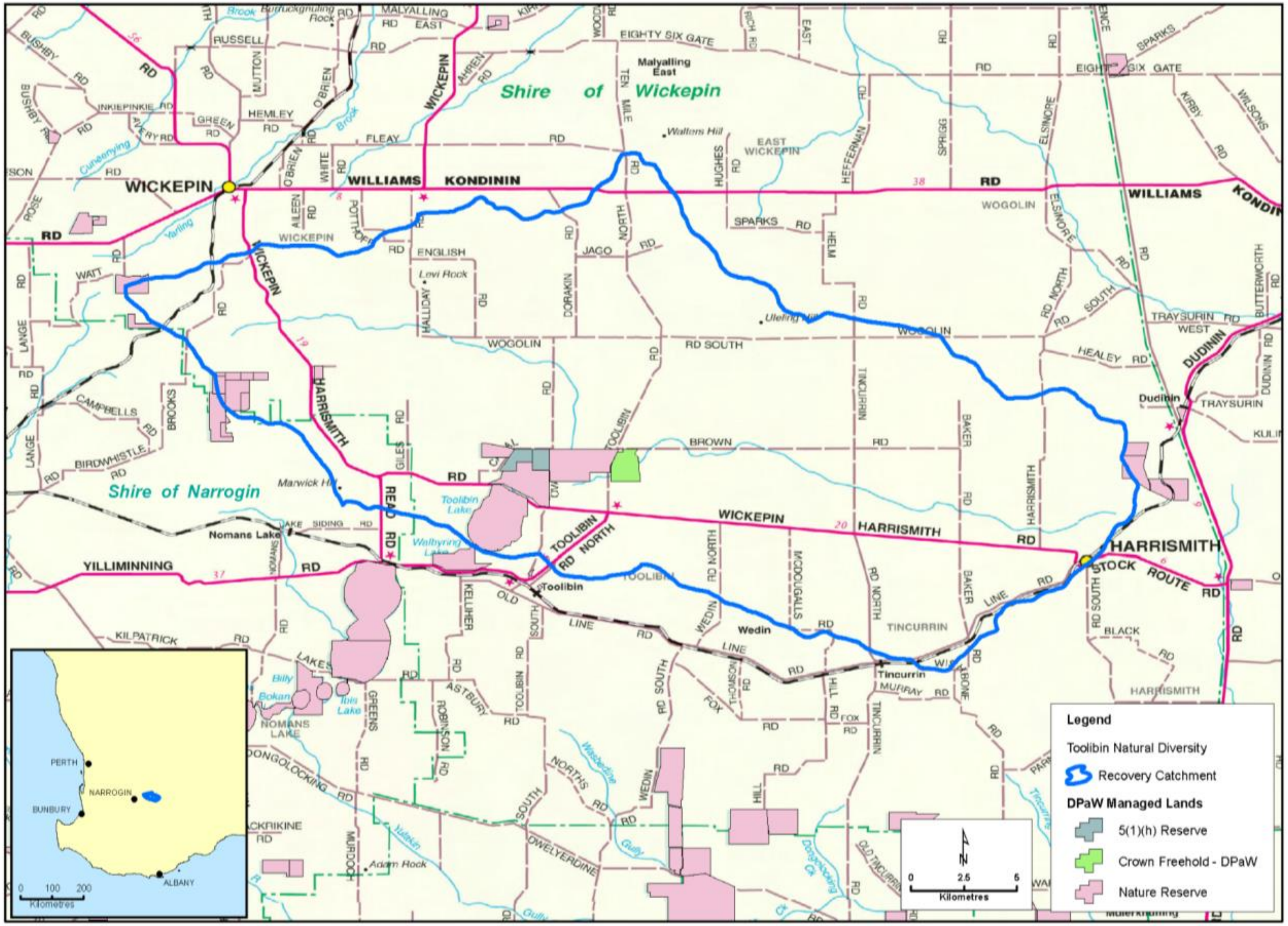


Figure 1 Site location and Recovery Catchment boundary

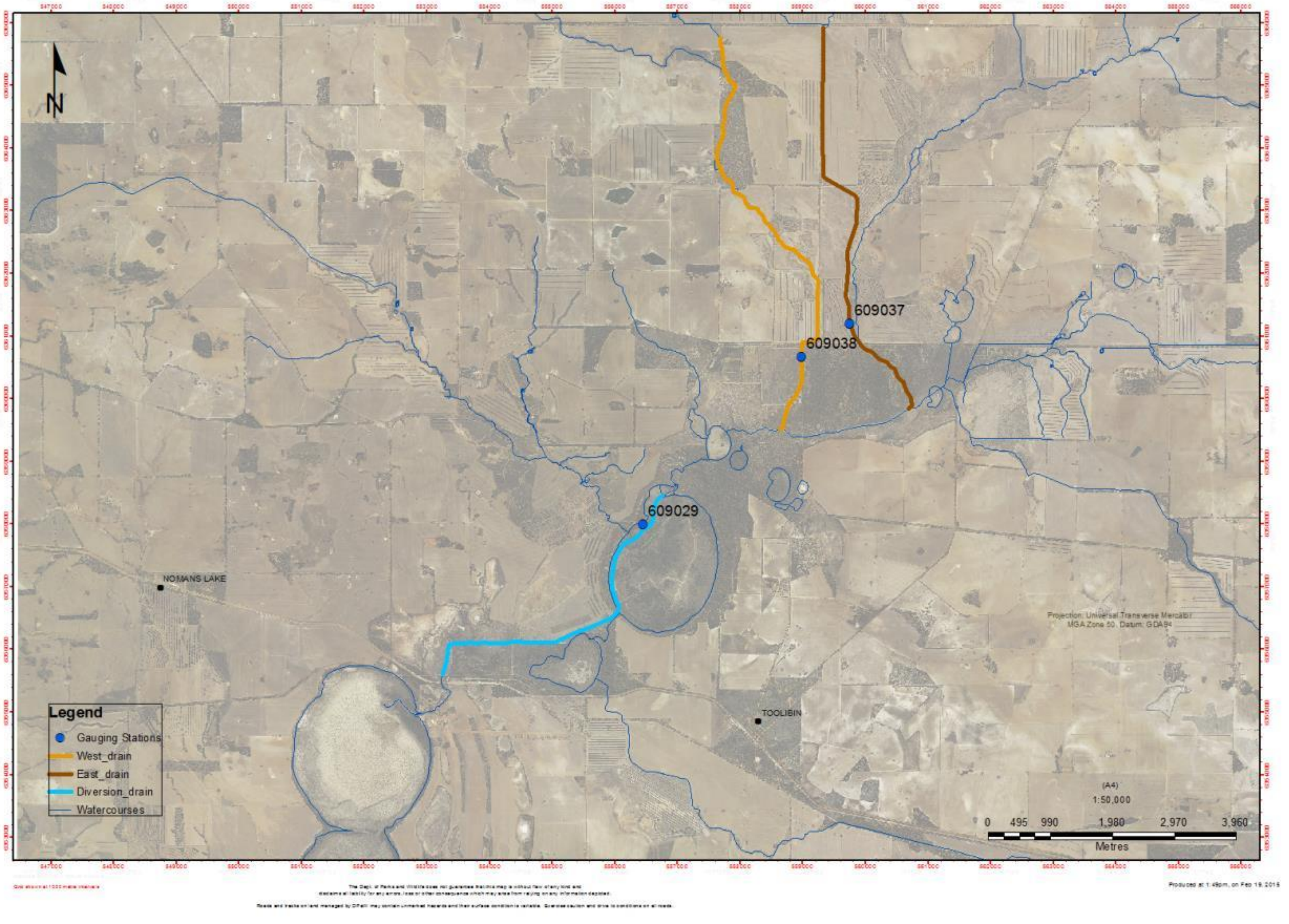


Figure 2 Site location, showing the main engineering structures

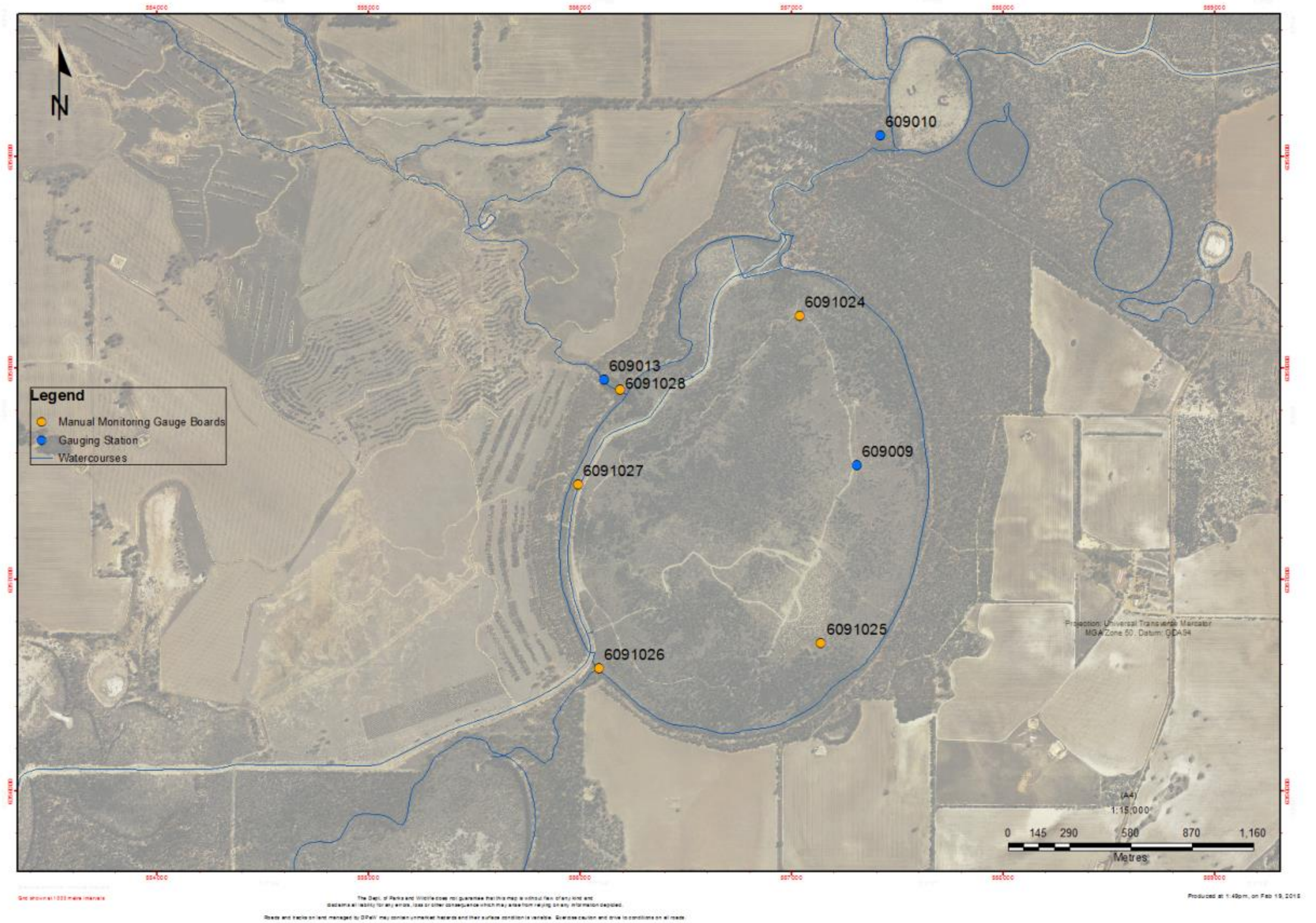


Figure 3 Site location, showing the main gauging stations

The location of stations that collect data for the WatBal model are shown in Figure and discussed in more detail in Muirden and Coleman (2014). The Department of Water's Water Information Network (WIN) database (DoW 2016) also maintains a publically available record of streamflow, Lake and groundwater levels and water quality for the Toolibin Lake stations. At the time of writing this report DoW station 609010 is the only station with continuous recording.

Table 2 Timeline

Date	Comment	Source
1969	Late 1960's - the first constructed outlet installed.	Muirden and Coleman (2014)
1978	Committee for rehabilitation of the Northern Arthur Wetlands carried out the first combined surface and groundwater water balance study.	Dogramaci *et al.* (2003)
1982	Good visual relationship between the WatBal model and Lake water levels (under moderate event conditions).	Dogramaci *et al.* (2003)
1983	Peak of 1983 events, level 298.78 m AHD.	DoW data
1983	Peak of 1983 events, level > 298.4 m AHD. Substantial streamflow over winter.	DoW data
1984	Larger event, less well modelled by WatBal.	Dogramaci *et al.* (2003)
1990	Peak of Jan 1990 event, level > 297.6 m AHD.	DoW data
1994	Toolibin Lake recovery plan developed.	Dogramaci *et al.* (2003)
1995	Channel (Separator) to divert flow from Northwest Creek around the Lake completed in late 1994 or early 1995. This excised the Booloo Ck catchment (41 km^2).	Dogramaci *et al.* (2003) George et al. (2004) Muirden and Coleman (2014)
1995	Construction of the east & west drains.	Muirden and Coleman 2014
1995-1999	11 production bores installed to pump and reduce groundwater levels beneath Toolibin Lake	Dogramaci *et al.* (2003) George et al. (2004)
2000	Separate outlet structure installed.	George et al. (2004)
2003	Bari & Peck WatBal model report.	Dogramaci *et al.* (2003)
2009	2008/09 Construction of Dulbining Channel.	Muirden and Coleman (2014)
2009	Construction of Toolibin L sump.	Muirden and Coleman (2014)
2010	Sump, channels and pumps constructed.	Muirden and Coleman (2014)
2012	Peak of Dec 2012 event, Muirden level > 296.68 m AHD.	DoW data Muirden and Coleman (2014)

1.3 Acknowledgements

The model adopted for this study was developed by Adrian Peck (Peck 2000). The model was updated and this manual prepared by Robin Connolly and Jasmine Rutherford, with peer review provided by Adrian Peck. Streamflow and Lake water level data were sourced from the Department of Water online WIN database (DoW 2015). Weather data were supplied by the Queensland Government (SILO 2015).

Page 7

2 WatBal model structure

2.1 Lake water balance equation

The spreadsheet model WatBal contains the main parameters to solve both a moderately complex Lake water and salt balance. The scope of the work undertaken in this report was to update the water balance.

The water balance quantifies the change in Lake inputs and outputs, which is the rate of volume change, which is in turn constrained by temporal changes of the Lake water area with respect to water depth. This is represented by a mass-balance equation for the chosen time step (one week in this implementation of the model). Calculation of the change of volume over any time-step depends on the lake area at the end of the previous time-step.

Empirically this can be described by the equation below:

$$Qin - Qout = dV/dt = A\ dh/dt$$

where:

Qin = input

Qout = output

V = Lake water volume (m^3)

dV/dt = rate of volume change (m^3/d)

A = Lake water area (m^2)

h = water depth (m)

The input and output balances can be expanded and described empirically:

$$Pin + Sin + Din - (E + Sout + Gout) = dV/dt = A\ dh/dt$$

as:

Qin = input (Pin + Sin + Din)

Qout = output (E + Sout + Gout)

Where:

Pin = precipitation (rainfall on surface of the Lake)

Sin = streamflow into the Lake

Din = drainage flow into the Lake

E= evapotranspiration

Sout = streamflow out of the Lake

Gout = groundwater outflow

Evaporation is calculated based on the recorded potential evaporation (Epan), wet area and salinity according to the following equation:

E = Epan*A*Epanfactor*(1-Salfactor*Sal)

where:

Epan = observed pan evaporation, input;

Epanfactor = a specified factor;

Salfactor = a specified factor

Sal = computer Lake water salinity.

2.2 WatBal model layout

The latest version of the WatBal model was sourced from the developer, Adrian Peck, by The Department of Parks and Wildlife in January 2016.

A schematic of the model workflow is shown in Figure.

The model takes the following as inputs to the Lake:

- Rainfall (on the wet area);
- Drainage in; and
- Streamflow in.

And calculates the following outputs:

- Evaporation (from the wet area);
- Seepage to groundwater; and
- Overflow.

Water and salt are tracked in the model.

The surface area, volume and level of water ponded in the Lake is calculated on a weekly time step. Lake volume is calculated for each time step accounting for the inputs and outputs. Area and water level are derived from a bathymetry lookup table.

Lake salinity is calculated based on the volume of water and mass of salt in the Lake at each time step.

The model is setup in Microsoft Excel as a series of linked worksheets (sheets) in a single file. Inputs are entered across a series of sheets. The water balance is computed automatically, as a standard Excel formula. The computed water and salt balance are presented in their own sheets. Key outputs are graphed in a separate sheet. Details of each sheet are given in Sections 0 and 0.

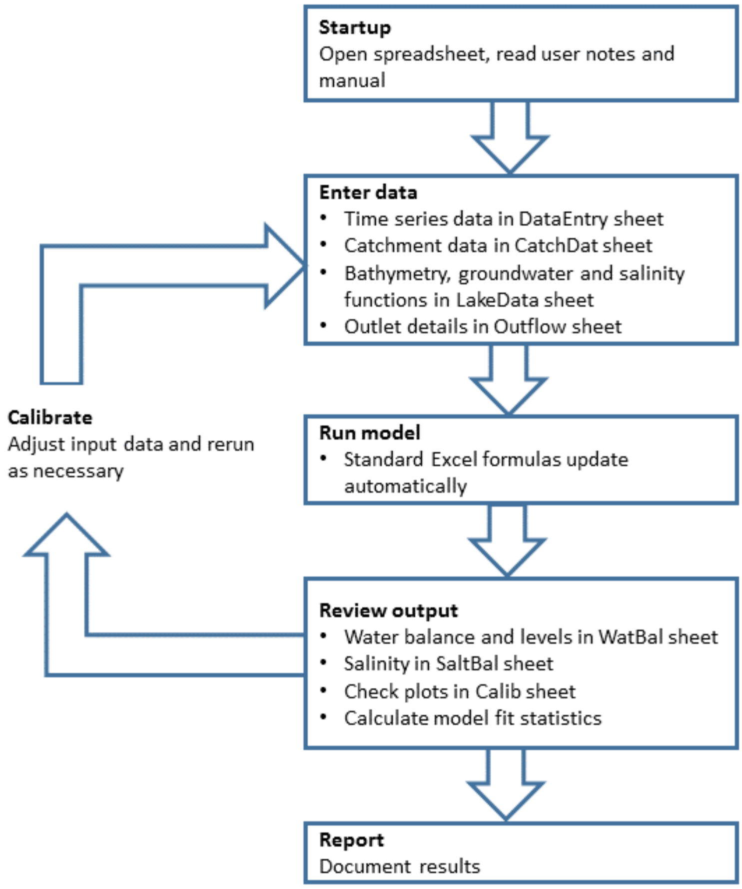


Figure 4 Model workflow schematic

A number of other sheets are retained in the model. These relate to data interpretation and model sensitivity testing. These have not been updated are not discussed in the user manual. In the model, these sheets have been moved to sit after the marker sheet 4.

The sheets are:

- WBSens;
- Sensitivity;
- WLData;
- SensGraph;
- WL&AreaProb;
- SBSens; and
- SalDat.

The following sheets relate to varying representations of Lake bathymetry and have not been updated:

- Conic;
- Spheric; and
- Elliptic.

2.2 Data sourcing

The available public time series data were used in updating the model.

Daily rainfall and pan evaporation data were sourced from SILO Data Drill (SILO 2015) and streamflow from the Department of Water's Station 609010 (DoW 2015). Streamflow was scaled by area to account for catchment downstream of Station 609010 (i.e. Booloo Creek).

A composite Lake water level series was developed based on observations at the Department of Water's Station 609009, supplemented with observations given in Muirden and Coleman (2014). Observations from the WatBal model as supplied were used.

2.3 Model changes

The model was extended from the current Jan 1980-Dec 2000 monthly time step to 1978 – 2015, with the model time step changed to weekly.

This user manual was developed based on the available documentation and reports and the WatBal model. Data and reports used in the model update and preparation of the user manual are referenced throughout this document.

The model was updated as is, i.e. without modification to the code or structure and without calibration. It is assumed that the model is fit for purpose. The existing depth volume relationship in the WatBal model was updated with a relationship developed by Rutherford (in prep) using topographic data sourced from a recent photogrammetric survey.

3 Model inputs and outputs

3.1 Model inputs

3.1.1 Notes (Notes sheet)

The first sheet is for notes regarding operation of the model.

3.1.2 Time series data input (DataEntry sheet)

Rainfall, evaporation, streamflow and drainage in and observed Lake level and salinity data are input in the DataEntry sheet.

Streamflow data is adjusted for a changing catchment area before and after 1 Jan 1995, to account for diversion of streamflow from Booloo Creek. Before 1 Jan 1995, streamflow at Station 601010 is scaled up by area to include the Booloo Creek catchment. From 1 Jan 1995 the Station 601010 data as reported is used.

Rainfall and evaporation are entered as depths and streamflow as a volume accumulated on a weekly time step. These are used in the water balance model in the WatBal sheet. Rainfall and evaporation can be sourced from the Bureau of Meteorology for nearby stations or using the Patched Point Dataset. Data collected by other agencies can also be used if available. Data needs to be aggregated to a weekly time step and be complete (i.e. no missing data).

Stream and drain flow salinity are set in this sheet and used in the water balance and salt balance calculations. These are currently set to constant values, but could be calibrated using observed data.

Observed water level (m AHD) and salinity (mg/L) are entered as discrete values. These are sourced from local gauges and graphed in the Calib sheet.

3.1.3 Catchment data (CatchDat sheet)

The Catchment data sheet contains information about the catchment and some model parameter values.

The value for Pan Evaporation Factor is used in the water balance model to calculate evaporation. This parameter can be varied to help calibrate predicted water levels to observed data. The calibrated value used for Toolibin Lake is 0.65.

The value for Rainfall salinity is used in the salt balance model. A value can be estimated from data reported by Hingston and Gailitis (1976).

Salinity of groundwater can be based on local monitoring data.

3.1.4 Lake data (LakeData sheet)

This sheet contains descriptions of the Lake bathymetry.

Bathymetry is best developed based on LiDar survey data. GIS software can be used to derive area and volume for increments from the lake bed to above the full water level.

Two representation of the bathymetry are currently represented for Toolibin L – pre and post 1995. The pre-1995 data are from the original WatBal model. The post 1995 data excludes the western part of the Lake, which is considered to be intercepted by the diversion drain (Figures 2 and 3). In the model, the drain is considered to be installed on 1 Jan 1995.

In the WatBal sheet, formulas refer to pre-1995 data for time steps before 1 Jan 1995 and 2016 data thereafter.

The LakeData sheet also includes parameters for prediction of Lake aquifer level and an evaporation rate versus salinity relationship.

The key evaporation rate-salinity parameters are:

- Initial Lake salt storage;
- Residual Lake salt storage
- Maximum Lake salinity; and
- Lake salinity evaporation factor (Salfactor).

These parameters can be estimated based on observations of salinity in the lake and by calibration to observed data. The Lake salinity evaporation factor parameter is for an equation developed by Coleman in 2000 (Peck 2000).

The Lake aquifer level is currently not turned on in the model. Parameters are:

- ho;
- h1;
- Lag; and
- Rate.

Should this component of the model be used, these parameter values would need to be derived by calibration to observed lake and groundwater levels informed by physical properties of the local shallow aquifer. More detail on this relationship is given in Peck (2000).

3.1.5 Outflow rating curve (Outflow sheet)

This sheet contains a depth versus flow relationship that is used in the water and salt balance to calculate surface water outflows (Appendix B).

This relationship was developed using a simple model of the outflow channel. It can be adjusted to help calibrate to observed lake water level data. More detailed modelling could also be used to develop a more physically realistic relationship.

3.2 Model outputs

3.2.1 Water balance (WatBal sheet)

The WatBal sheet contains the main water balance calculations for the model. These equations are described in Section 0. The main output is in the column titled Model WL, which is graphed in the Calib sheet.

Many of the formula refer to the same row in the DataEntry sheet.

A Sum of Squares calculation is provided to compare goodness of fit between modelled and observed water level. Currently this is not in use.

There is a second water balance calculation which includes discharge from a drainage system. This is currently not used in the model.

If the model is being modified or additional data added, be aware that formula can vary from row to row.

3.2.2 Salt balance (SaltBal sheet)

The salt balance is calculated in the SaltBal sheet. The main output is the column titled Model Salinity, which is graphed in the Calib sheet.

As for the WatBal sheet, there is a second salt balance calculation that includes drainage inflow. This is currently not in use.

A sum of squares calculation is provided. It is currently not in use but can be activated should suitable observed data be available to compare against the modelled salinity.

The salt balance model refers to data in the WaterBal sheet, as well as other sheets.

4 Model calibration

4.1 Water balance (Calib sheet)

The Calib sheet presents a graph of observed and predicted water level for the modelled period (**Error! Reference source not found.**).

On the graph:

- Model WL is taken from the water level predicted in the WatBal sheet;
- Lake WL is data used in the sum of squares calculation (currently not used so not plotted on the chart) and taken from the DataEntry sheet; and
- Observed WL refers to data in the DataEntry sheet.

4.2 Salt balance (Calib sheet)

The Calib sheet presents a graph of observed and predicted Lake salinity for the modelled period (Figure). As with the water balance graph, the graph entries are taken from the SaltBal and DataEntry sheets.

The tabulated model data are in the SaltBal sheet.

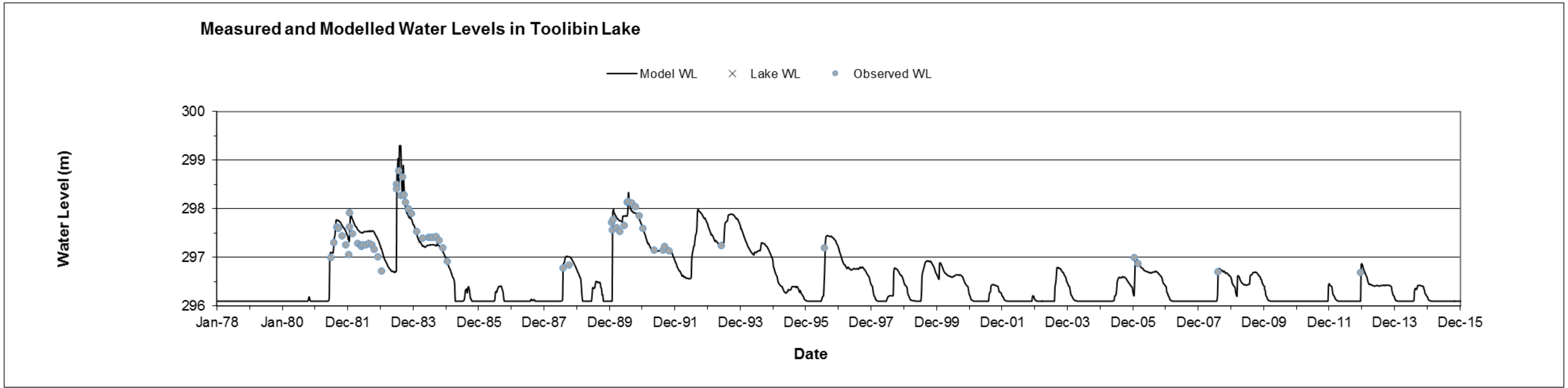


Figure 6 Predicted and observed water levels

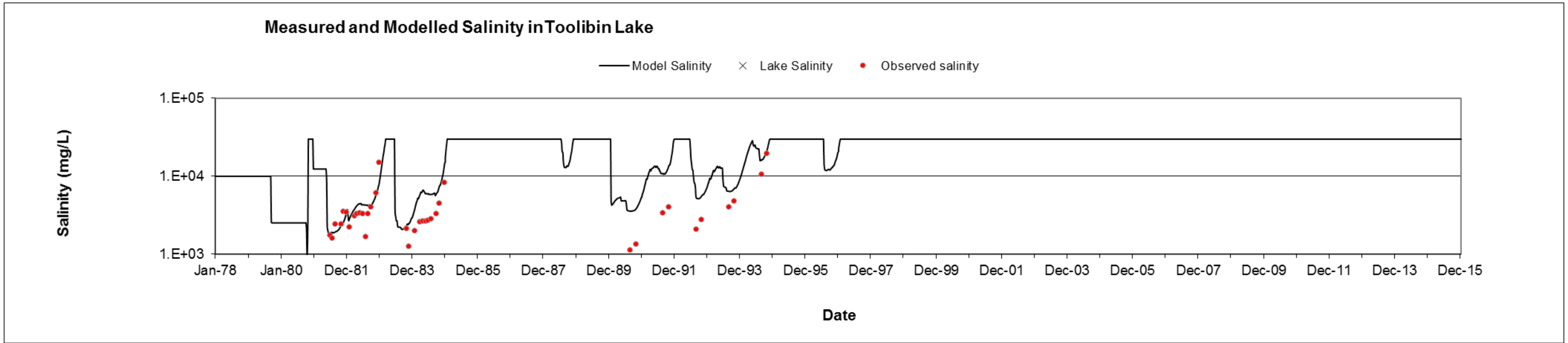


Figure 6 Predicted and observed salt concentration

5 References

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6 Limitations

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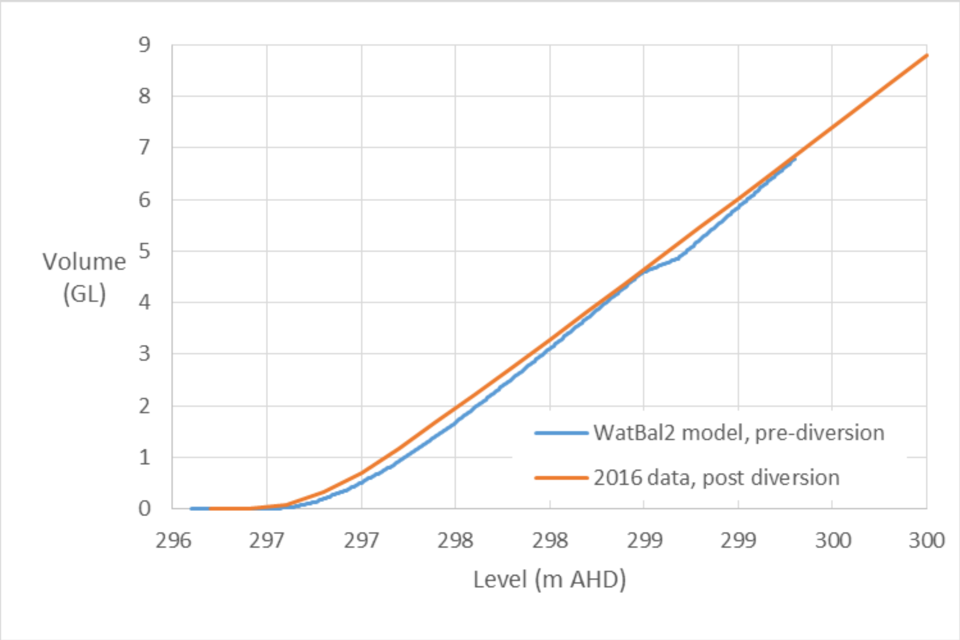
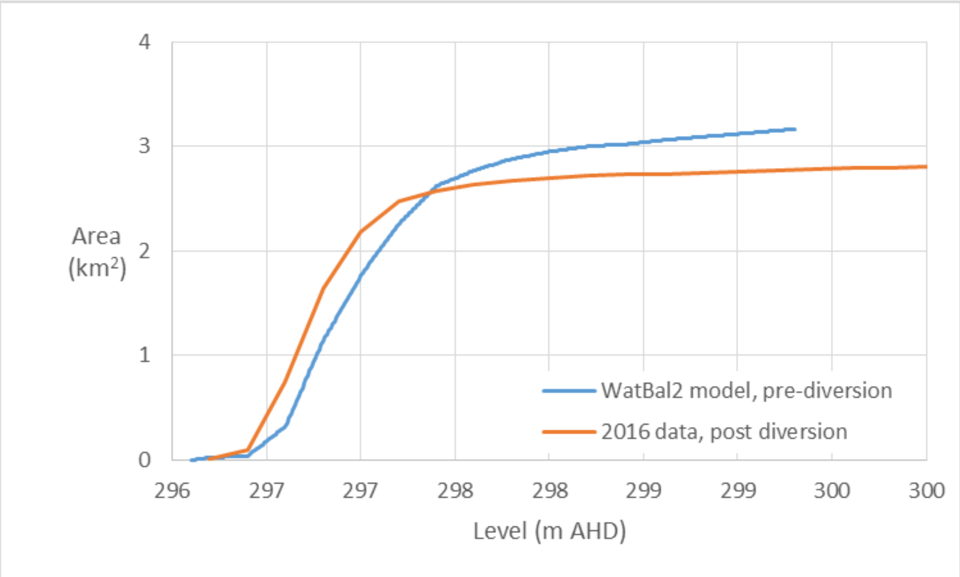
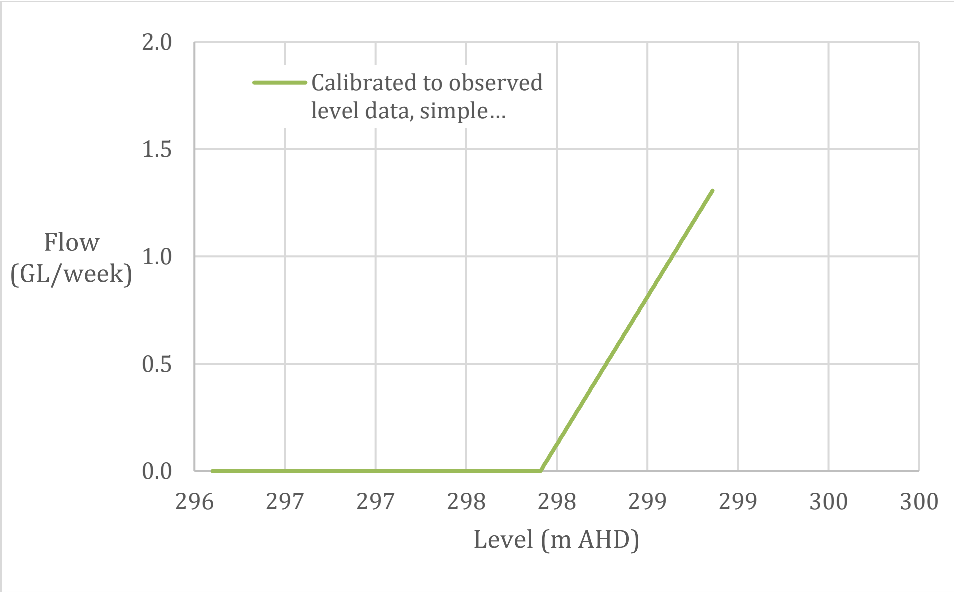
Appendix A: Toolibin Lake depth-volume relationship



Lake depth-area relationships



Appendix B: Toolibin Lake outflow; level (mAHD) vs flow relationship



Appendix 6 Surface water levels – manual measurements: site 609009 (1978-2018)

Date	Depth (m) @ SWWMP gauge board	Water level (mAHD)	Water level at 609009 (mAHD)	Source
31/05/1978	0.00	296.06	0.00	SWWMP
25/10/1978	0.00	296.06	0.00	SWWMP
14/11/1978	0.00	296.06	0.00	SWWMP
15/01/1979	0.00	296.06	0.00	SWWMP
17/05/1979	0.00	296.06	0.00	SWWMP
13/07/1979	0.00	296.06	0.00	SWWMP
12/09/1979	0.00	296.06	0.00	SWWMP
08/11/1979	0.00	296.06	0.00	SWWMP
18/01/1980	0.00	296.06	0.00	SWWMP
12/03/1980	0.00	296.06	0.00	SWWMP
13/05/1980	0.00	296.06	0.00	SWWMP
29/10/1980	0.00	296.06	0.00	SWWMP
15/01/1981	0.00	296.06	0.00	SWWMP
01/07/1981	0.92	296.98	0.52	609009
18/07/1981	0.80	296.86	0.40	SWWMP
05/08/1981	1.24	297.30	0.84	609009
02/09/1981	1.56	297.62	1.16	609009
15/09/1981	1.54	297.60	1.14	SWWMP
22/09/1981	1.53	297.59	1.13	609009
05/11/1981	1.37	297.43	0.97	609009
15/11/1981	1.35	297.41	0.95	SWWMP
15/12/1981	1.20	297.26	0.80	609009
14/01/1982	0.53	296.59	0.13	SWWMP
19/01/1982	0.99	297.05	0.59	609009
23/01/1982	1.85	297.91	1.45	609009
26/01/1982	1.56	297.62	1.16	609009
03/02/1982	1.54	297.60	1.14	SWWMP
23/02/1982	1.42	297.48	1.02	609009
16/03/1982	1.32	297.38	0.92	SWWMP
21/04/1982	1.23	297.29	0.83	609009
09/05/1982	1.19	297.25	0.79	SWWMP
27/05/1982	1.17	297.23	0.77	609009
03/06/1982	1.16	297.22	0.76	609009
24/06/1982	1.18	297.24	0.79	609009
11/07/1982	1.18	297.24	0.78	SWWMP
29/07/1982	1.19	297.25	0.79	609009
25/08/1982	1.21	297.27	0.81	609009
12/09/1982	1.16	297.22	0.76	SWWMP
28/09/1982	1.19	297.25	0.79	609009
28/10/1982	1.10	297.16	0.70	609009
08/11/1982	1.05	297.11	0.65	SWWMP
08/12/1982	0.94	297.00	0.54	609009
08/01/1983	0.90	296.96	0.50	SWWMP
19/01/1983	0.66	296.72	0.26	609009
21/05/1983	0.00	296.06	0.00	SWWMP
01/07/1983	2.44	298.51	2.05	609009
06/07/1983	2.35	298.41	1.95	609009
15/07/1983	2.40	298.46	2.00	SWWMP
26/07/1983	2.72	298.78	2.32	609009
18/08/1983	2.21	298.27	1.82	609009
08/09/1983	2.59	298.65	2.19	609009
11/09/1983	2.48	298.54	2.08	SWWMP
23/09/1983	2.22	298.28	1.82	609009
12/10/1983	2.07	298.13	1.67	609009
10/11/1983	1.94	298.00	1.54	609009
10/11/1983	1.93	297.99	1.53	SWWMP
16/11/1983	1.92	297.98	1.52	609009
15/12/1983	1.83	297.89	1.43	609009

Date	Depth (m) @ SWWMP gauge board	Water level (mAHD)	Water level at 609009 (mAHD)	Source
16/01/1984	1.66	297.72	1.26	SWWMP
16/02/1984	1.47	297.53	1.07	609009
10/03/1984	1.40	297.46	1.00	SWWMP
17/04/1984	1.32	297.38	0.92	609009
12/05/1984	1.32	297.38	0.92	SWWMP
21/06/1984	1.34	297.40	0.94	609009
17/07/1984	1.35	297.41	0.95	609009
18/07/1984	1.34	297.40	0.94	SWWMP
16/08/1984	1.34	297.40	0.94	609009
14/09/1984	1.36	297.42	0.96	609009
16/09/1984	1.36	297.42	0.96	SWWMP
17/10/1984	1.29	297.35	0.89	609009
07/11/1984	1.11	297.17	0.71	SWWMP
29/11/1984	1.13	297.19	0.74	609009
15/01/1985	0.85	296.91	0.45	609009
29/01/1985	0.78	296.84	0.38	SWWMP
15/03/1985	0.00	296.06	0.00	SWWMP
19/09/1985	0.00	296.06	0.00	SWWMP
06/11/1985	0.00	296.06	0.00	SWWMP
18/09/1986	0.00	296.06	0.00	SWWMP
18/09/1987	0.00	296.06	0.00	SWWMP
07/11/1987	0.00	296.06	0.00	SWWMP
02/08/1988	0.72	296.78	0.32	609009
13/09/1988	0.80	296.86	0.40	SWWMP
04/10/1988	0.78	296.84	0.38	609009
06/11/1988	0.60	296.66	0.20	SWWMP
15/09/1989	0.00	296.06	0.00	SWWMP
10/11/1989	0.00	296.06	0.00	SWWMP
30/01/1990	1.66	297.72	1.26	609009
31/01/1990	1.50	297.56	1.10	609009
08/02/1990	1.72	297.78	1.32	609009
21/03/1990	1.55	297.61	1.15	609009
26/04/1990	1.46	297.52	1.06	609009
13/06/1990	1.59	297.65	1.19	609009
23/07/1990	2.07	298.13	1.67	609009
27/07/1990	2.08	298.14	1.68	609009
06/09/1990	2.05	298.11	1.65	609009
11/09/1990	1.93	297.99	1.53	SWWMP
17/10/1990	1.98	298.04	1.58	609009
08/11/1990	1.88	297.94	1.48	SWWMP
29/11/1990	1.78	297.84	1.38	609009
10/01/1991	1.53	297.59	1.13	609009
15/05/1991	1.08	297.14	0.69	609009
27/08/1991	1.08	297.14	0.68	609009
10/09/1991	1.16	297.22	0.76	609009
18/09/1991	1.16	297.22	0.76	SWWMP
25/10/1991	1.07	297.14	0.68	609009
09/11/1991	1.03	297.09	0.63	SWWMP
16/09/1992	1.88	297.94	1.48	SWWMP
10/11/1992	1.75	297.81	1.35	SWWMP
01/06/1993	1.18	297.24	0.78	609009
15/09/1993	1.81	297.87	1.41	SWWMP
11/11/1993	1.68	297.74	1.28	SWWMP
16/09/1994	1.09	297.15	0.69	SWWMP
10/11/1994	0.88	296.94	0.48	SWWMP
08/11/1995	0.00	296.06	0.00	SWWMP
31/07/1996	1.13	297.19	0.73	609009
19/09/1996	1.15	297.21	0.75	SWWMP
06/11/1996	0.96	297.02	0.56	SWWMP

Date	Depth (m) @ SWWMP gauge board	Water level (mAHD)	Water level at 609009 (mAHD)	Source
30/04/1997	0.00	296.06	0.00	SWWMP
19/09/1997	0.60	296.66	0.20	SWWMP
17/09/1998	0.58	296.64	0.18	SWWMP
10/11/1998	0.00	296.06	0.00	SWWMP
12/09/1999	0.60	296.66	0.20	SWWMP
10/11/1999	0.00	296.06	0.00	SWWMP
11/09/2000	0.00	296.06	0.00	SWWMP
07/11/2000	0.00	296.06	0.00	SWWMP
11/09/2001	0.00	296.06	0.00	SWWMP
07/11/2001	0.00	296.06	0.00	SWWMP
19/09/2002	0.00	296.06	0.00	SWWMP
08/11/2002	0.00	296.06	0.00	SWWMP
03/11/2003	0.00	296.06	0.00	SWWMP
16/09/2004	0.00	296.06	0.00	SWWMP
07/11/2005	0.00	296.06	0.00	SWWMP
15/01/2006	0.93	296.99	0.53	609009
18/01/2006	0.96	297.02	0.56	SWWMP
23/02/2006	0.81	296.87	0.41	609009
14/03/2006	0.69	296.75	0.29	SWWMP
14/09/2006	0.00	296.06	0.00	SWWMP
04/11/2006	0.00	296.06	0.00	SWWMP
01/04/2007	0.00	296.06	0.00	SWWMP
31/07/2008	0.63	296.69	0.23	609009
03/11/2008	0.00	296.06	0.00	SWWMP
12/09/2009	0.00	296.06	0.00	SWWMP
11/09/2011	0.00	296.06	0.00	SWWMP
05/11/2011	0.00	296.06	0.00	SWWMP
13/12/2012	0.62	296.68	0.22	609009
02/11/2014	0.00	296.06	0.00	SWWMP
12/02/2017	2.24	298.30	1.84	DBCA Narrogin
13/02/2017	2.19	298.25	1.79	DBCA Narrogin
14/02/2017	2.04	298.10	1.64	DBCA Narrogin
01/03/2017	1.69	297.75	1.29	DBCA Narrogin
08/03/2017	1.66	297.72	1.26	DBCA Narrogin
14/03/2017	1.64	297.70	1.25	DBCA Narrogin
15/03/2017	1.64	297.70	1.25	DBCA Narrogin
17/03/2017	1.61	297.67	1.21	DBCA Narrogin
22/03/2017	1.64	297.70	1.24	DBCA Narrogin
29/03/2017	1.61	297.67	1.21	DBCA Narrogin
06/04/2017	1.57	297.63	1.17	DBCA Narrogin
12/04/2017	1.54	297.60	1.14	DBCA Narrogin
09/05/2017	1.50	297.56	1.10	DBCA Narrogin
17/05/2017	1.49	297.55	1.09	DBCA Narrogin
14/06/2017	1.48	297.54	1.08	DBCA Narrogin
03/07/2017	1.51	297.57	1.11	DBCA Narrogin
10/07/2017	1.50	297.56	1.10	DBCA Narrogin
19/07/2017	1.50	297.56	1.10	DBCA Narrogin
16/08/2017	1.57	297.63	1.17	DBCA Narrogin
13/09/2017	1.49	297.55	1.09	DBCA Narrogin
14/09/2017	1.49	297.55	1.09	DBCA Narrogin
17/10/2017	1.45	297.51	1.05	DBCA Narrogin
18/10/2017	1.44	297.50	1.04	DBCA Narrogin
25/10/2017	1.42	297.48	1.02	DBCA Narrogin
14/11/2017	1.30	297.36	0.90	DBCA Narrogin
22/11/2017	1.31	297.37	0.91	DBCA Narrogin
06/12/2017	1.25	297.31	0.85	DBCA Narrogin
13/12/2017	1.18	297.25	0.79	DBCA Narrogin
04/01/2018	1.07	297.13	0.67	DBCA Narrogin
19/02/2018	0.81	296.87	0.41	DBCA Narrogin
08/03/2018	0.69	296.75	0.29	DBCA Narrogin
15/03/2018	0.66	296.72	0.26	DBCA Narrogin
27/03/2018	0.57	296.63	0.17	DBCA Narrogin
12/04/2018	0.40	296.46	0.00	DBCA Narrogin

Appendix 7Toolibin Lake – surface water profiling results

Site	Date	Time	Depth from surface (m)	Temp (oC)	SpC (mS/cm)	DO (mg/L)	pH	Salinity (mg/L)	DO (%)	ORP (mV)	Turbidity (NTU)	EC (mS/cm) - TPS	Temp (oC) - TPS
DoW - 609009	9/05/2017	12:10:00 PM	0.20	17.63	1.127	2.44	7.20	700	25.40	15.00	16.40	1.114	18.30
DoW - 609009	9/05/2017	12:10:00 PM	0.40	17.60	1.127	1.38	7.54	700	14.40	26.00	13.10	1.114	18.20
DoW - 609009	9/05/2017	12:10:00 PM	0.60	17.50	1.127	1.19	7.38	700	12.40	32.00	13.30	1.115	18.10
DoW - 609009	9/05/2017	12:10:00 PM	0.80	17.43	1.128	1.01	7.29	700	10.40	37.00	13.60	1.113	18.00
DoW - 609009	9/05/2017	12:10:00 PM	1.00	17.26	1.128	0.83	7.24	700	8.60	41.00	15.40	1.176	17.90
DoW - 609009	9/05/2017	12:10:00 PM	1.20	17.17	1.128	0.60	7.22	700	6.30	42.00	15.70	1.178	17.70
DoW - 609009	17/10/2017	1:45:00 PM	0.20	19.58	1.360		5.92						
DoW - 609009	17/10/2017	1:45:00 PM	0.30	19.58	1.360		5.87						
DoW - 609009	17/10/2017	1:45:00 PM	0.40	19.58	1.359		5.87						
DoW - 609009	17/10/2017	1:45:00 PM	0.50	19.56	1.359		5.88						
DoW - 609009	17/10/2017	1:45:00 PM	0.60	19.56	1.358		5.89						
DoW - 609009	17/10/2017	1:45:00 PM	0.70	19.53	1.359		5.90						
DoW - 609009	17/10/2017	1:45:00 PM	0.80	19.52	1.359		5.93						
DoW - 609009	17/10/2017	1:45:00 PM	0.90	19.51	1.359		5.95						
DoW - 609009	17/10/2017	1:45:00 PM	1.00	19.51	1.359		5.97						
DoW - 609009	17/10/2017	1:45:00 PM	1.10	19.51	1.360		6.02						
DoW - 609009	17/10/2017	1:45:00 PM	1.20	19.53	1.360		6.03						
DoW - 609009	6/12/2017	12:35:00 PM	0.20	23.80	1.930					-89.00			
DoW - 609009	6/12/2017	12:35:00 PM	0.40	23.70	1.920					-88.00			
DoW - 609009	6/12/2017	12:35:00 PM	0.60	23.50	1.920					-88.00			
DoW - 609009	6/12/2017	12:35:00 PM	0.80	23.30	1.920					-89.00			
DoW - 609009	6/12/2017	12:35:00 PM	1.00	22.60	1.930					-104.00			
Sump	9/05/2017	11:05:00 AM	0.10	17.70	1.134	1.40	6.75	700	14.60	76.00		1.104	18.50
Sump	9/05/2017	11:05:00 AM	0.20	17.40	1.140	1.16	6.68	700	11.90	75.00	16.00	1.175	18.10
Sump	9/05/2017	11:05:00 AM	0.40	17.35	1.140	0.87	6.66	700	9.00	75.00	13.70	1.174	18.00
Sump	9/05/2017	11:05:00 AM	0.60	17.06	1.140	0.55	6.71	700	5.70	74.00	11.10	1.173	17.60
Sump	9/05/2017	11:05:00 AM	0.80	17.03	1.135	0.54	6.72	700	5.50	74.00	11.70	1.174	17.60
Sump	9/05/2017	11:05:00 AM	1.00	16.99	1.130	0.51	6.75	700	5.30	73.00	11.70	1.175	17.50
Sump	9/05/2017	11:05:00 AM	1.20	16.90	1.135	0.51	6.77	700	5.30	73.00	12.50	1.189	17.50
Sump	17/10/2017	2:45:00 PM	0.20	19.26	1.353		6.90						
Sump	17/10/2017	2:45:00 PM	0.30	19.27	1.353		6.75						
Sump	17/10/2017	2:45:00 PM	0.40	19.29	1.353		6.69						
Sump	17/10/2017	2:45:00 PM	0.50	19.29	1.354		6.63						
Sump	17/10/2017	2:45:00 PM	0.60	19.30	1.354		6.61						
Sump	17/10/2017	2:45:00 PM	0.70	19.29	1.354		6.58						
Sump	17/10/2017	2:45:00 PM	0.80	19.30	1.354		6.57						
Sump	17/10/2017	2:45:00 PM	0.86	19.30	1.354		6.56						
Sump	6/12/2017	11:00:00 AM	0.20	22.50	1.910					-42.00			
Sump	6/12/2017	11:00:00 AM	0.40	22.00	1.910					-47.00			
Sump	6/12/2017	11:00:00 AM	0.60	21.70	1.910					-49.00			
Sump	6/12/2017	11:00:00 AM	0.80	21.68	1.910					-50.00			
Sump	6/12/2017	11:00:00 AM	1.00	21.55	1.910					-51.00			
Sump	6/12/2017	11:00:00 AM	1.20	21.50	1.910					-52.00			
Sump	6/12/2017	11:00:00 AM	1.40	21.42	1.910					-53.00			

Site	Date	Time	Depth from surface (m)	Temp (oC)	SpC (mS/cm)	DO (mg/L)	pH	Salinity (mg/L)	DO (%)	ORP (mV)	Turbidity (NTU)	EC (mS/cm) - TPS	Temp (oC) - TPS
Sump	6/12/2017	11:00:00 AM	1.50	21.14	1.910					-219.00			
TL25	9/05/2017	11:50:00 AM	0.20	18.00	1.132	3.61	7.66	700	36.70	37.00	19.00	1.181	18.80
TL25	9/05/2017	11:50:00 AM	0.40	17.82	1.134	3.83	7.23	700	40.10	55.00	20.60	1.193	18.40
TL25	9/05/2017	11:50:00 AM	0.60	17.66	1.137	1.28	7.12	700	13.10	60.00	14.90	1.190	18.30
TL25	9/05/2017	11:50:00 AM	0.80	17.29	1.133	0.85	7.09	700	8.50	49.00	13.80	1.186	18.00
TL25	9/05/2017	11:50:00 AM	0.90	17.24	1.132	0.47	7.05	700	4.90	11.00	12.50	1.187	17.90

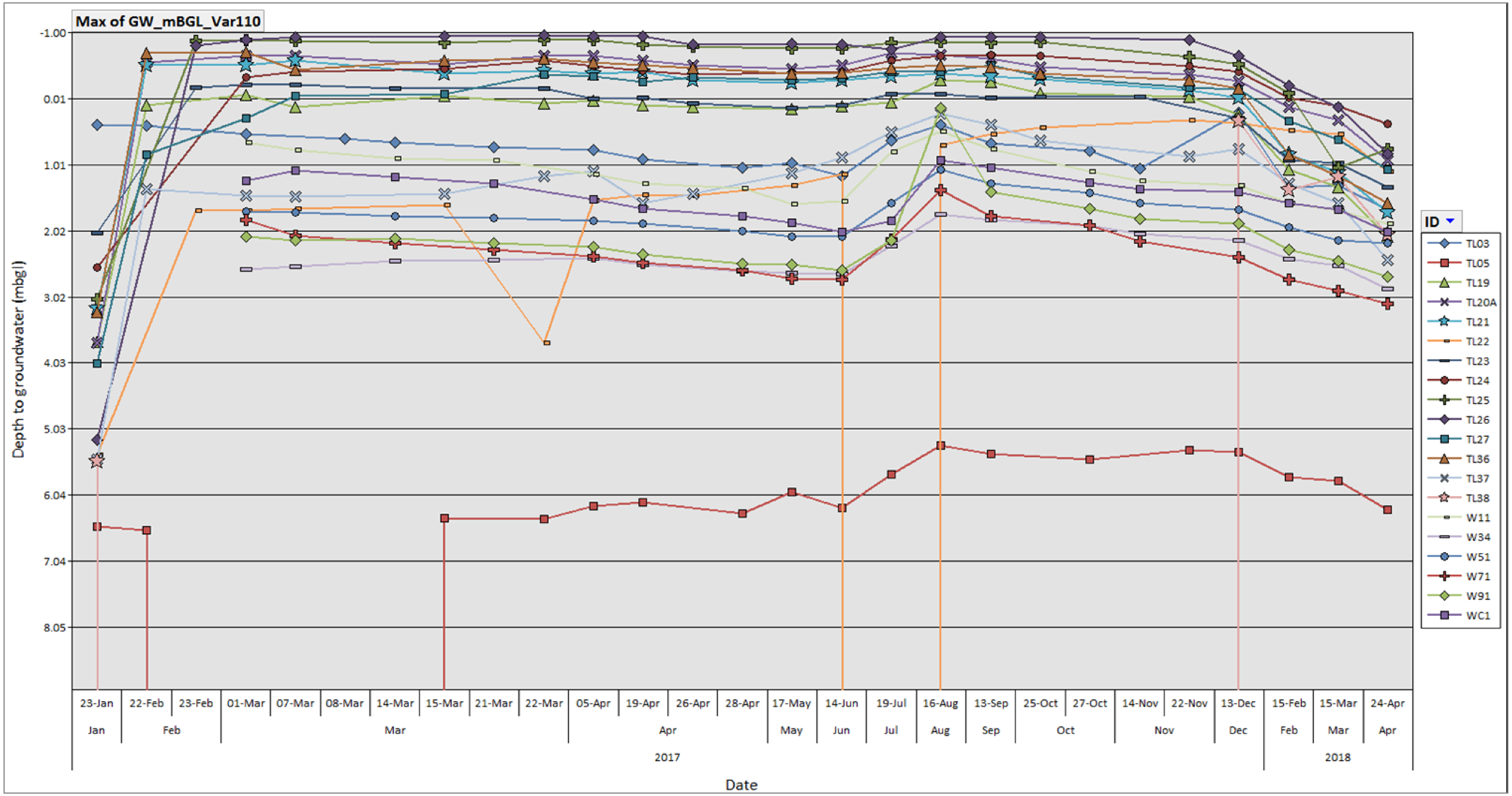
Appendix 8 Toolibin Lake – February 2017 event groundwater monitoring program

SiteID	X_MGA50	Y_MGA50	GWL_mbgl_Oct16	GWL_mbgl_22_23Feb17	GWL_mbgl_28Feb17	GWL_mbgl_1March17	Groundwater trend - post inflow	Groundwater trend - post inflow	MonitoringFrequency_recommendations
TL03	556558	6358618	1.14	0.42		0.54	>0.7m rise - now in decline		Weekly
TL05	555836	6357381	7.07	6.58		3.37	delayed rise		Weekly
TL21	556111	6356885	3.19	-0.5		-0.5	Max reached in Feb		Weekly
TL37	556056	6357400	5.7	1.39		1.48	Max reached in Feb		Weekly
TL38	556071	6357364	5.621				under water		Weekly
TL20	556182	6357262	3.5	0.6		-0.07	continuing to rise		Weekly
TL20A	556230	6357211	3.56	-0.54		-0.65	Max reached early March - now flowing		Weekly
TL27	556654	6357659	4.18	0.86		0.31	continuing to rise		Weekly
TL36	556674	6357920	3.2	-0.69		-0.7	Max reached in Feb - flowing		Weekly
TL19	556854	6358134	3.84	0.1		-0.05	Max reached early March - close to flowing		Weekly
TL28	557121	6357750	3.6			1.13	under water Feb 2017		Weekly
TL30	557270	6357822	7.91	7.52		3.69	delayed rise		Weekly
TL26	557450	6357682	5.36	-0.8		-0.89	flowing bore		Weekly
TL25	557393	6357241	2.93	-0.87		-0.89	flowing bore		Weekly
TL35	557901	6357759	10.85	10.79		10.7	Max reached in Feb		Weekly
TL35A	557800	6357763	9.22	9.05		9.01	Max reached in Feb		Weekly
TL31	556984	6357376	3.46	1.86		1.81			Weekly
TL24	556812	6357120	3.08	-0.24		-0.32			Weekly
TL32	557144	6356890	2.9	1.61		1.89	Max reached in Feb		Weekly
TL34	557319	6356891	5.16	1.45		4.26	?large decline - incorrect reading?		Weekly
TL23	557413	6356814	1.87	-0.16		-0.2	Max reached in Feb - small flow		Weekly
TL22	556883	6356645	5.26	1.71		1.71	Max reached in Feb		Weekly
TL33	556846	6356599	4.47	3.75		4	Max reached in Feb		Weekly
W91	555769	6356815	3.18			2.1		Rise in March	Weekly
W71	555702	6357138	3.21			1.85		Rise in March	Weekly
W34	555801	6357654	3.07			2.65		Rise in March	Weekly
W11	555876	6357955	1.56			0.67		Rise in March	Weekly
W51	555602	6357610	2.33			1.73		Rise in March	Weekly
WC1	555401	6357467	2.34			1.25		Rise in March	Weekly
RM3	562407	6360857	1.63		0.49			Rise in Feb	Weekly (one measurement then return to biannual)
RM17	562200	6360995	1.34		0.9			Rise in Feb	Weekly (one measurement then return to biannual)
RM22	562633	6361200	1.33		0.77			Rise in Feb	Weekly (one measurement then return to biannual)
LT07	561611	6360123	1.2		0.58			Rise in Feb	Weekly (one measurement then return to biannual)
85LTC10A	559087	6360893	DRY		1.63			Shallow aquifer response	Weekly (one measurement then return to biannual)
JC4	559263	6361901	1.94		1.24			Rise in Feb	Weekly (one measurement then return to biannual)
85LTC9A	559060	6361567	DRY		1.12			Shallow aquifer response	Weekly (one measurement then return to biannual)
JC5	557706	6365835	1.92		1.08			Rise in Feb	Weekly (one measurement then return to biannual)
KM1	556504	6365990	1.08		0.58			Rise in Feb	Weekly (one measurement then return to biannual)

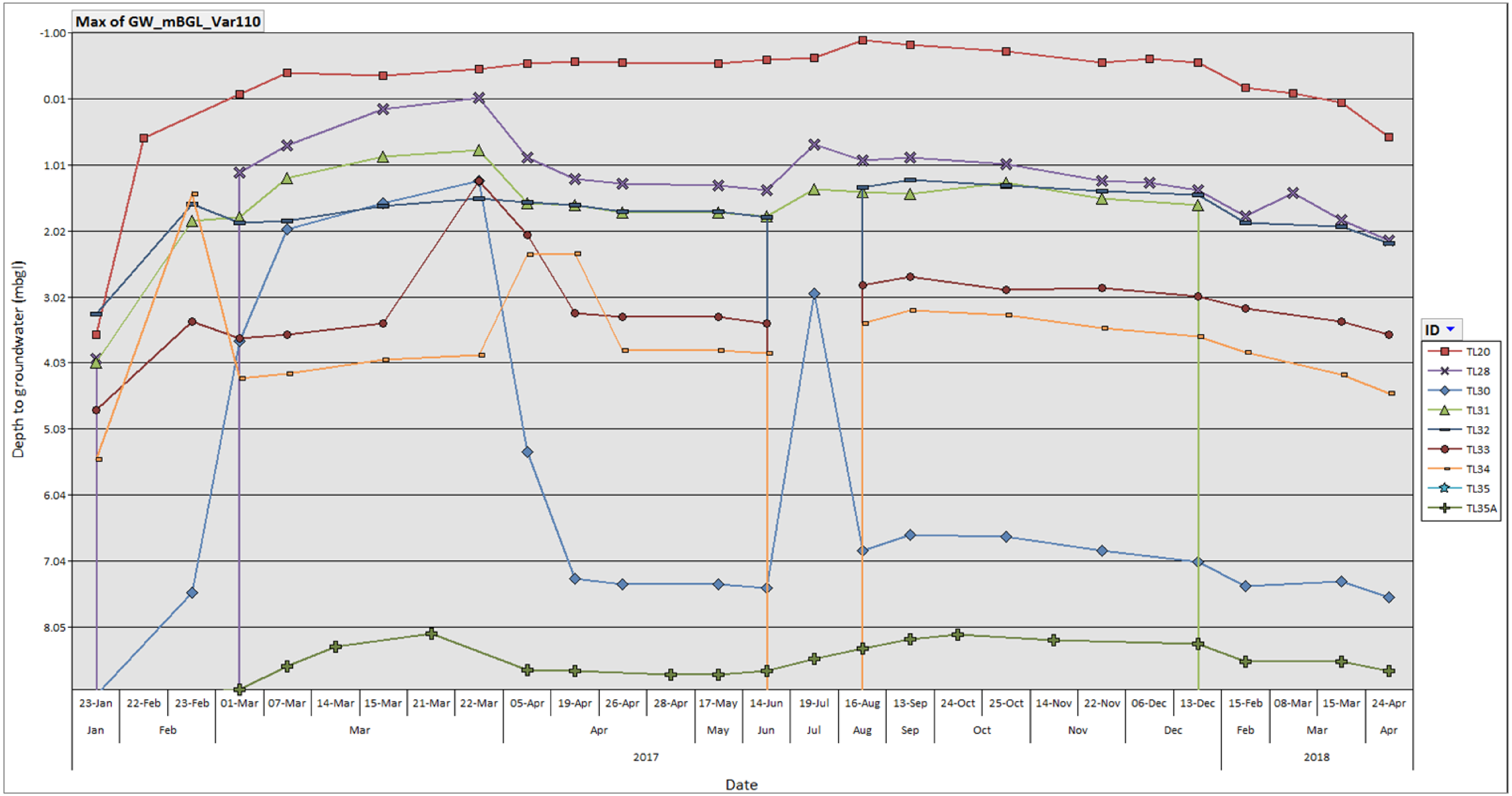
Note bores highlighted in blue=weekly to fortnightly monitoring (dependent on ease of access and rates of change); bores highlighted in green to be monitored in Feburary and March 2017, then return to biannual monitoring

Appendix 9 Toolibin Lake groundwater levels – graphed manual measurements

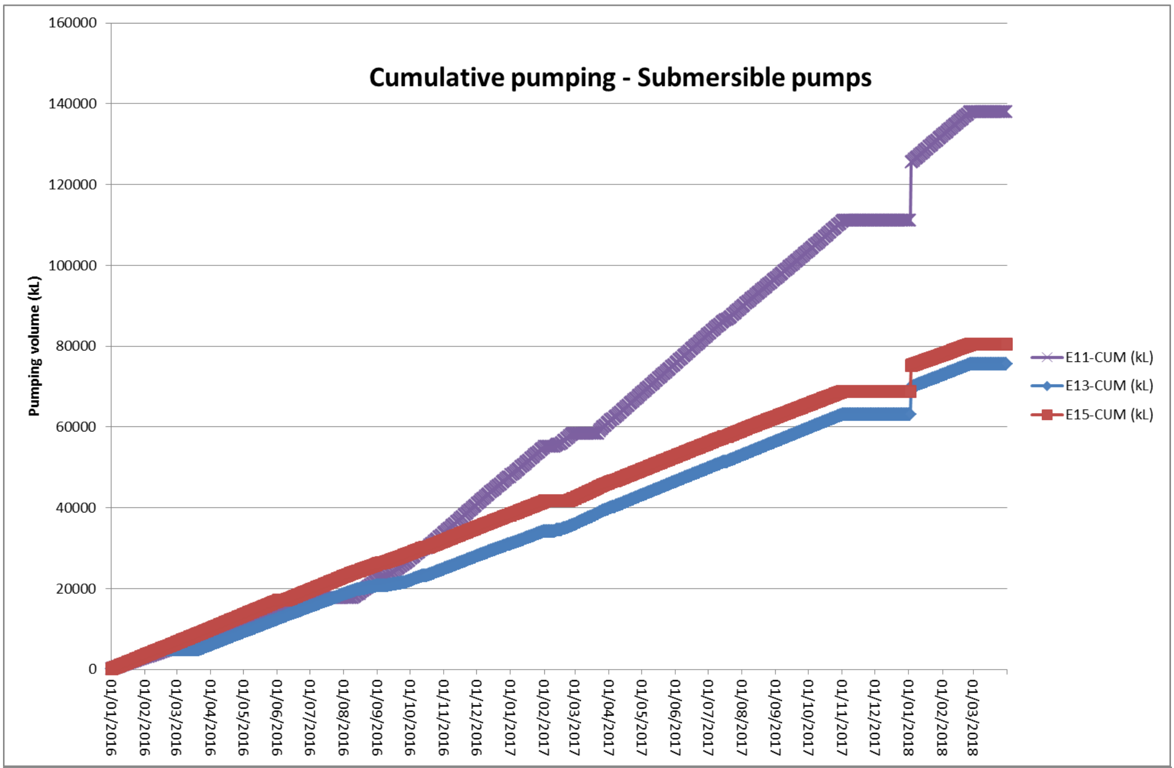
Groundwater level observations for Toolibin Lake groundwater monitoring bores screened across the surficial aquifer

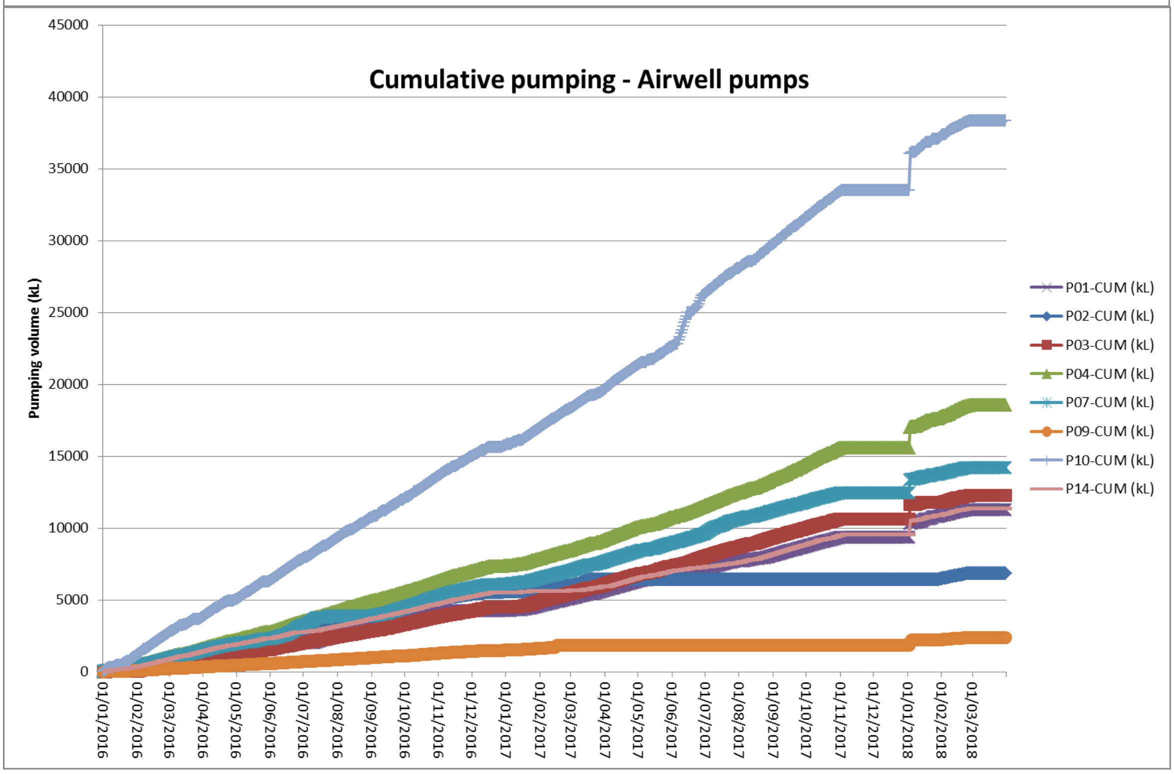


Piezometric head observations for Toolibin Lake groundwater monitoring bores screened across deeper semi-confined saprolite and sedimentary aquifers



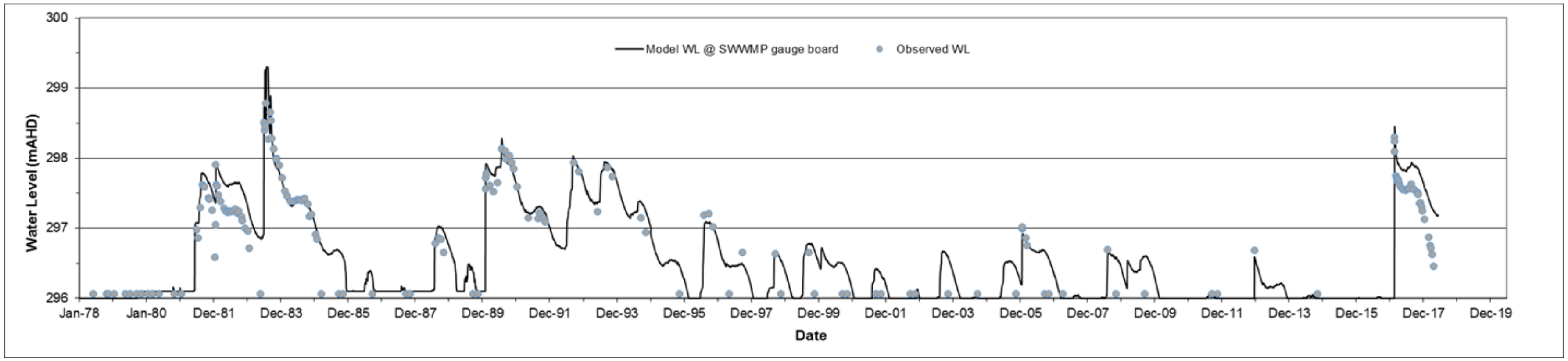
Appendix 10 Toolibin Lake – cumulative groundwater pumping volumes for individual pumps (2016-2018)



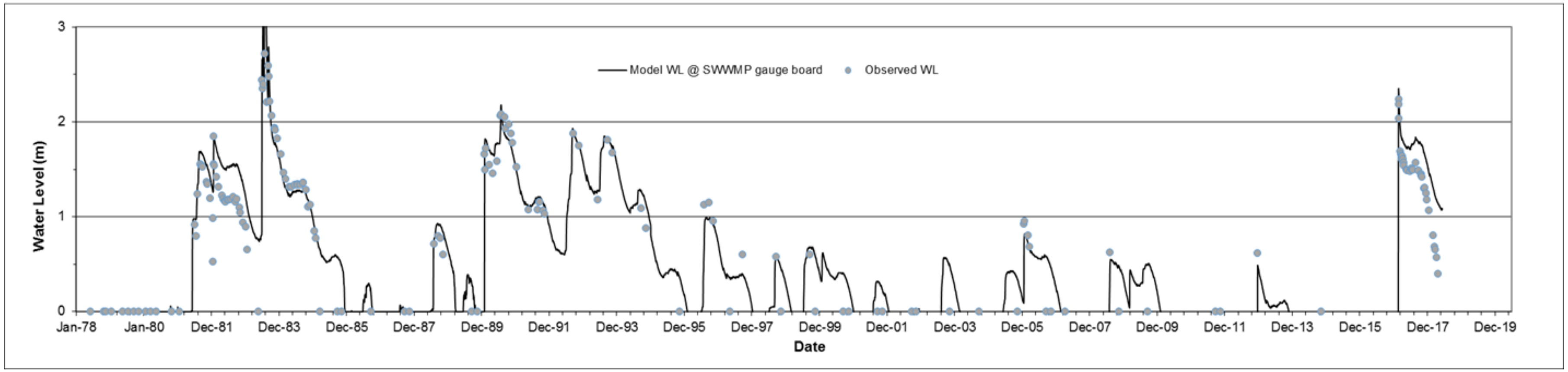


Appendix 11 WatBal modelling outputs

Updated daily time-step WatBal results of modelled versus observed lake water levels (mAHD) (Appendix 6) for the period 1 January 1978 to 31 May 2018



Updated daily time-step WatBal model results of water level (depth in metres at the SWWMP gauge board) (Appendix 6) for the period 01/01/1978 to 31/05/2018



Appendix 12 DBCA Memo – Toolibin Lake salinity predictions September 2017

Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

MEMO

Date 1 September 2017

TO: Maria Lee: Conservation Officer (Toolibin Lake)

CC: Peter Lacey: Nature Conservation Program Leader, Wheatbelt Region

Adrian Pinder: Program Leader, Wetlands Conservation Program

Jasmine Rutherford: Senior Hydrogeologist, Wetlands Conservation Program

SUBJECT: TOOLIBIN LAKE CATCHMENT – SHORT-TERM SURFACE WATER MONITORING PROGRAM RECOMMENDATIONS FOR TOOLIBIN LAKE

Dear Maria,
The occurrence of high summer rainfall and catchment-scale surface water flows in February 2017 led to the decision by the Wheatbelt Region to divert fresh surface water inflows into Toolibin Lake. This led to Toolibin Lake inundationing to an estimated 2.0 m, the highest water level since 1983 (Toolibin Lake Catchment Newsletter, winter-spring 2017).

Data recently collected across the Toolibin Lake Catchment by the Wheatbelt Region staff have been reviewed and analysed to understand Toolibin Lake water level and salinity response since this inundation event. This memorandum provides a summary of this analysis and a discussion on the projections for the lake water levels and salinity. These findings form the basis of a recommended monitoring program to assist with the tracking of water level and salinity trends over time to inform the adaptive management of lake water levels and salinity in accordance with the "*Management guidelines for Toolibin Lake hydrological infrastructure*" (Parks and Wildlife, undated).

Since the inundation event of February 2017, observations of water levels at the gauge board located at Site F (DoW site 609009) in Toolibin Lake show that water levels receded to 1.10 m in May 2017 (**Error! Reference source not found.**). Since then, water levels a have been largely stable at 1.10 m, although an increase in water levels of 0.07 m to 1.17 m was observed on 16 August 2017 due to rainfall associated with a strong winter frontal system. Salinity of the lake since March 2017 has been relatively stable at around 1.1 mS/cm, which equates to about 600 mg/L Total Dissolved Solids (TDS) (**Error! Reference source not found.**).

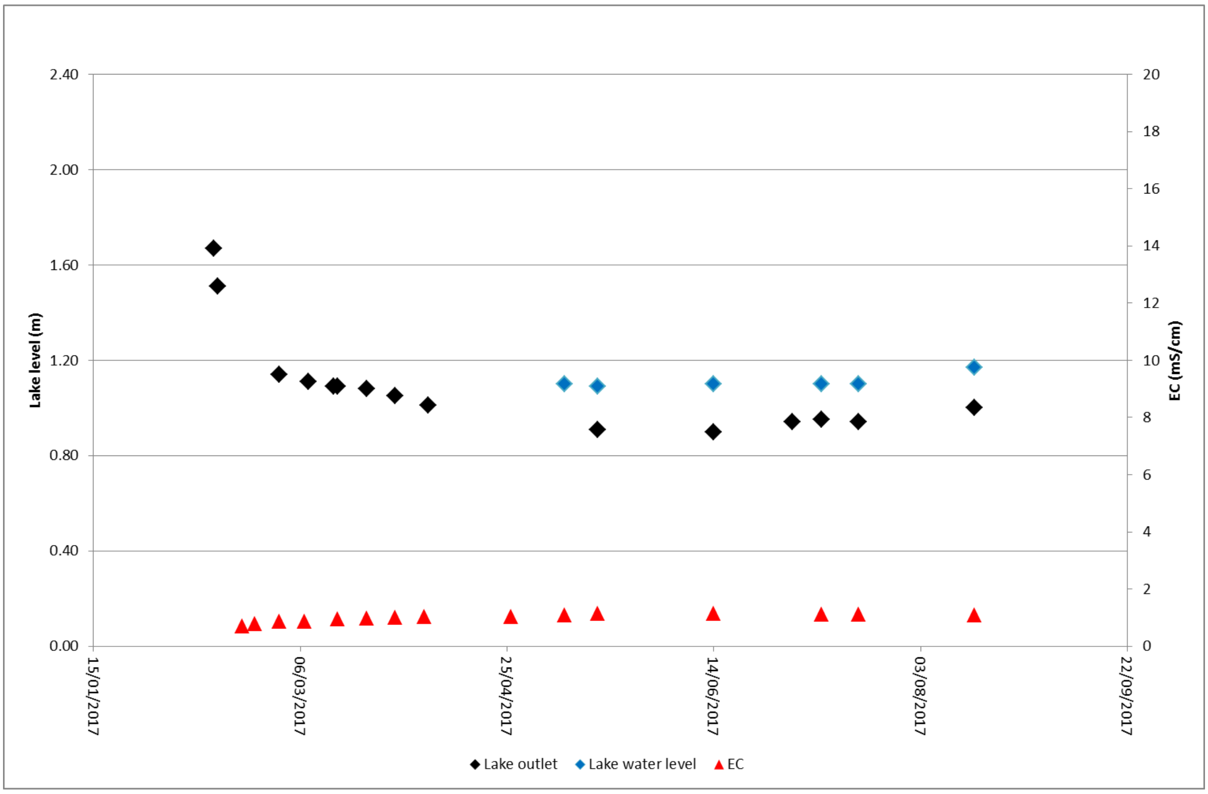


Figure 1 Plot of water level observed in Toolibin Lake (Site F - DoW site 609009) and its outlet (Site S – DoW site 6091026) and electrical conductivity observed in the lake (Site E – Sump on the lake floor)

Analysis methods and results

A simplistic water balance and salt balance spreadsheet model was developed to predict lake water levels and lake salinity (TDS) for the period August 2017 to December 2018. Details on the model, data sources and assumptions are summarised in Appendix A.

A plot of predicted lake water levels (**Error! Reference source not found.**) shows that a decline occurs at a rate of about 4.5 mm per day from August 2017 to April 2018. Water levels in the lake are predicted to rise slightly during the wetter months of June to September 2018 to about 0.20 m and then the lake levels fall thereafter until November 2018 where the lake is predicted to dry, although isolated pools may still be present in the lowest lying areas of the lake.

A plot of predicted salinity (Electrical Conductivity) trends shows an inverse relationship with water level. Salinity is predicted to increase exponentially over time and is estimated to exceed 35 mS/cm in October 2018, which is equates to about 20,000 mg/L TSD when water levels in the lake are predicted to be about 0.10 m. Salinity is predicted to exceed 45,000 mg/L TDS prior to drying in November 2018. Rule 6 of the *“Management guidelines for Toolibin Lake Hydrology Infrastructure”* (Parks and Wildlife, Undated), specifies that when surface water salinity exceeds 10 mS/cm then the sump pump is to be turned on to remove surface water from the lake. Results of the salt balance model suggest that this lake salinity threshold will be exceeded in March 2018 (**Error! Reference source not found.**).

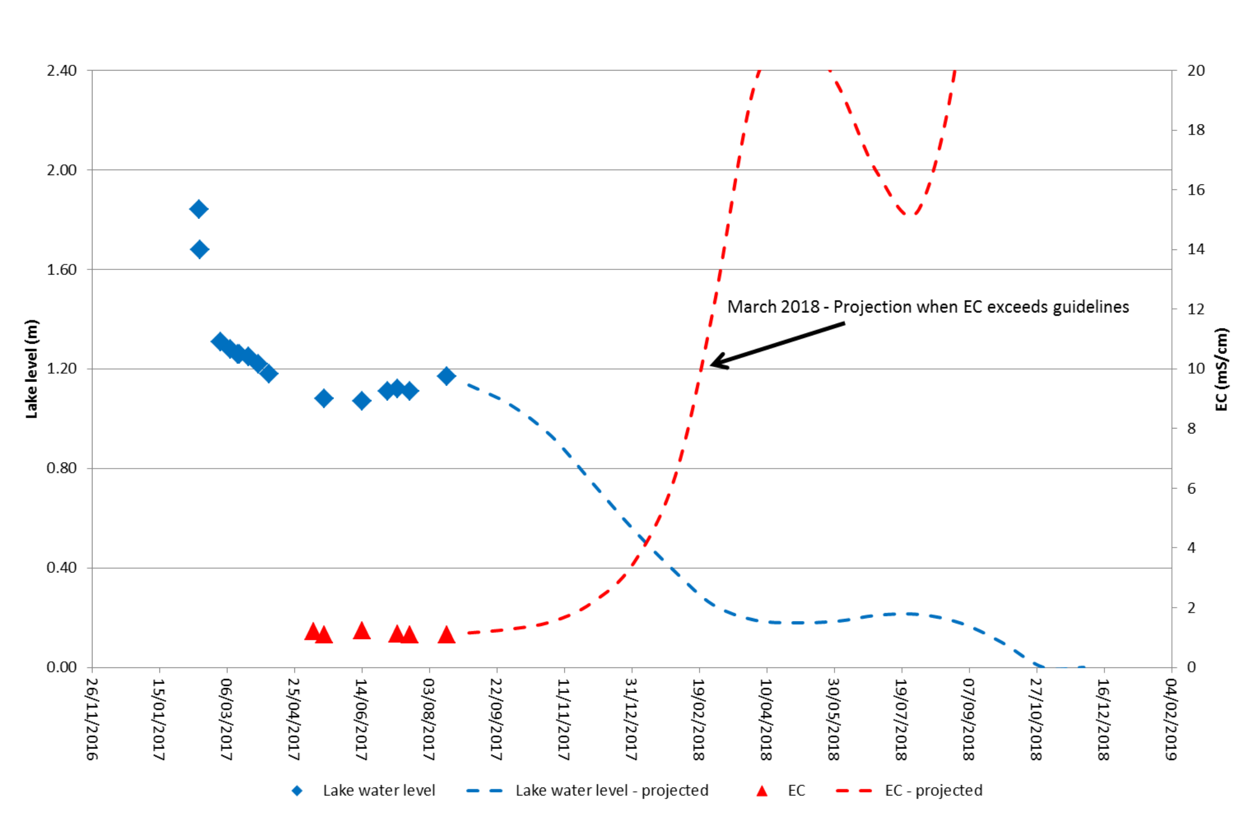


Figure 2 Plot of observed water levels and salinity in Toolibin Lake and the projected water level and salinity for the period August 2017 to December 2018. Rule 6 of the *Management Guidelines for Toolibin Lake Hydrology Infrastructure (Parks and Wildlife, undated)* trigger the operation of the sump pump to remove surface water from the lake at 10 mS/cm.

Conclusion and recommendations

The first-pass assessment presented in this memorandum indicates that Toolibin Lake will contain surface water for at least another 12-months and that salinity will accordingly rise exponentially. It is predicted that salinity of the lake will exceed the *Management Guidelines for Toolibin Lake hydrology infrastructure* in March 2018. Reaching these criteria will trigger a review of surface water level and salinity with a view to potentially seeking approval for the removal of surface water from Toolibin Lake.

The water and salt balance model developed for this assessment however is a simplistic representation of a very complex system and therefore the presented predictions should be considered as indicative. In order to provide a robust basis to inform the management of surface water within the lake it is important for the ongoing capture of water level and salinity data at key locations and to continually revise the water level and salinity predictions.

In addition to the application of hydrological data to inform management of lake water levels, the capture of ongoing data will be used to update a more complex spreadsheet water balance model for Toolibin Lake, known as WatBal, originally developed in 2000 and revised in 2016. The revision of this water balance model and interpretation of information collected during, and following the inundation event of February 2017 will be presented in a report scheduled for delivery in late 2017. I look forward to preparing this report in collaboration with yourself and other staff in the region.

Details on the monitoring site locations, frequency and parameters to achieve the above are provided in Appendix D. Weekly resolution data is required, however to maximise the available resources and to overcome access constraints likely to occur as the lake dries, then the recommended program combines the use of fortnightly or monthly manual measurements with data acquired with data loggers. Previous experience managing data logging infrastructure has shown that a short-term deployment of equipment and validation of data against regular manual measurements will maximise the cost/benefit and will ensure the capture of good quality high resolution data. It is recommended that data loggers are deployed as soon as practical and are decommissioned by December 2018.

The initial deployment and ongoing management of data loggers to the Toolibin Lake Catchment is estimated to cost about $10,600, plus labour (see Appendix E). The proposed activities and outputs are complimentary to current investigations being undertaken in the Toolibin Lake Catchment under the Science Project Plan SP2015-001. Given that resources are available within the Wetlands Conservation Program then the costs for commissioning and management of the data logging infrastructure can be absorbed within our current budget.

The capture of manual measurements, as detailed in Appendix D, is to be undertaken by the Wheatbelt Region staff Catchment staff in accordance with the standard operating procedure for the monitoring of water levels and water quality in surface water (Appendix F). This procedure document is a draft in progress and will be revised once data quality assurance and data management practices are finalised. In the short-term data quality assurance and data management will be undertaken by the Wetlands Conservation Program Hydrologist. A review of the groundwater monitoring program and data review is also currently in preparation and recommendations regarding the associated monitoring program will be provided in due course.

I look forward to your response, particularly to indicate whether the recommended monitoring program is achievable and is supported by the Wheatbelt region. If these recommendations are endorsed then I am available to commission the data loggers at the earliest convenience.

Please let me know if you require any advice or assistance with the above recommendations.

Lindsay Bourke
Wetlands Conservation Program Research Scientist (Hydrology)

Appendix A – Water and salt balance data sources and assumptions
Appendix B – Water balance results
Appendix C – Salt balance results
Appendix D – Monitoring recommendations
Appendix E – Estimated expenditure to deploy and manage data logging infrastructure
Appendix F – Monitoring of surface water level and water quality, and water quality of pump transfer stations: Toolibin Lake Hydrology standard operating procedure TL-H01

Data sources and references

Bureau of Meteorology. (2017). Daily 9am rainfall for Wickepin - Station number 10654, opened 1911 Latitude 32.78^{O}S, Longitude 117.50^{o}E. Accessed 32 August 2017 http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=10654.

Department of Water. (2017). Water levels for site 609009. Sourced from the Water Reporting Information (WIR) on-line resource. Accessed on 23 August 2017. http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx.

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Appendix A – Water and salt balance data sources and assumptions

- Data sources:
  1. Regional-scale interpolated evaporation for Narrogin (Luke et al, 1987)
  2. Daily 9am rainfall for Wickepin, station 10654 (Bureau of Meteorology, 2017)
  3. Toolibin Lake depth to volume relationship (Hydrologia, 2017)
  4. South west wetlands monitoring program (SWWMP) historical water level and salinity data – Toolibin Lake (Lane et al, 2015)
  5. Historical water level data for Department of Water site 606009 (Department of Water, 2017)

- Model construction:
- Monthly time-step based on the following equation:

- $\frac{\Delta V}{\Delta t} = Gi + Si + P - Go - So - ET = 0$

  - Where $\Delta V/\Delta t$ is the change in lake volume (V) over time (t), G_i and S_i are groundwater and surface water inflow rates, G_o and S_o are groundwater and surface water outflow rates and P and ET are precipitation and evapotranspiration respectively.

- Model assumptions
  1. No losses or gains from groundwater (i.e. G_i and G_o = 0);
  2. No further diversion of surface water inflows to the lake (i.e. S_i = 0);
  3. No surface water outflows via the outlet or breaches of the bund wall (i.e. S_o = 0);
  4. Average contemporary (2000-2016) rainfall trends apply over the model period
  5. No account for rainfall recharge, interception losses etc.
  6. No account for transpiration from lake bed vegetation
  7. Evaporation represented by interpolated regional, long-term average monthly data and therefore no account for local conditions
  8. Pan to lake evaporation coefficient of 0.7 applied to evaporation data
  9. Salt within the water body is conservative (i.e. no additional inputs or outputs)

- Based on the above assumptions the water balance equation is simplified to:

- $\frac{\Delta V}{\Delta t} = P - ET = 0$

- **Appendix B - Water balance results**

YEAR	MONTH	Rainfall (2000-2016)	Rainfall (1912-2016)	Class A evaporation	Potential evaporation (pan/lake coefficient 0.7)	Balance (mm)	Predicted water level (mm)	Predicted water level (m)
2017	July	60.12	68.84	51	35.7	24.42		
2017	August	47.71	52.34	64	44.8	2.91	1170	1.17
2017	September	34.12	34.95	99	69.3	-35.18	1134.82	1.13
2017	October	23.45	25.79	143	100.1	-76.65	1058.17	1.06
2017	November	17.54	15.78	207	144.9	-127.36	930.81	0.93
2017	December	14.85	11.37	286	200.2	-185.35	745.46	0.75
2018	January	28.09	12.78	314	219.8	-191.71	553.75	0.55
2018	February	10.15	16.73	257	179.9	-169.75	383.99	0.38
2018	March	19.68	18.17	217	151.9	-132.22	251.77	0.25
2018	April	26.28	27.02	126	88.2	-61.92	189.85	0.19
2018	May	46.28	53.44	81	56.7	-10.42	179.43	0.18
2018	June	41.03	70.33	50	35	6.03	185.46	0.19
2018	July	60.12	68.84	51	35.7	24.42	209.88	0.21
2018	August	47.71	52.34	64	44.8	2.91	212.79	0.21
2018	September	34.12	34.95	99	69.3	-35.18	177.61	0.18
2018	October	23.45	25.79	143	100.1	-76.65	100.96	0.10
2018	November	17.54	15.78	207	144.9	-127.36	-26.40	0.00
2018	December	14.85	11.37	286	200.2	-185.35	-211.75	0.00

- **Appendix C – Salt balance results**

YEAR	MONTH	Predicted water level (m)	Water level (mAHD)	Volume (m3)	Area (m2)	TDS - TONNES	TDS - mg/L	EC	EC mS/cm
2017	August			2342910		1418.51	605.45	1099.52	1.10
2017	September	1.13	297.59	2231820	2231820	1418.51	635.58	1154.81	1.15
2017	October	1.06	297.52	2015580	2015580	1418.51	703.77	1279.93	1.28
2017	November	0.93	297.39	1692310	1692310	1418.51	838.21	1526.60	1.53
2017	December	0.75	297.21	1199450	1199450	1418.51	1182.63	2158.57	2.16
2018	January	0.55	297.01	744526	744526	1418.51	1905.25	3484.48	3.48
2018	February	0.38	296.84	404996	404996	1418.51	3502.53	6415.26	6.42
2018	March	0.25	296.71	217497	217497	1418.51	6521.98	11955.53	11.96
2018	April	0.19	296.65	133028	133028	1418.51	10663.24	19554.19	19.55
2018	May	0.18	296.64	120961	120961	1418.51	11727.00	21506.04	21.51
2018	June	0.19	296.65	133028	133028	1418.51	10663.24	19554.19	19.55
2018	July	0.21	296.67	157162	157162	1418.51	9025.78	16549.67	16.55
2018	August	0.21	296.67	169229	169229	1418.51	8382.19	15368.77	15.37
2018	September	0.18	296.64	120961	120961	1418.51	11727.00	21506.04	21.51
2018	October	0.10	296.56	69188	69188	1418.51	20502.25	37607.42	37.61
2018	November	0.00	296.46	30259.1	30259.1	1418.51	46878.79	86004.73	86.00
2018	December	0.00	296.46	30259.1	30259.1	1418.51	46878.79	86004.73	86.00

Appendix D – Monitoring recommendations

ID	Description	X	Y	Water level	EC/temp	Manual measurement frequency	Comment
A	Diversion gate - Upstream of weir	556779.34	6358430.34	No	No	N/A	Assume no flows diverted to Toolibin
B	Booloo (west) creek downstream of culvert (DoW 609013)	556043.05	6358016.61	No	No	N/A	
C	Diversion channel/boundary track crossing in south-west corner	555958.00	6357258.00	No	No	N/A	
D	TL25 (SWWMP gauge board B)	557376.53	6357228.14	Yes	Yes	Monthly	
E	Sump GB	556415.71	6356940.87	Yes	Yes	Monthly*	Deploy data logger
F	Toolibin Lake (DoW) gauge board (DoW 609009)	557295.81	6357548.86	Yes	Yes	Monthly*	Deploy data logger
G	Wickepin-Harrismith Road downstream of culvert	557362.02	6359028.43	Yes	No	Monthly	Data supports observations at Site J
H	Toolibin Road North culvert (road side drain from Brown Road)	561538.88	6360260.91	No	No	N/A	
I	Toolibin Road road and Brown rd intersection NE corner upstream	561813.88	6360874.06	No	No	N/A	
J	Wickepin-Harrismith Road upstream of culvert, DoW gauging station (609010)	557381.19	6359043.95	Yes	Yes	Monthly+	Data collected to validate data logged by DoW
K	East Drain downstream Brown road	559918.18	6360852.38	No	No	N/A	
L	West Drain downstream of Brown road	558979.28	6360672.44	No	No	N/A	
M	Dulbining waterway at Oval Road	559062.91	6359391.90	No	No	N/A	
N	DULB - Dulbining Lake GB (SWWMP gauge board B2)	557556.39	6359088.87	Yes	Yes	Monthly*	Deploy data logger
O	Dulbining 2 GB	558006.54	6358980.60	No	No	N/A	
P	Dulbining 3 GB	558498.05	6358515.17	No	No	N/A	
Q	Western pumping station	555867.97	6357302.64	N/A	Yes	Fortnightly	Sample whilst undertaking pumping infrastructure inspections
R	Southern pumping station	556959.58	6356274.00	N/A	Yes	Fortnightly	Sample whilst undertaking pumping infrastructure inspections
S	Toolibin outlet (DoW 69106)	556074.21	6356573.64	Yes	Yes	Monthly	
T	Toolibin outlet site 2	556109.54	6356588.08	No	No	N/A	
U	Bypass waterway, downstream of diversion (DoW 609029)	556532.15	6357958.28	No	No	N/A	Assume no flows diverted to Toolibin
V	TOOL - SWWMP Gauge board A	557595.00	6357254.00	Yes	Yes	Monthly	
W	WALB - Walbyring (SWWMP gauge board)	555497.14	6355626.54	No	No	N/A	

*High resolution data to be collected with the aid of a data logger
+Monitoring of water quality to occur only when flowing (as per standard operating procedure). Water levels to be recorded even when site is dry.

Appendix E – Estimated expenditure to deploy and manage data logging infrastructure

Item	Details	Unit cost	#units	Subtotal
Data loggers	CTD diver	$2,800.00	3	$8,400
Miscellaneous materials	Mounting hardware etc	$200.00	1	$200
Accommodation/meals	4 x trips, 1 night per trip	$150.00	4	$600
Plant	~500km per trip, 4 x trips	$0.70	2,000	$1,400
Labour	Field work only - excludes data analysis and reporting	$0.00	60	$0
Total				$10,600

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