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Water Sensitive Cities

Assessment of options to improve amenity and performance of the Roselea Boulevard Compensation Basin, City of Stirling

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Cooperative Research Centre for Water Sensitive Cities Regional Project 6.4

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EXECUTIVE SUMMARY

The Roselea Boulevard Compensation Basin (RBCB) was developed together with surrounding public open space within the Roselea Residential Estate, situated in the City of Stirling, Western Australia. The RBCB is susceptible to algal blooms (*Potamogeton cripsus*), particularly in the summer months, resulting in amenity and odour complaints from residents. Water Corporation commissioned The University of Western Australia undertake an assessment of the sources of water and nutrients to RBCB, and to make recommendations on actions that might ameliorate eutrophication of the basin.

Key findings of the report include:

1. Sub-soil drainage from the land being developed to the east of RBCB discharges water of poor quality to the Albert Street Branch Drain (ASBD).
2. The RBCB receives approximately half of its water from the inflowing ASBD and half from diffuse groundwater sources entering along its eastern boundary.
3. The RBCB receives about 60% of TN and 95% of TP from diffuse groundwater sources entering along its eastern boundary.
4. Nutrient management in the ASBD and RBCB must consider surface flows from the upstream catchment, and also diffuse groundwater inputs from the east.
5. Water levels in the RBCB have an impact on amenity, available storage volumes during storm events and also groundwater flows into the drain and lake.

Key recommendations for nutrient management include:

1. The sediment in the upper section of the RBCB should be dredged, and removed off site. The bottom basin level should be reset to the as-constructed level.
2. A living stream upstream of RBCB should be created to attenuate nutrients carried by the ASBD. The design of living stream/wetland should include (as per best practice):
   - a gross pollutant trap prior to the drain entering the living stream;
   - the first section of the living stream should be a deeper sedimentation pond;
   - The living stream could possibly be designed with alternating surface and sub-surface flow pathways.
3. Groundwater entering the RBCB either directly via diffuse inflows, or via sub-soil drainage of groundwater, should be infiltrated well before entering the RBCB.
4. Water levels should be managed carefully, possibly via the use of removeable weir boards, as used in similar constructed wetlands in Perth.
5. A water level management strategy should be developed in consultation with stakeholders, and a communication plan developed.
6. While outside the scope of the current study, it is further recommended that investigation be undertaken to assess the impact on nutrient cycling in RBCB, of acid sulphate soil disturbance by adjacent land development.

1 PROJECT RATIONALE

The Roselea Boulevard Compensation Basin (RBCB) was originally a wetland reserve vested to Water Corporation for the purposes of drainage. In 2009, the RBCB was developed together with surrounding public open space within the Roselea Residential Estate, situated in the City of Stirling, Western Australia. The RBCB has a catchment area of 7.44 ha and remains part of Water Corporation’s drainage network, with water flowing north-south, entering and departing the basin via the Albert Street Branch Drain (ASBD). The RBCB has vertical side walls, is supplied by a combination of open and piped (sub-soil) drains, and intercepts groundwater.

There are two issues that have arisen in the RBCB and ASBD:

a) The RBCB is susceptible to algal blooms (*Potamogeton cripsus*), particularly in the summer months, resulting in amenity and odour complaints from residents;

b) The road surface of Veronica Parkway, that runs close to the ASBD, experiences frequent cracking and instability due to unconsolidated fill beneath the road and the steep banks of the ASBD.

The Water Corporation and the City of Stirling wish to rehabilitate the ASBD and RBCB to tackle both issues, and are seeking advice on possible rehabilitation options. The ASBD runs next to public playing fields and there is an opportunity for Water Sensitive Urban Design (WSUD) to be implemented in the current buffer zone. There is minimal available land around the basin itself due to the close proximity of residential housing. Groundwater inputs to the drain and basin complicate nutrient attenuation performance of WSUD options; this must be considered in any recommendations for rehabilitation.

2 DETAILED SITE DESCRIPTION AND HISTORY

The 42 ha Roselea Residential Estate is situated in the City of Stirling, and is bounded by Karrinyup Rd to the south and Grindleford Drive to the east (Figure 1). Prior to urban development, the site was used for market gardens and small hobby farms, and a stormwater drainage network was installed by Water Corporation. The Roselea Estate was developed between 1999 and 2004 (WR Carpenter Properties Ltd 2007), and a drainage network was installed. An existing wetland was developed as a Compensation Basin and landscaped into an ornamental lake within the south-east corner of the estate.

The estate is located in an area at high risk of acid sulphate soils (Acid Sulphate Soil Risk Map, Swan Coastal Plain, DWER-055, SLIP). The previous use of the lands for market gardens and subsequent drainage, suggests historical lowering of the water table; acidification of soil water may have subsequently occurred. An investigation by the Water and Rivers Commission in 2002, recommended backfilling of surface water bodies in the Roselea Lake Estate, active water table management to minimize acidification, and an assessment of the impact of ongoing drainage around Roselea Lake on downstream waters (Water and Rivers Commission, 2002).

The City of Stirling Council noted in 2009 that development of the Roselea Estate risked exposure of peat and organic -rich sands and subsequent potential for acidification (City of Stirling, 2009). The Council Minutes noted an (undated) environmental report completed by Watkins and Oldmeadow, highlighting the risk of acid sulphate soil exposure. A subsequent report by SKM (date unknown) recommended an intensive investigation into options for management of acidity during the development of the Roselea Estate.

The Roselea Estate has a highly engaged group of residents who mostly live around RBCB, and who continue to maintain pressure on agencies to resolve the ongoing issues. This group holds a valuable and comprehensive library of documents relating to RBCB, that is otherwise dispersed across the agencies.

Figure 1. Location of the Roselea Residential Estate (shaded in red) in the City of Stirling, Perth (Nearmap, July 2018).

3 OVERVIEW OF DESIGN AND MANAGEMENT OF THE ALBERT ST BRANCH DRAIN AND ROSELEA BOULEVARD COMPENSATION BASIN

The RBCB Basin is approximately 2.36 in area (WR Carpenter Properties Ltd 2007). Excavation of an existing wetland took place between 1999 and 2003, and perimeter retaining walls were constructed from limestone and backfilled with sand. Water Corporation undertook a bed level survey in 2014 (Water Corporation, Plan AG33-001-016-01A), and showed that the bottom of the RBCB sits at 8 m AHD, and is typically 2m deep, making the standing water surface around 10 m AHD. Survey data from 2007 (Water Corporation, Plan AG33-004-001-01B) indicates that the bottom of the basin sat at 7.5 m AHD, and normal static water height was at 10.2 m AHD, suggesting a standing water depth of 2.7m.

Recent monitoring of adjacent water table depths shows summer minima of 11.3-13.4m AHD, and winter maxima of 11.6-13.9m AHD. The pipe invert levels of ASBD, and other smaller drains entering the RBCB, sit between 8.2 – 9.9m AHD (Water Corporation, Plan AG33-004-001), and groundwater will therefore discharge into the ASBD and RBCB across the whole year.

The 1:2 flood level is estimated to be at 10.3 m AHD, and the 1:10 year flood at 11.4 m AHD; the basin is expected to contain a 1:10 year flood utilising adjacent public open space (WR Carpenter Properties Ltd 2007).

The ASBD enters the basin at its north-eastern end. Road run-off from nearby areas is directed via culverts into the basin at three points, one at the end the western lobe, one on the eastern side, and another halfway along the basin (WR Carpenter Properties Ltd 2007) (Figure 2). These drain flows into the RBCB have never been monitored.

ASBD previously ran between Roselea Blvd and Karrinyup Drive, and was diverted in 2004 (Water Corporation, Plan AG33-1-11B) to run through the Compensation Basin. After exiting the RBCB, it flows to the Candella Square Compensation Basin.

<u>RBCB details</u> (Water Corporation, Plan AG33-004-001)
1:100 yr level = RL 11.95
1:10 yr level = RL 11.4

Static water level = RL10.2
Base of basin = RL 7.5
Storage volume S_{10} =44,800 m^3
Storage volume S_{100} =68,700 m^3
Normal water surface area – 2.34 Ha
Storage volume at RL10.2 – 30.690 m^3

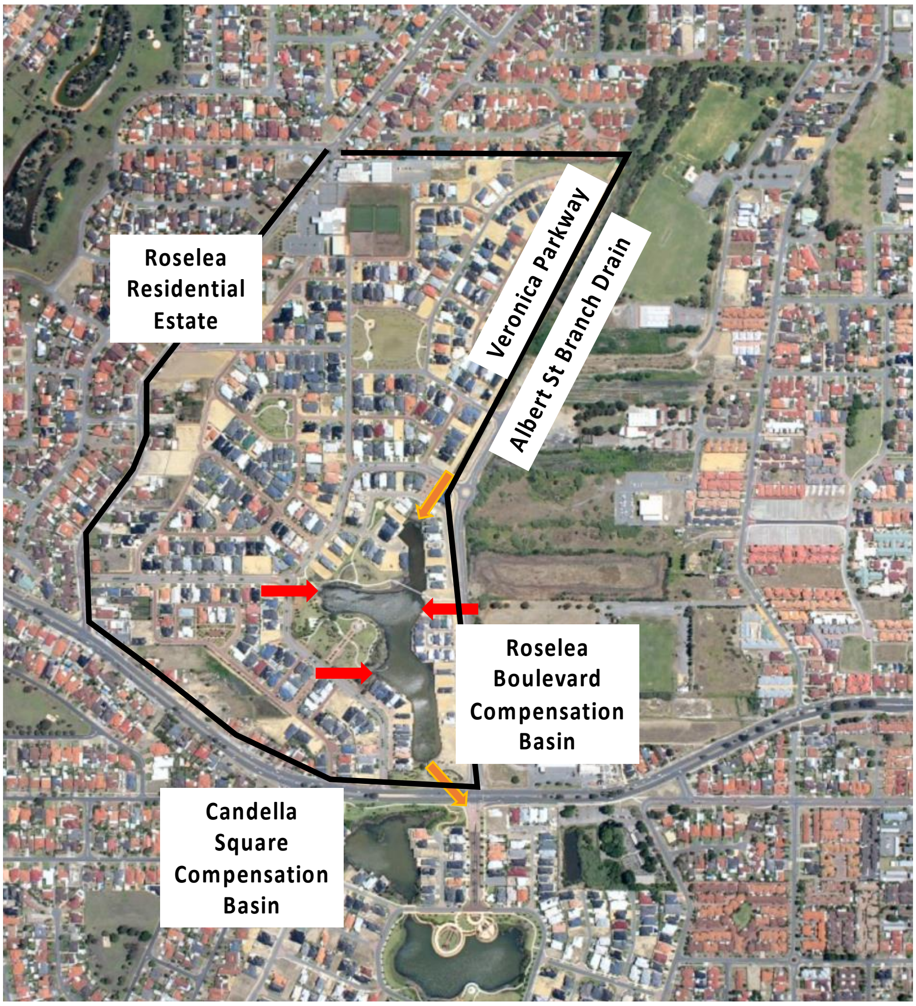

Figure 2. Albert St Branch Drain inflows and outflows (orange), and road runoff inflows (red) into the Roselea Blvd Compensation Basin (Nearmap, December 2009).

A) B)

Figure 3. Water quality issues are visible most years May-June in a) the northern-most section of Roselea Compensating Basin, and b) the Candella Square Compensation Basin (CSCB) (Nearmap, June 2007).

4 PREVIOUS WATER BALANCE ESTIMATES

Carpenter (2007) stated that the basin receives water from the ASBD (4,000 m^3/day in summer, and 12,000 m^3/day in winter), and from the superficial groundwater (2,000,000 m^3/day). The values given for summer and winter conditions appear to be base flows; stormflows are unknown. The flows from the superficial aquifer provided by Carpenter (2007) were considered to be several orders of magnitude too high. A revised provisional estimate of groundwater inflows is provided in Section 5 below.

5 ANALYSIS OF HISTORICAL DATA (DRAIN DISCHARGE, DRAIN AND BASIN NUTRIENT CONCENTRATION DATA, GROUNDWATER LEVELS AND WATER QUALITY, COMPENSATION BASIN INFLOWS AND OUTFLOWS)

Figure 4. Historical and current monitoring sites around RSCB. Surface and bottom water samples were collected from S1, S2 and S3 and analysed for a range of chemicals (Appendix 1A) in 2008. Surface water sites GDS01 and GDS02, and groundwater sites GD01, 02, 03, 04. 05, 06, 07, and 08, were monitored for a range of physico-chemical properties in 2017-2018; water samples were also collected from some of these sites and analysed for nutrients.

5.1 Estimation of groundwater inflows

Hydraulic conductivity for Swan Coastal Plain sands is estimated at k = 0.5 – 2.5 m/day (Salama et al. 2005). The top of the water table sits at ≈ 11m AHD, the basin bottom is at ≈ 8 mAHD, the RSCB has ≈ 2 m deep water column, so standing water surface is at ≈ 10m AHD. The distance from the borehole where water table was measured, and the edge of the basin ≈ 100m. We assumed groundwater discharges as a seepage face across the basin sediments, thus with basin depth ≈ 2 m, distance from edge of basin to middle of basin ≈ 100 m, basin length L≈ 400 m, a discharge face would result with A ≈ 40,000 m^2. Using the Dupuit approximation for unconfined aquifers (homogenous and isotropic), it is estimated that 100 m^3/day groundwater discharges to the RBCB along its eastward seepage face.

The basin water balance was therefore expected, based on historical data, to be dominated by inflowing drain water, both in winter and summer, even under base flow conditions. Field monitoring was required to confirm these preliminary estimates.

5.2 Estimation of nutrient budget

Using recent drain monitoring data provided by Enviro360 (reproduced in Section 13 of this report), drain inflows estimated by Carpenter (2007) and the above estimate of groundwater seepage, we can estimate nutrient budget for the compensation basin. The preliminary nutrient budget was comprised of the following components.

5.2.1 For the inflowing Albert Street Branch Drain

$Q_{IN,drain}$ = 4,000 – 12,000 m^3/day, TN_{drain} = 2.8 mg/L = 2.8 x 10^3 mg/ m^3 and TP_{drain} = 0.3 mg/L = 0.3 x 10^3 mg/ m^3. Therefore, the estimated $Load_{TN,\ drain}$ = 11 – 33 kg/day, and $Load_{TP,\ drain}$ = 1.2 – 3.6 kg/day.

5.2.2 For inflowing groundwater seepage

$Q_{IN,\ GW}$ = 100 m^3/day, TN_{gw} = 2 mg/L = 2 x 10^3 mg/ m^3 and TP_{gw} = 0.7 mg/L = 0.7 x 10^3 mg/ m^3. Therefore, the estimated $Load_{TN,\ gw}$ = 0.2 kg/day and $Load_{TP,\ gw}$ = 0.07 kg/day.

5.2.3 For the drain flowing out of the RBCB

Q_{OUT} = (4,000-12,000)+100 = 4,100-12,100 m^3/day, TN_{OUT} = 0.7 mg/L = 0.7 x 10^3 mg/ m^3 and TP_{OUT} = 0.06 mg/L = 0.06 x 10^3 mg/ m^3. Therefore, the estimated $Load_{OUT,TN}$ = 2.8 – 8.5 kg/day and $Load_{OUT,TP}$ = 0.2 – 0.7 kg/day.

5.3 Nutrient load reduction

Based on these preliminary calculations, we estimated that the RBCB was reducing the total nitrogen load by 8 - 30 kg/day (75-90% removal of TN). The basin was reducing total phosphorus load by 1- 3 kg/day (60-72% removal of TP).

5.4 Residence time in basin

The RBCB is 2.36 ha = 2.36 x 10^4 m^2, and assuming a constant water depth = 2m, it has a volume of 5 x 10^4 m^3. The basin residence time, under assumed baseflow conditions, would therefore be 4-12 days. The storm flow rates and storm residence times are unknown.

Based on historical data, the Roselea Blvd Compensating Basin is attenuating inflowing nutrients well (up to 90% TN, and 75% TP). The cause of the basin attenuation is unknown, and there are likely a number of mechanisms responsible, including settling of particulate nutrients, sorption to basin sediments, and uptake by algae and aquatic vegetation. The steady source of nutrients to the basin appears to trigger algal blooms each year. It is possible that nutrients are being flushed out of the catchment and upstream drains by the first storm flows of the season. This occurs at a time when base flow is still low, and therefore residence times in the Compensation Basin are still relatively long. The historical aerial photographs (NearMap) also indicate ochre-coloured water in May-June each year, in the northern lobe of the RBCB, and also in CSCB. The causes of the discolouration should be investigated.

If we assume that the nutrient loads have remained the same over the decade since the Compensation Basin was constructed, then the basin has received a large load of nutrients. These have likely accumulated in the basin sediments. Because of the constriction in flows due to rubble near the bridge, it is likely that the first section of basin is acting as a sedimentation pond.

6 FLOW MONITORING AND WATER SAMPLING IN 2019

Field data collection was undertaken from February 1 2019 to March 31 2019, to capture conditions conducive to algal blooms, and to investigate potential groundwater inflows into ASBD and RBCB, and thus better constrain the water balance and nutrient budget, and support option testing and decision making.

1) A surface water exploration was undertaken to identify the magnitude and location of groundwater discharge into the ASBD and the RBCB under base flow conditions (February and March 2019). This was achieved using a conductivity-temperature probe to survey surface water of the RBCB and a multi-parameter probe (including conductivity-temperature)

for the ASBD, allowing us to locate areas of effective groundwater flows (both gaining and losing). The surface water exploration included a characterisation of water flowing into the RBCB from existing stormwater pipes. The outcomes are a map for RBCB and a longitudinal profile along ASBD showing groundwater discharge areas. At the same time, preliminary flow discharge measurements at inflow and outflow locations were also undertaken.

2) Water levels, passive tracers and nutrient concentrations were monitored at inflows, outflows, and across the basin during a rainfall event, to characterize hydrographs. We proposed to do this using water level sensors and conductivity-temperature-depth probes. The data could then provide more accurate estimates of residence times under stormflow conditions, the travel time of fresh water through the system and the time taken for groundwater discharge to return to pre-event baseflow conditions. From historical data, this was expected to be between 7 and 15 days after the rainfall event. The nutrient concentration data should allow improved nutrient budgets to be estimated for the basin under stormflow conditions. This task was not completed due to lack of a storm of sufficient magnitude (isolated, and single pulse) during the period November 2018-March 2019 (http://www.bom.gov.au, Perth Metro, Station: 9225). Only water level data at RBCB was collected for preliminary assessment of its dynamics during the period March-May 2019.

6.1 Surface water exploration along ASBD

A field campaign in February 1 2019 along the ASBD, identified three different sections based on geometry (cross section, side slope) and depth along a 600 m reach, transitioning from a shallow depth and gentle side slopes to a deep drain-compound channel at the end of reach prior its discharge into the RBCB.

Table 1 presents the main characteristics of the identified drain sections and a summary of work undertaken by the Water Corporation and the City of Stirling at different stages of construction (identified from Nearmap aerial images). A series of photographs illustrating the different sections of the ASBD are presented in Appendix 1C.

Table 1. Characteristics of identified ASBD sections.

Section name	Length	Cross-section remarks	Section reconstruction
A1	320 m	Shallow depth with gentle side slopes. Groundwater surface seepage area found.	August 2010 - Drain cross section reconstructed (deepened and modified).
A2	170 m	Deep drain with steep side slope. Trapezoidal cross section. Street crossing at the end of the reach via two large circular pipes (1.80 m diameter).	August 2010 - Drain cross section reconstructed (deepened and modified). April-May 2016 - New drainage area (piped) connected to ASBD along Grindleford Dr.
A3	110 m	Deep drain with compound channel: Low flow: rectangular cross section (wooden board). High flow: trapezoidal cross section.	August 2017 - Drain cross section modified (straightened using wooden boards).

A surface water quality exploration along a 600 m reach of ASBD was conducted in February 20 2019 to identify groundwater discharge, following recommendations by Hunt et al. (2017). The field technique used a multi-parameter water quality probe (YSI EXO2) measuring water temperature, electrical conductivity at 25°C (specific conductance), salinity, dissolved oxygen and redox potential, mounted on a floating frame to perform water quality measurements in shallow depth flows (Figure 5). Figure 6 (left) shows the locations of sampling points and includes drainage pipes discharging along the reach. For example, sampling point 11 indicates the location of pipe draining the Grindleford Dr catchment. The data can be found in Appendix 1B.

Figure 5. Water quality measurements in ASBD.

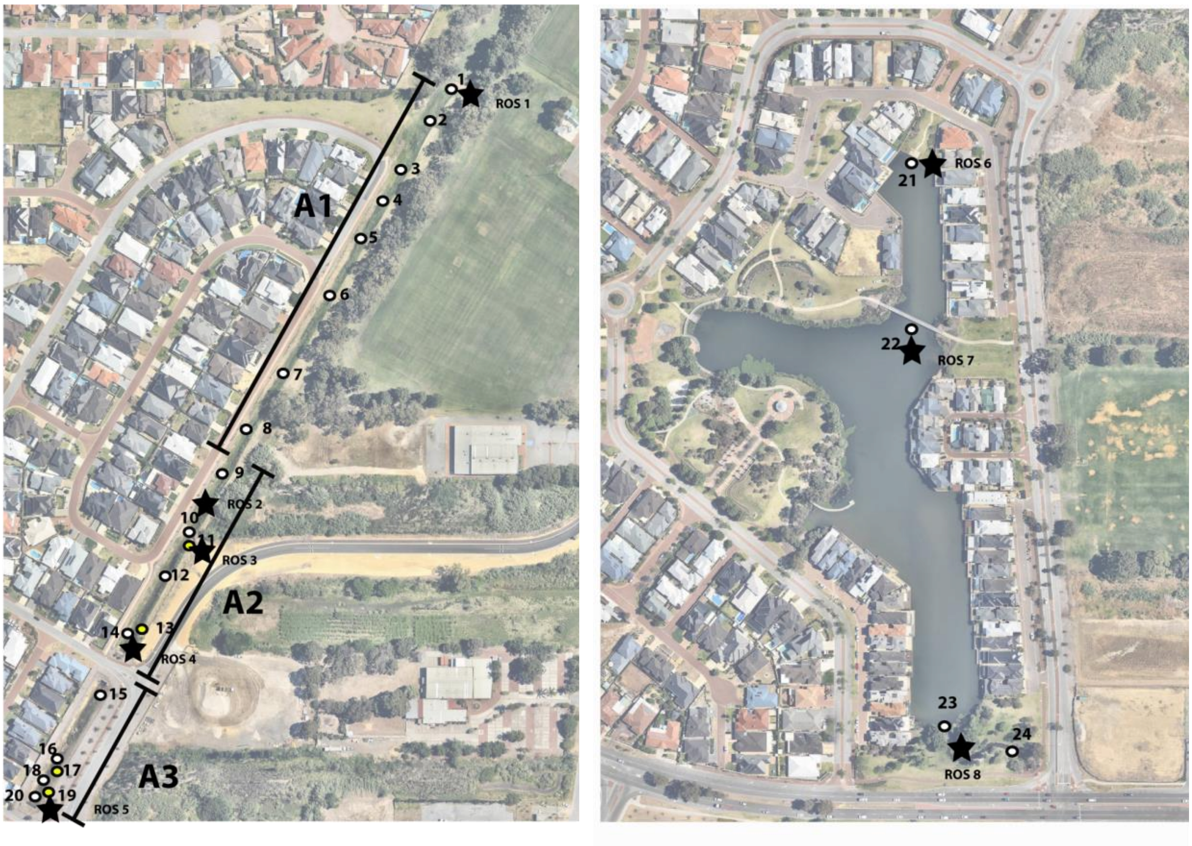

Figure 6. Location of surface water quality measurements along ASBD (left) and RBCB (right). Dots and numbers indicate water quality measurement location. Star symbols followed by identification name (ROS 1) indicate water sampling for nutrient analysis undertaken in February 22 2019 (Source: Nearmap).

The results from temperature, specific conductance (SC) and redox potential (Eh) clearly identified different trends and parameter values consistent with groundwater discharge as both point sources (e.g., drainage pipes) and diffuse sources (Figure 7) along the different sections of the ASBD (e.g., A1, A2 and A3).

Water temperature (Figure 7a) increased downstream until sampling point 10 (sections A1 and A2) and continued this trend until point 16 (section A3), after which it levelled off. Large temperature differences were observed at two key locations; warmer water (Grindleford Dr pipe, point 11) and cooler water (point 17, section A3) discharges were observed and both impacted the water temperature trends along the drain.

The SC spatial variability showed the opposite trend to that found for temperature (Figure 7b) but its key change points were similar (e.g., points 11 and 17). As a passive tracer, SC highlights inflows of groundwater from the eastern side of the drain, characterized by readings in the range of 800-1600 $\mu S\ cm^{-1}$ (see Appendix 1A for compilation of available historical data). Groundwater discharges via a seepage face upstream of sampling point 2 (this diffuse source was observed during fieldwork) and via the drainage pipe at Grindleford Drive (sampling point 11). The low SC value recorded at sampling point 17 seems to be related to a local source likely to be groundwater underneath the urbanized area; this requires further investigation.

Water quality monitoring by previous studies (see Appendix 1A) showed that groundwater is characterized by low dissolved oxygen levels and redox potential values between -30 mV and 3 mV. Figure 7c shows that the redox potential values along ASBD presented a significant drop over the length of the section A2 and A3 and coincided with sampling point 11 and 17.

The spatial variability of the above parameters was confirmed during water sample collection in February 22, 2019. The results indicate that most of groundwater discharge was occurring along sections A2 and A3 of the ASBD and was likely to result from both deeper drain and steeper side slopes, facilitating the interception and discharge of groundwater.

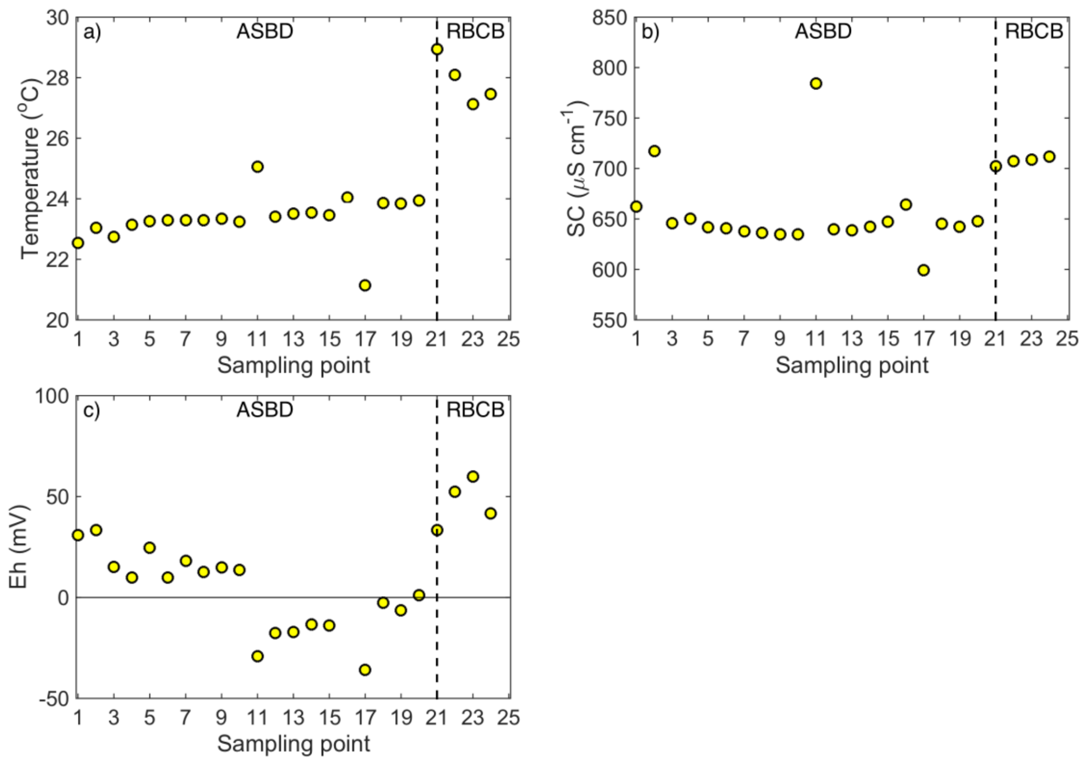

Figure 7. Water quality parameters along the ASBD and RBCB measured on February 20, 2019: a) water temperature, b) specific conductance (SC) and c) redox potential (Eh). Each data point represents the average value of three readings.

6.2 Surface water exploration at RBCB

The field campaign in February 20 2019 extended into the RBCB lake with three sampling points (Figure 6, right panel): inflow location at the northern side (point 21), lake centre at the bridge (point 22) and outflow point at the southern end (point 23). The stream outlet location (point 24) was also monitored as its low position in the landscape (relative to the lake and groundwater level in the area) has potential for gaining groundwater.

The results for water temperature, SC and Eh are presented in Figure 7 (right side indicted by RBCB). As expected, water temperature in the lake was higher due to direct influence of solar radiation and its large heat storage capacity. Overall, the four sampling points showed that the lake presented higher SC values than the corresponding to ASBD and a trend of increasing SC values towards the lake's outlet. The Eh values increased in the water but still remained close to values representing the groundwater in the area.

Although the above parameters were very useful in identifying groundwater discharge into the ASBD, they do not provide sufficient evidence to identify the location and quantity of groundwater discharged into RBCB. A further field campaign was required to allow a more detailed water balance of the lake; the water balance is presented in Section 8.

A more comprehensive surface water monitoring at the western and northern sections of RBCB was conducted in March 28, 2019 to identify groundwater discharge locations. This activity was restricted to these sections due to difficulties of accessing the private properties along the southern end of the lake. Water temperature and SC sensors with a datalogger (TPS 90LVM) and a GPS logger were fitted on a hydroboard and pulled across the lake to scan the lake surface water. Sensors were deployed at 0.2 m from the water surface and data collected at a 4 second-time interval. Figure 8 shows the different tracks followed by the hydroboard across the lake surface.

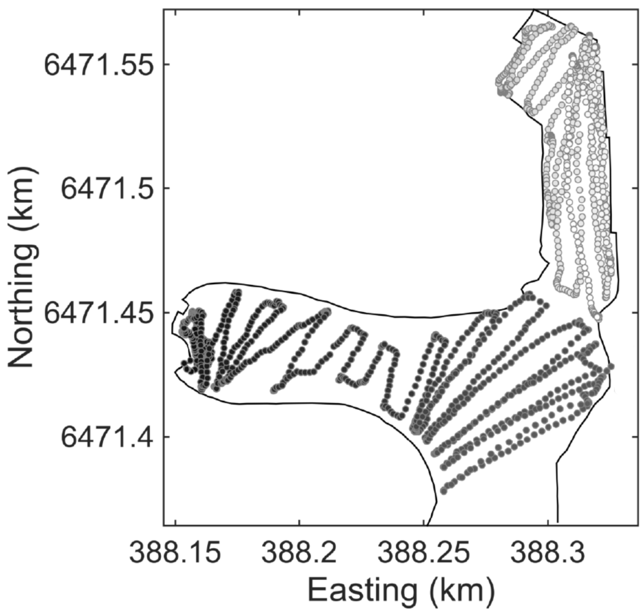

Figure 8. Tracks followed by the hydroboard with temperature and conductivity sensors and GPS. Lake boundaries obtained using Google Earth maps.

Colour maps representing the spatial distribution of water temperature and SC are presented in Figure 9 and Figure 10 respectively.

The water temperature mapping (Figure 9) clearly shows the presence of different compartments within the lake. Cooler water was found at the lake centre, coinciding with deeper water (depth > 2.3 m). The northern section presented a more uniform temperature distribution (values of ~25.7 ^{o}C) and areas of warmer water (see green spots) in wind protected zones (afternoon south-westerly breeze was recorded during the survey). The western area showed more temperature variability than the northern end, and a warm water spot near the shore. However, temperature mapping was unable to identify groundwater seepage areas (diffuse) or point sources areas in the proximity to drainage pipes.

The SC mapping (Figure 10) corroborated the locations for different lake compartments and in particular the centre and northern end. Small variations on SC values were found at the northern end with SC values similar to inflow water from the ASBD (SC = 633 μS cm^{-1}). Higher SC values of approximately 670 μS cm^{-1} were found at the centre (depth > 2.3 m) and western side of the lake and these values agreed with those measured close to the bottom of the lake (e.g., SC = 669 μS cm^{-1}). These results could indicate that groundwater discharge, as a diffuse source, may occur along the shoreline in public open space areas. This increase in SC values was not observed in the northern end as the containing walls in building areas could restrict groundwater discharge towards the lake. Finally, the mapping clearly identified an area of high SC values (approximately 950 μS cm^{-1}) at the eastern side of the lake in the proximity of a stormwater drainage pipe. The location and extension of this plume agreed with observations from Nearmap aerial images.

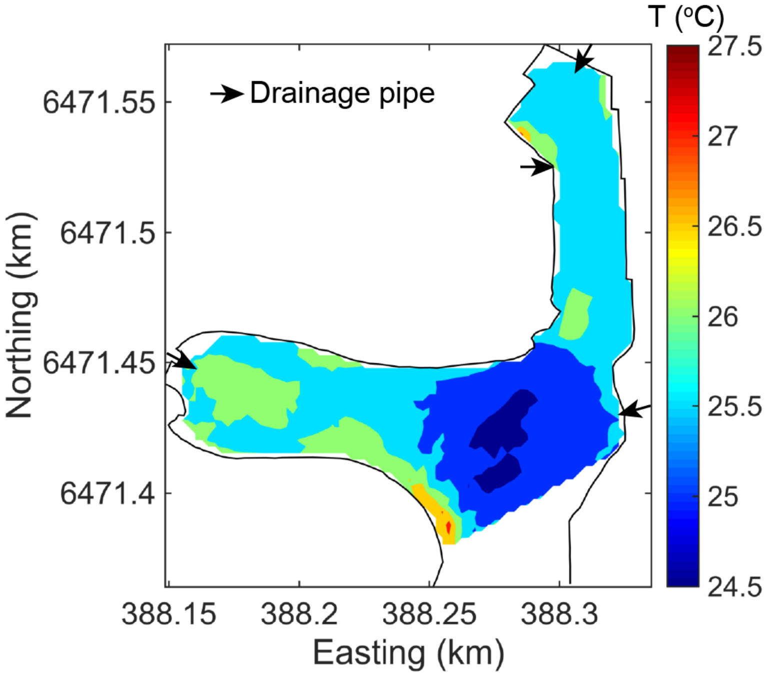

Figure 9. Surface water temperature mapping. Arrows indicate location of drainage pipes entering RBCB.

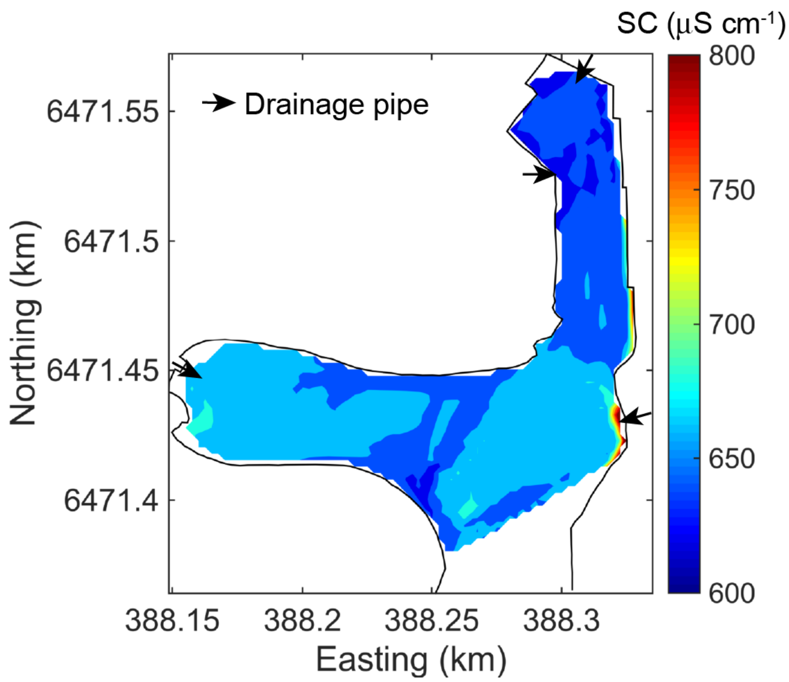

Figure 10. Surface water Specific Conductance (SC) mapping. Arrows indicate location of drainage pipes. Note high SC values located on the eastern side in proximity to drainage pipe.

6.3 Water quality sample collection

Water sample collection for nutrient analysis (nitrogen and phosphorus) was conducted in February 22 2019 after the occurrence of an algal bloom in the northern section of RBCB (point 21 in Figure 6). The incident was reported to Water Corporation on February 15 by residents (N. Scott, pers. comm.). Warm weather conditions prevailed during the previous week (temperatures above 35 ^{o}C) and contractors removed lake macrophytes and floating residues on February 20 and 21, i.e. prior to the sampling date. Water quality measurements were also taken on February 22. Base flow conditions were measured in the ASBD, with no precipitation recorded in the area over the previous 7 days, and less than 6 mm over the previous 30 days (http://www.bom.gov.au, Perth Metro, Station: 9225).

Eight water samples were collected at representative locations (ROS 1 to ROS 8 in Figure 6). Water samples for dissolved nutrient analysis were filtered in the field (0.45 μm) and stored on ice and transported to the Chemistry Centre of WA (NATA credited). Samples were analysed for total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonia (NH_3), nitrite+nitrate (NO_x), total phosphorus (TP) and soluble reactive phosphorus (SRP); laboratory results can be found in Appendix 1B.

6.4 Nutrient concentration values along ASBD: variability and attenuation

Figure 11 shows concentration values for TN and dissolved nitrogen species. Different concentration patterns along the ASBD were identified and will be presented in relation to the nature and amount of the inflow water sources and biogeochemical processes. TN values (Figure 11a) showed a decrease in concentration until sampling point 10 (a reduction of 57 %) but it remained constant along the downstream sections (A2 and A3) as shown by sampling points 14 and 20. The inflow from Grindleford Dr drainage pipe (point 11) showed high TN concentration (2.6 mg/L) and contributed to the observed TN pattern downstream. A similar pattern along ASBD was observed for NO_x (nitrite + nitrate) (Figure 11c), the largest contribution to TN (up to 83 %), with an initial drop of 63 % along the A1 section (sampling point 10). In contrast, the TKN concentration (a measure of organic nitrogen capable of undergoing further transformations) and NH_3 (Figure 11b,c) increased in the downstream direction, particularly around section A2 (point 11) where Grindleford Drive discharge takes place.

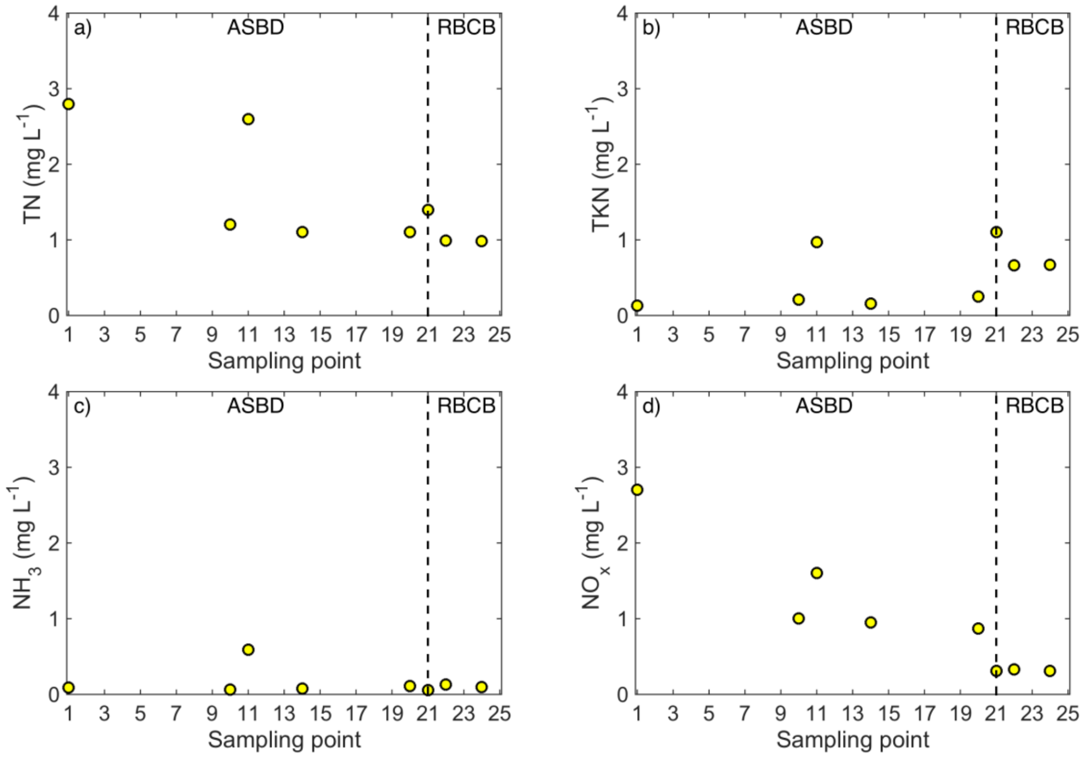

Figure 11. Nitrogen concentration values along the ASBD and RBCB from water samples collected in February 22 2019: a) total nitrogen (TN), b) total Kjeldahl nitrogen (TKN), c) ammonia (NH_3) and d) nitrite+nitrate (NO_x).

The TP and SRP concentration values are presented in Figure 12. Along the ASBD, TP showed a similar pattern to those observed for TN and NO_x, with an initial drop in concentration (76 %) followed by steady values before its discharge into RBCB (Figure 12a, point 20). The largest TP concentration (0.25 mg/L) corresponded to water discharged by Grindleford Dr drain. While SRP represented a small portion of TP (less than 10 %) and suggests TP is mainly composed of particulate and organic phosphorus, it followed the same pattern as TP (Figure 12b).

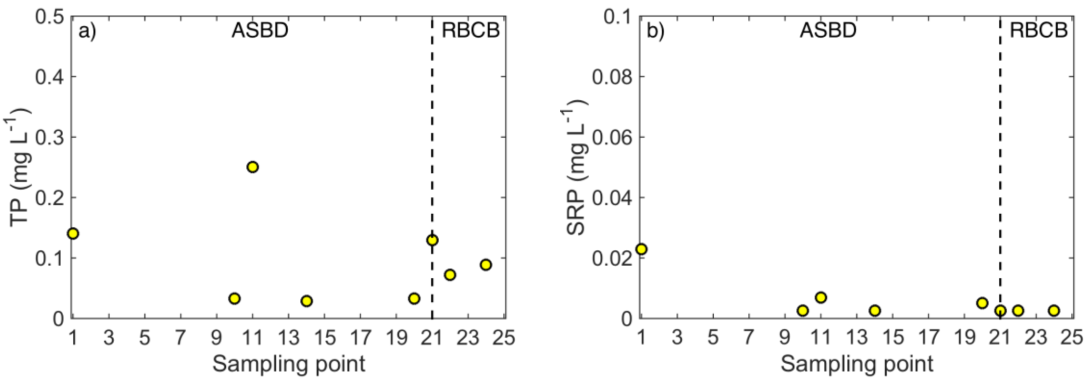

Figure 12. Phosphorus concentration values along the ASBD and RBCB from water samples collected in February 22 2019: a) total phosphorus (TP) and b) soluble reactive phosphorus (SRP).

There are a number of possible explanations for the spatial pattern observed for TN and TP concentrations. Firstly, the attenuation of TN and TP cannot be explained by dilution from a different water source entering the ASBD along Section A1, as observed for SC (Figure 7b). Vegetation uptake, particle trapping and biogeochemical processes are likely to occur in Section A1, as water flows over the highly vegetated channel; vegetation slows the flow and increases the residence time within the reach. Secondly, the steady concentration values (little to no attenuation) observed in Sections A2 and A3 are likely the result from groundwater discharge, as supported by the increase in SC values (Figure 7b). Groundwater samples collected in previous studies from bores at the eastern side of the drain (see GD02 and GD03 in Table in Appendix 1A and Figure 4 for locations) showed TN values ranging between 1.31 and 3.05 mg/L and TP values between 0.57 and 1.17 mg/L. Groundwater discharge containing high TN and TP values can mask any attenuation signals expected within the drain, and could result in the observed TN and TP patterns. Finally, we note that TN and TP concentrations in Grindleford Dr drain are similar to those previously measured in local groundwater and it is likely that the drain intersects and conveys groundwater into the ASBD.

6.5 Nutrient concentration values at RBCB: variability and attenuation

At the RBCB, TN showed a decrease of 29 % in concentration values at the northern end section (Figure 11a, points 21 and 22) but displayed a minor change (1 %) when compared to the southern end at the lake's outflow (point 23). It is important to note an increase in TKN (point 21 in Figure 11b) and the dominance of organic nitrogen (1.04 mg/L) in the RBCB waters. On the other hand, TP concentrations at the RBCB showed little variation within the lake with an average value of 0.097 mg/L. As found in the ASBD, SRP represented a small proportion of TP (~ 2.6 %) in the lake water, with concentrations values of 0.0025 mg/L.

The nutrient dynamics within RBCB are much more complex than in the ASBD, and caution should be exercised when interpreting water quality data. Historical TN and TP concentrations in groundwater bores (see GD06 and GD07 in Table in Appendix 1A and Figure 4 for locations) showed values ranging between 1.9 and 2 mg/L and between 0.52 and 2.31 mg/L respectively. TN values are close to those observed in RBCB waters but differed by an order of magnitude for TP; further understanding of controls and cycling processes within the lake is required.

6.6 Water level dynamics at RBCB: response to rainfall events and outflow control

Water level was continuously monitored from March 26 2019 to May 20 2019 using a water level sensor (pressure transducer, LT3001 Solinst) and data collected at a 10 minute-time interval. Figure 13 shows water level responses to rainfall events, pumping and operational activities at the RBCB outflow point.

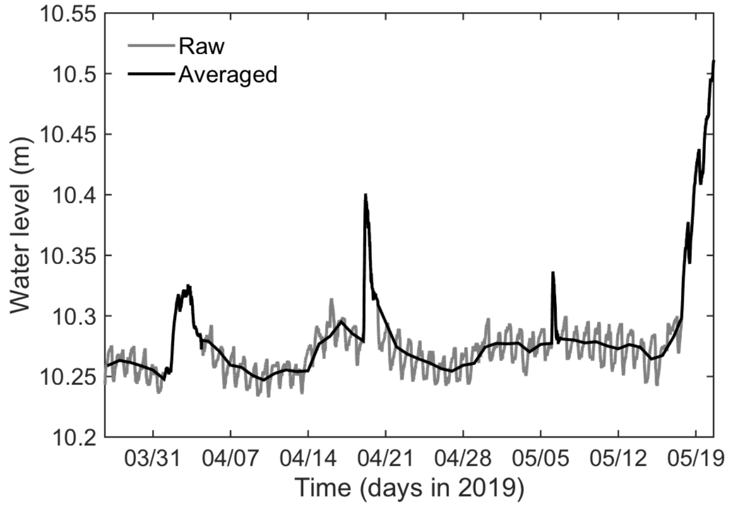

Figure 13.Time series of water level at RBCB: grey line (labelled as raw) represents small diurnal variations in levels and the black line (averaged) represents filtered data plus raw data for individual rainfall events. Water level in metres relative to footbridge level (11.710 m).

Three rainfall events of different magnitude and duration were recorded over the monitoring period, with the largest event on April 19 after an overnight rainfall of 23 mm (http://www.bom.gov.au, Perth Metro, Station: 9225). Water levels also showed small, rapid declines (on average 0.03 m) during the morning hours (daily, between 6 am and 10 am) before recovering over the next few hours; this dynamic is consistent with a pump operation cycle, possibly for irrigation of public open space (Figure

13, indicated as raw data). Towards the end of the monitoring period, water levels displayed a continuous rise (at a rate of 0.08 m/day) and reached the 10.51 m mark by May 20. This increase in water level corresponded with the closure of the outflow section (hay bales were installed at outlet structure on Karrinyup Rd., N. Scott personal communication), that was required to increase water depth at the RBCB's northern section, prior commencement of dredging work by the Water Corporation.

The water level promptly responded to a 23 mm intense-rainfall event recorded on April 19 2019 (Figure 14). The hydrograph rising limb started at 12:40 am and water level peaked at 10.41 m by 4:30 am. The recession of the hydrograph showed a rapid decrease in water level over the first 12 hours (until 4:50 pm) and continued at a slower rate over the following day. Note that this event was preceded by light rainfall totalling 13 mm, from April 15 to April 17 2019.

As a result of the inflow event on April 19, the water temperature dropped by approximately 4.5 ^{o}C (Figure 14) while the air temperature remained relatively constant at around 14 ^{o}C over the day (air temperature measured at the lake's shoreline).

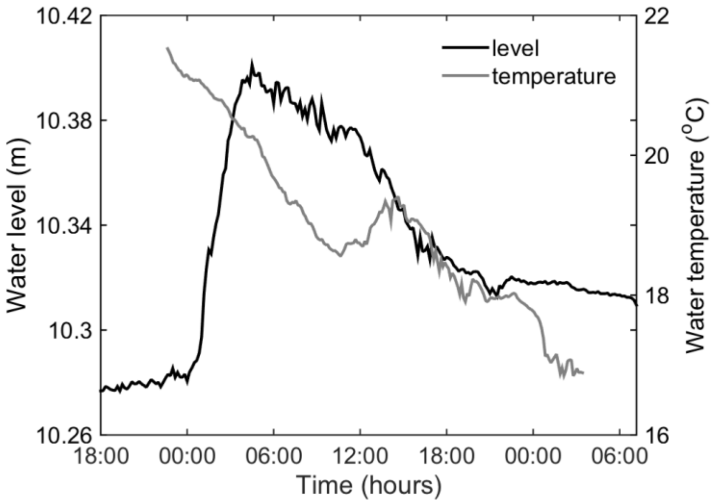

Figure 14.Time series of water level and temperature at RBCB for the April 19 2019 rainfall event. Water level in metres relative to footbridge level (11.710 m).

The observed water level response to rainfall (magnitude and timing) and outflow controls agreed with previous observations by local residents (N. Scott, personal communication) and this data can assist in the development of water level management strategies for water quality and amenity improvements at RBCB.

7 WATER BALANCE FOR THE BASIN, IDENTIFYING GROUNDWATER INPUTS

The ASBD inflows and outflows and RBCB's outflows were measured over the period February-March 2019 under baseflow conditions; measurement locations corresponded to the ASBD inflow (point 1), the outlet of ASBD section A2 (Cranberry Gardens Rd crossing, point 14), and RBCB outlet pipes across Karrinyup Rd (point 24). An acoustic doppler flow meter (Startflow, UNIDATA) was used to determine discharge via the area-velocity method and readings averaged over a two-minute time period. A series of photographs illustrating the different drainage pipes and pits is presented in Appendix 1C.

The Grindleford Dr drainage pipe continuously discharged into ASBD (point 11 in Figure 6) over the two-month period (February-March 2019). Volumetric measurements were undertaken using a container of known volume and stopwatch. Table 2 presents a summary of discharge measurements.

Table 2. Summary of discharge measurements.

Date	Sampling Point	Depth (m)	Velocity (m/s)	Discharge (L/s)	Location
22/02/2019	11	-	-	1.09	Grindleford Dr pipe
01/03/2019	11	-	-	1.13	Grindleford Dr pipe
01/03/2019	14	0.09	0.59	29.20	Cranberry Gardens Rd crossing
08/03/2019	1	0.63	0.03	23.60	Inlet point
08/03/2019	14	0.06	0.53	29.18	Cranberry Gardens Rd crossing
08/03/2019	24	0.10	0.59	56.40	Karrinyup Rd
28/03/2019	24	0.17	0.34	62.00	Karrinyup Rd

Flow conditions in the ASBD did not change significantly (less than 6%) over the measurement period, with water levels in the RBCB at 10.5 m AHD (using reference point at the lake's bridge at 11.710 m; Water Corporation, Plan AG33-004-001). However, vegetation removal and maintenance work at the RBCB outlet and living stream were conducted by Water Corporation on March 23 2019 and had resulted in a drop of ~ 0.292 m in the lake water level (see Appendix 1C for RBCB inflow and outflow photographs) by the time lake monitoring was conducted. New outflow hydraulic conditions were observed and discharge measurements were repeated in March 28 2019, when the lake water level was at 10.25 m.

7.1 Updated groundwater discharge estimates

Using discharge values (Table 2), preliminary estimates of groundwater discharge into the ASBD and the RBCB were obtained as follows:

7.1.1 For the ASBD (between points 1 and 14)

$Q_{ASBD,GW} = Q_{14} - Q_{11} - Q_{1} =$ 29.2 L/s - 1.10 L/s -23.6 L/s = 4.5 L/s

Therefore, the estimated groundwater contribution (gain) via diffuse source was 4.5 L/s or approximately 389 m^3/day. This value represents a gain of 0.89 m^3/day per metre of drain length. Groundwater contribution may be even higher at 484 m^3/day if the Grindleford Dr drain water is considered as groundwater discharge.

7.1.2 For the RBCB between points 14 and 24

$Q_{RBCB,GW} = Q_{24} - Q_{14} =$ 56.4 L/s - 29.2 L/s = 27.2 L/s

The estimated groundwater contribution (gain) is 27.2 L/s or approximately 2350 m^3/day. This value represents a gain of 4.7 m^3/day per metre along the shoreline of public open space (~ 500 m) with a lake water level at 10.500 m. This contribution estimate was repeated for the new lake's water level at 10.25 m after the outflow clean up. It was found that the discharge Q_{24} increased to 62 L/s on March 28 2019 resulting in a groundwater contribution of 32.8 L/s or approximately 2834 m^3/day; the contribution increased by 20%.

These new estimates of the basin water balance under baseflow conditions (summer flows) indicated that the groundwater contributed up to 53 % of the outflow (Figure 15c). Drainage pipe pits entering the lake showed near stagnant water and low levels at the time of inspection, suggesting no substantial water discharge to the lake via point sources (see Appendix 1C for Drainage pipes and pits photographs). However, the surface water SC mapping identified substantial groundwater discharge in the eastern side of the lake in the proximity of a stormwater drainage pipe, and this suggested groundwater sources discharging via the pipe.

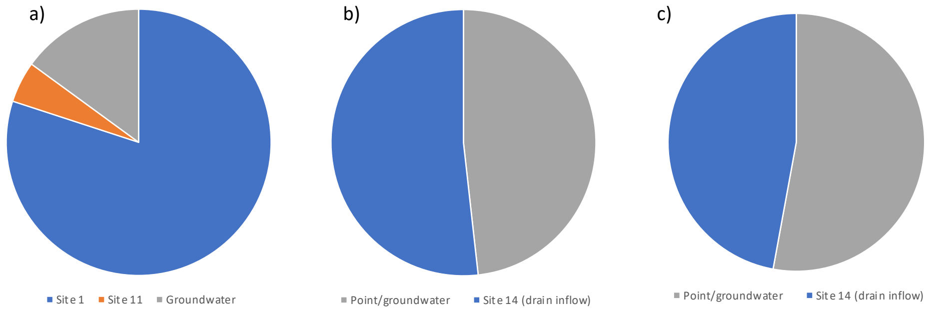

Figure 15. Proportions of water a) flowing into the RBCB from the ASBD; b) flowing out of RBCB on March 8th 2019; c) flowing out of RBCB on March 28th 2019, after drain maintenance.

8 SOURCES OF NUTRIENTS TO RBCB

With the water balances identified, and nutrient concentrations of inflows and outflow determined, a nutrient budget could be estimated for RBCB. This is of particular interest to determine the relative sources of nutrients from drain inflows versus groundwater inflows. The results from this analysis is highly relevant to development of management options to improved management of nutrients.

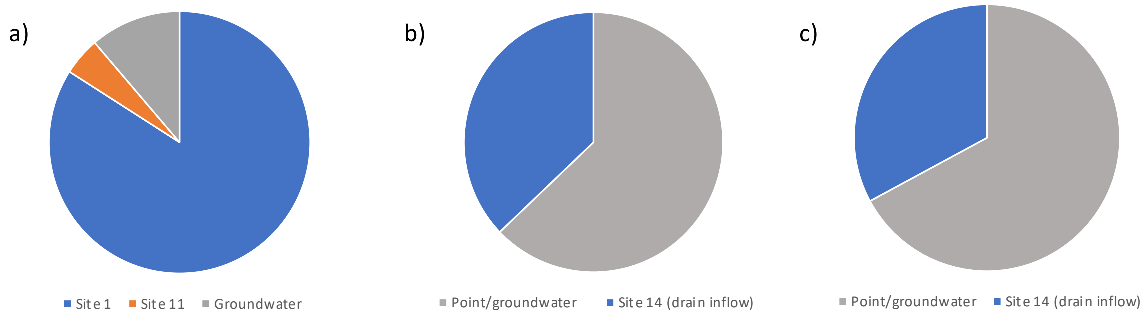

Figure 16. Total nitrogen loads in the a) inflow into ASBD, b) inflow into RBCB on March 8th 2019, and c) inflow into RBCB on March 28th 2019.

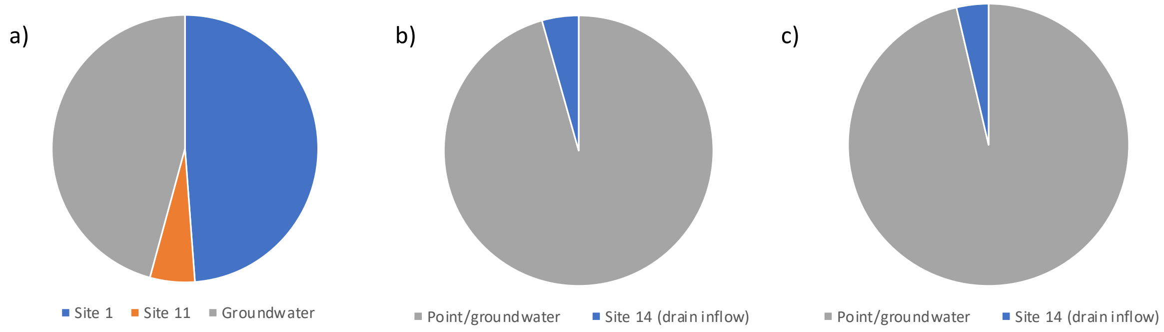

Figure 17. Total phosphorus loads in the a) inflow into ASBD, b) inflow into RBCB on March 8th 2019, and c) inflow into RBCB on March 28th 2019.

The estimated nutrient budgets showed that approximately 60% of the total nitrogen, and 95% of total phosphorus entered RBCB via the groundwater flowing in from the eastern boundary (Figure 16 and 17). The clearing of vegetation from the outflow drain from RBCB on March 28th, lowered the water levels in RBCB by about 30 cm, and this slightly increased the proportion of groundwater-borne TN and TP entering RBCB.

These data highlight the importance of treating both inflowing drain water and inflowing groundwater.

9 RECOMMENDED OPTIONS FOR IMPROVEMENT OF RBCB WATER QUALITY

From the analysis undertaken above, options for improvement can be considered as short-term remedial actions, or longer-term actions that would prevent similar situation arising in the future.

9.1 Short term remedial options

The sediment in the upper section of the RBCB should be dredged, and removed off site. The bottom basin level should be reset to the as-constructed level.

Rubble that constrains flows under the bridge could be removed, however this requires careful consideration. Increased flows through RBCB will flush nutrients out of the basin, however will discharge those nutrients into downstream waters. While likely to improve the water quality in RBCB, downstream waters may experience the same water quality problems currently observed in RBCB.

9.2 Preventative options

The data clearly indicate that both the inflowing drain water and groundwater flowing in from the east, should be treated prior to entering the lake.

9.2.1 Treatment of drain water nutrients

It is recommended that the creation of a living stream upstream of RBCB would be beneficial. The creation of the living stream would also allow remedial action to be done on the Albert St drain levee (currently unstable in places).

The design of living stream/wetland should include (as per best practice)

A. A gross pollutant trap prior to the drain entering the living stream;

B. The first section of the living stream should be a deeper sedimentation pond

C. The living stream could possibly be designed with alternating surface and sub-surface flow pathways.

Note that we do not believe that the current proposal for an aerator addresses the immediate issue of nutrient inputs and low levels of flushing under base flow conditions, nor does it address the longer-term issue of preventing nutrients entering the RBCB. To the contrary, it may in fact exacerbate water quality issues by mobilizing sediment-bound nutrients.

9.2.2 Treatment of groundwater nutrients

Groundwater entering the RBCB, either directly via diffuse inflows or via sub-soil drainage of groundwater, should be infiltrated well before entering the RBCB. Such biofilters basins have been successfully used elsewhere in Perth to treat both stormwater and groundwater prior to discharge to receiving waters (Ocampo et al. 2017).

9.3 Management of water levels

Water levels in the RBCB have an impact on amenity, available storage volumes during storm events and also groundwater flows into the drain and lake. Water levels should be managed carefully, possibly via the use of removeable weir boards, as used in similar constructed wetlands in Perth. It is recommended that the water level management strategy be developed in consultation with stakeholders, and a communication plan be developed.

9.4 Acidity management

While outside the scope of the current study, it is recommended that further investigation be undertaken to assess the impact of acidification on nutrient cycling in RBCB.

10 REFERENCES

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WR Carpenter Properties Ltd (2007) Roselea residential estate compensating basin and southern outflow drain management plan.

11 APPENDICES

11.1 APPENDIX 1A - Compilation of available data

Site	pH	Acidity as $CaCO_3$	EC (mS/cm)	SO_4 (mg/L)	Cl (mg/L)	Cl/SO_4	Hydr. Alk as $CaCO_3$	Carb alk as $CaCO_3$	Biocarb alk as $CaCO_3$	Tot alk. $CaCO_3$
S1T[1]	7.81	6	0.734	72	90.3	1.25	<1	<1	150	150
S1B[1]	7.87	5	0.746	73	92.2	1.26	<1	<1	147	147
S2T[1]	7.9	6	0.721	70	84.6	1.21	<1	<1	153	153
S2B[1]	7.88	7	0.717	71	84	1.18	<1	<1	149	149
S3T[1]	7.79	11	0.802	83	88.9	1.07	<1	<1	175	175
QA1[1]	7.69	8	0.717	68	84.1	1.24	<1	<1	148	148
GD01[2]										
GD02[2]	6.73		1.147							
GD03[2]	7.13		1.388							
GD04[2]										
GD05[2]										
GD06[2]	6.20		0.675							
GD07[2]	6.55		1.648							
GDS01[2]	6.9		1.080							
GDS02[2]	7.28		0.805							

Site	TDS	Sulphur as S	Al Diss	Al Total	As Diss	Cu Diss	Fe Diss	Fe Total	Ni Diss	Zn Diss
S1T[1]	474	24	<0.01	<0.10	<0.001	<0.001	0.05	2.52	<0.001	<0.005
S1B[1]	490	24	<0.01	0.11	<0.001	<0.001	<0.05	2.22	<0.001	<0.005
S2T[1]	524	23	<0.01	0.13	<0.001	<0.001	<0.05	1.91	<0.001	<0.005
S2B[1]	496	24	<0.01	0.13	<0.001	<0.001	0.05	1.96	<0.001	<0.005
S3T[1]	454	28	<0.01	<0.10	<0.001	<0.001	0.05	4.14	<0.001	<0.005
QA1[1]	562	23	<0.01	0.16	<0.001	<0.001	<0.05	2.07	<0.001	<0.005
GD01[2]										
GD02[2]										
GD03[2]										
GD04[2]										
GD05[2]										
GD06[2]										
GD07[2]										
GDS01[2]										
GDS02[2]										

Site	Cd Diss	Cr Diss	Mn Diss	NOx	TKN-N	NH_4-N	NO_3-N	TN	TP
S1T[1]	<0.001	<0.001	0.041	0.888	0.7	0.205	0.849	1.6	0.07
S1B[1]	<0.001	<0.001	0.038	0.812	0.8	0.237	0.765	1.6	0.07
S2T[1]	<0.001	<0.001	0.036	0.748	0.8	0.263	0.696	1.5	0.03
S2B[1]	<0.001	<0.001	0.036	0.706	1	0.229	0.654	1.7	0.04
S3T[1]	<0.001	<0.001	0.07	0.641	0.5	0.174	0.568	1.1	0.06
QA1[1]	<0.001	<0.001	0.037	0.701	0.8	0.231	0.641	1.5	0.05
GD01[2]									
GD02[2]				1.31	1.75	0.14		3.05	0.57
GD03[2]				0.09	1.9	0.28		2	1.17
GD04[2]									
GD05[2]									

GD06[2]				0.60	1.4	0.19		2	2.31
GD07[2]				1.07	1.9	1.07		1.9	0.52
GDS01[2]				1.80	1.00	0.11		2.77	0.29
GDS02[2]				0.37	0.33	0.08		0.7	0.06

Site	Temp	DO (mg/L)	Redox (mV)	Min gw levels (mbsl)	Min gw levels (mbsl)	Min gw levels (mAHD)	Max gw levels (mAHD)		
S1T[1]									
S1B[1]									
S2T[1]									
S2B[1]									
S3T[1]									
QA1[1]									
GD01[2]				1.59	2.21	11.78	12.40		
GD02[2]	18.80	0.82	3.0	0.66	0.97	13.44	13.64		
GD03[2]	17.4	2.07	-21	0.76	1.34	11.36	11.69		
GD04[2]				0.92	1.60	12.69	13.37		
GD05[2]				0.78	1.04	11.44	11.67		
GD06[2]	20.5	0.95	30	1.97	2.57	13.24	13.60		
GD07[2]	19.2	1.75	-70	0.79	2.55	10.98	12.69		
GD08				0.63	1.53	13.42	13.93		
GDS01[2]	20	4.28	41.67						
GDS02[2]	22	6.29	41.33						

[1]WR Carpenter Property Ltd (2007), Appendix A

[2]Environ360 (Justine Jones) and Parcel Property (Jeremy Cordina) via Water Corporation (Suzanne Brown).

11.2 **APPENDIX 1B - Water quality data and Laboratory results**

Time	Location	Lat (deg S)	Long (deg E)	Temp (°C)	SC (µScm^{-1})	Sal (psu)	DO (% Sat)	DO (mgL^{-1})	Eh (mV)	pH	TDS (mgL^{-1})
13:54:20	1	-31.880925	115.822900	22.55	662.40	0.32	69.25	6.01	30.95	7.73	431.00
14:01:37	2	-31.881163	115.822733	23.03	717.47	0.35	46.33	3.99	33.33	7.48	466.00
14:06:42	3	-31.881450	115.822500	22.75	645.83	0.31	42.40	3.67	15.03	7.42	420.00
14:11:13	4	-31.881590	115.822400	23.13	650.40	0.32	43.07	3.70	10.00	7.44	423.00
14:17:25	5	-31.881880	115.822200	23.26	641.90	0.31	40.43	3.47	24.67	7.44	417.00
14:22:48	6	-31.882250	115.822000	23.30	640.93	0.31	37.80	3.23	9.83	7.43	417.00
14:28:45	7	-31.882660	115.821700	23.29	637.93	0.31	39.13	3.35	18.10	7.45	415.00
14:34:41	8	-31.883080	115.821400	23.29	636.30	0.31	37.97	3.25	12.73	7.48	414.00
14:41:53	9	-31.883390	115.821200	23.33	634.80	0.31	36.80	3.15	14.90	7.54	413.00
14:50:12	10	-31.883750	115.820900	23.24	634.53	0.31	36.30	3.11	13.70	7.46	412.00
14:53:05	11	-31.883800	115.820933	25.06	784.33	0.38	90.13	7.47	-29.13	7.80	510.00
15:01:06	12	-31.883980	115.820800	23.41	639.53	0.31	41.00	3.50	-17.57	7.70	416.00
15:12:29	13	-31.884437	115.820500	23.51	638.60	0.31	43.33	3.70	-17.07	7.56	415.00
15:14:07	14	-31.884440	115.820500	23.55	642.40	0.31	41.80	3.56	-13.40	7.45	417.33
15:50:47	15	-31.884820	115.820300	23.46	647.37	0.31	46.67	3.98	-13.93	7.78	421.00
15:57:42	16	-31.885290	115.819900	24.05	664.40	0.32	54.03	4.56	-63.97	7.47	432.00
15:59:45	17	-31.885313	115.819900	21.14	599.03	0.29	29.23	2.61	-35.80	7.67	389.33
16:02:34	18	-31.885400	115.819867	23.86	645.10	0.31	58.63	4.97	-2.53	7.35	419.00
16:05:05	19	-31.885460	115.819800	23.85	642.37	0.31	69.00	5.85	-6.50	7.48	417.67
16:07:06	20	-31.885470	115.819800	23.94	647.67	0.31	61.57	5.21	1.07	7.49	421.00
16:19:43	21	-31.886230	115.819000	28.94	702.47	0.34	143.33	11.08	33.30	8.28	456.67
16:35:49	22	-31.887280	115.819000	28.10	707.37	0.34	135.87	10.66	52.40	8.21	460.00
16:49:25	23	-31.889910	115.819300	27.13	708.63	0.34	142.07	11.34	59.93	8.24	460.67
16:53:50	24	-31.889940	115.819700	27.45	711.93	0.34	106.37	8.44	41.63	8.18	463.00

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Civil Environmental and Mining Engineering
35 Stirling Highway, M051
CRAWLEY WA 6009
Attention: Carlos Ocampo

Report on: 8 samples received on 22/02/2019

LAB ID	Material	Client ID and Description
18S3323 / 001	water	ROS1
18S3323 / 002	water	ROS2
18S3323 / 003	water	ROS3
18S3323 / 004	water	ROS4
18S3323 / 005	water	ROS5
18S3323 / 006	water	ROS6
18S3323 / 007	water	ROS7
18S3323 / 008	water	ROS8

LAB ID			001	002	003	004
Client ID			ROS1	ROS2	ROS3	ROS4
Sampled			22/02/2019	22/02/2019	22/02/2019	22/02/2019
Analyte	**Method**	**Unit**				
Nitrogen, ammonia	iNPSi1SFAA	mg/L	0.089	0.064	0.59	0.076
* Nitrogen, organic - Filterable	iNPCALC2	mg/L	0.041	0.13	0.35	0.076
Nitrogen, total kjeldahl	iNPCALC1	mg/L	0.13	0.21	0.97	0.16
Phosphorus, sol. reactive	iNPSi1SFAA	mg/L	0.023	<0.005	0.007	<0.005
Nitrogen, total	iNPT1SFAA	mg/L	2.8	1.2	2.6	1.1
Nitrogen, nitrate + nitrite	iNPSi1SFAA	mg/L	2.7	1.0	1.6	0.95
Phosphorus, total	iNPT1SFAA	mg/L	0.14	0.033	0.25	0.029
Phosphorus, total soluble	iNPT1SFAA	mg/L	0.029	0.010	0.013	0.010
Nitrogen, total soluble	iNPT1SFAA	mg/L	2.8	1.2	2.5	1.1

LAB ID			005	006	007	008
Client ID			ROS5	ROS6	ROS7	ROS8
Sampled			22/02/2019	22/02/2019	22/02/2019	22/02/2019
Analyte	**Method**	**Unit**				
Nitrogen, ammonia	iNPSi1SFAA	mg/L	0.11	0.060	0.13	0.099
* Nitrogen, organic - Filterable	iNPCALC2	mg/L	0.12	0.28	0.24	0.22
Nitrogen, total kjeldahl	iNPCALC1	mg/L	0.25	1.1	0.66	0.67
Phosphorus, sol. reactive	iNPSi1SFAA	mg/L	0.005	<0.005	<0.005	<0.005
Nitrogen, total	iNPT1SFAA	mg/L	1.1	1.4	0.99	0.98
Nitrogen, nitrate + nitrite	iNPSi1SFAA	mg/L	0.87	0.31	0.33	0.31
Phosphorus, total	iNPT1SFAA	mg/L	0.033	0.13	0.072	0.089
Phosphorus, total soluble	iNPT1SFAA	mg/L	0.010	0.013	0.012	0.009
Nitrogen, total soluble	iNPT1SFAA	mg/L	1.1	0.65	0.70	0.63

Method	Method Description
iNPCALC1	Total Kjeldahl Nitrogen (Calculated TN - Nitrate/Nitrite_N).
iNPCALC2	Organic Nitrogen - Filterable, calculated from TSN, TON and ammonia
iNPSi1SFAA	Low Level Nutrients by Segmented Flow Auto Analyser
iNPT1SFAA	Low Level Nutrients by Segmented Flow Auto Analyser

These results apply only to the sample(s) as received. Unless arrangements are made to the contrary, these samples will be disposed of after 30 days of the issue of this report.
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*Analysis not covered by scope of ChemCentre's NATA accreditation.

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Chemist
SSD Inorganic Chemistry
7-Mar-2019

Hanna May
Team Leader
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11.3 **Appendix 1C - ADDITIONAL PHOTOGRAPHS**

11.3.1 ASBD - SECTION A1

Downstream

Upstream

11.3.2 ASBD - SECTION A2

Downstream

Upstream

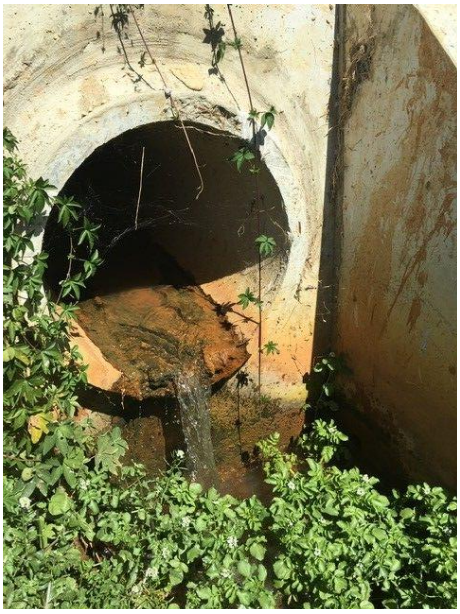
11.3.3 ASBD - SECTION A3

Downstream

Upstream

11.3.4 DRAINAGE PIPES AND PITS

Grindleford Dr pipe



Grindleford Dr and Lycium Quays pit

Coralvine Grange and Roselea Blvd pit

Karrinyup Rd pipe: flow measurement

11.3.5 RBCB INFLOW AND OUTFLOW

Sediment accumulation at the Inflow northern end: lake level at 10.25 m (March 28 2019)

Lake outlet stream at the southern end

Before clean up (February 20 2019)

After clean up (March 28 2019)