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City of South Perth

Neil McDougall Park Lake

INTEGRATED MANAGEMENT & REMEDIATION SOLUTION

PRELIMINARY DESIGN

FINAL REPORT

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For City of South Perth

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GLOSSARY

Word or phrase	***Refers to***
Algae	Informal term for a large, diverse group of photosynthetic organisms
Benthic	Relates to the bottom of a body of water, e.g. a habitat at the lowest level of a body of water
Biota	Animal and plant life of a particular region or habitat
Consanguineous	Relating to/ denoted from the same ancestor/origin
Cyanobacteria	A phylum of bacteria that obtain energy from photosynthesis
Cyanotoxins	Toxins produced by cyanobacteria
Eutrophic	Excessive richness in nutrients in a waterbody
Filamentous	The growth of bacteria into elongated filaments or threads
Phytoplankton	Plankton consisting of free-floating algae, protists and cyanobacteria

ABBREVIATIONS

Abbreviation or acronym	***What it stands for***
AHD	Australian height datum
ANZECC	Australia and New Zealand Environment Conservation Council
ASS	Acid sulphate soils
BGL	Below ground level
CDS	Continuous Deflection Separation
DoH	Department of Health
DWER	Department of Water, Environment and Regulation
GPT	Gross pollutant trap
HAB (and cHAB)	Harmful Algal Bloom (Cyanobacterial HAB)
HDPE	High-density polyethylene
ms^{-1} or m/s	Metre per second
L/s	Litres per second
NHMRC	National Health and Medical Research Council
NOx	Nitric Oxides (Nitrite, Nitrate)
OMC	Order of Magnitude Cost
PEU	Phytoplankton Ecology Unit (part of the Department of Water and Environment Regulation)

se	Standard error
SERCUL	South Eastern Regional Centre for Urban Landcare
SWMS	Safe work method statement
TN	Total Nitrogen as N
TP	Total Phosphorus as P
TKN	Total Kjeldahl Nitrogen

EXECUTIVE SUMMARY

Syrinx was engaged by the City of South Perth (the City) in April 2018 to develop an appropriate and sustainable solution for the management of duckweed (Lemna) and cyanobacterial blooms in Neil McDougall Park Lake (the Lake). This study was prompted by concerns from the public associated with the reoccurrence of a dense Lemna mat that grows across the Lake. More recently, a cyanobacteria (blue-green algae) bloom followed the removal of Lemna, and this has become an additional and possibly more pressing issue in the Lake needing remediation.

This current report follows on from a previous investigation and concept design stage, and details the preliminary design of an integrated treatment system for the Lake.

For context, Neil McDougall Lake is a highly modified basin wetland. It was formerly part of a natural chain of wetlands and was historically a seasonally inundated sumpland, interacting with the groundwater in winter and drying out over summer. The original 'swamp' was modified in the 1960's to create a permanent lake. In 1995, the lake was deep dredged to maintain permanent water levels, due to falling groundwater levels associated with a drying climate.

The recurring water quality problems within the Lake from the following key factors:

1. Direct stormwater inputs from four pipes draining four large catchments (72 ha total), which, for the most part, do not have upstream treatment interventions.
2. Poor circulation patterns within the Lake, particularly during non-rainfall periods.
3. Oxygen depletion and accumulation of nutrients in sediments due to the constant cycling of *Lemna* and cyanobacteria.
4. Bird droppings and gross pollutants entrained in surface run-off.

An integrated solution has been proposed as follows:

1. Construction of sedimentation zones and vegetated filtration zones at all stormwater outlets to treat 'first flush' and low flow stormwater as far as practicable before discharge to the Lake.
2. Construction of a treatment wetland adjacent to the Lake to treat Lake water via a pumped recirculation system, as well as stormwater from catchment A.
3. Installation of aeration pumps at two locations to improve lake circulation and oxygenation within the Lake
4. Planting fringing lake vegetation to prevent the direct entry of pollutants (e.g. bird droppings) entrained in surface run-off.
5. Interception and treatment of groundwater via planting of deep rooted plant species.

These works can be staged in accordance with Council budgets.

PART 1 PROJECT CONTEXT

1.0 PROJECT BACKGROUND

1.1 PROJECT HISTORY

1.1.1 Key Drivers

Syrinx was engaged by the City of South Perth (the City) in April 2018 to develop an appropriate and sustainable solution for the management of *Lemna* and cyanobacterial blooms in Neil McDougall Park Lake (the Lake). This study was prompted by concerns from the public associated with reoccurring *Lemna* (duckweed) mats covering the surface of the Lake. More recently, a cyanobacteria (blue-green algae) bloom followed the removal of Lemna, and given cyanobacteria blooms can potentially pose a public health risk, this has become an additional and possibly more pressing issue.

From October 2016 till mid-2017, the *Lemna* bloom at the Lake was extensive with the mat (green floating scum) covering almost the entire surface of the Lake. This was a cause of concern for some of the local residents who perceived the *Lemna* as an aesthetic nuisance. In late October 2017, the City manually removed the *Lemna* from the Lake.

Physical removal of *Lemna* provided favourable conditions for phytoplankton and resulted in a shift towards cyanobacteria dominance, a pattern that is common in urban lakes in Perth. Water testing in January 2018 confirmed the presence of the cyanobacteria species *Dolichospermum circinale* (previously known as *Anabaena circinalis*) which can produce potentially harmful neurotoxins.

Despite the effort by the City, reoccurrence of *Lemna* and cyanobacteria blooms remain a constant issue. *Lemna* was observed again in winter 2018, and in October 2018 the *Lemna* mat was noted to again cover almost the entire Lake surface.

While the initial removal of *Lemna* has helped prevent complaints from residents about the visual appearance of the Lake in the short-term, the occurrence of toxic cyanobacteria in the Lake is likely to prompt further complaints. Hence, a long-term solution is needed.

1.1.2 Lake Remediation Project - Aims & Approach

Driven by the reoccurring water quality, aesthetic and potential public health issues, the City initiated this current remediation project which is focused on developing a sustainable, long term solution to address the underlying causes and improve the overall health of the Lake.

The overall aim of this Project is:

To develop the most appropriate, integrated and site-responsive solution for remediation of Neil McDougall Park Lake.

A progressive and staged management approach was adopted to achieve this objective, with the following stages:

STAGE 1: **Problem characterisation** - desktop study + field investigations (water & sediment quality sampling, groundwater levels)

STAGE 2: **Concept Design** - development of an integrated remediation solution

STAGE 3: **Preliminary Design**

1.1.3 Project Chronology

The first two stages of the project were finalised by Syrinx in June 2018 and presented to the City. The City adopted the concept design in July 2018, enabling design progression to the preliminary stage.

In December 2018 a draft version of the preliminary design report was issued to the City for comments and approval ahead of detailed design and construction.

Between February and March 2019 the community was given the opportunity provide feedback on the preliminary design as detailed in Section 12.

In April 2019 Syrinx undertook a site-specific environmental investigations and prepared an Acid Sulfate Soil (ASS) Investigation and Management Plan and a Dewatering Management Plan (ASSIDMP) for land disturbance works during construction of the integrated remediation solution, as detailed in Section 13.

The inputs from the City, feedback from the community engagement process and findings from the ASSIDMP were then used to refine and finalised the preliminary design of the proposed remediation system.

This final version of the report presents the key outputs of the preliminary design process, and together with the drawing set, forms the Stage 3 deliverable.

1.2 PROBLEM IN BRIEF

As part of work during the concept design stage, Syrinx characterised the key underlying issues driving the observed blooms, and their likely causes. Detailed problem characterisation, including water and sediment data quality analysis and description of the lake water regime, is contained in the Concept Design report (*Neil McDougall Park Lake: Remediation Solution Concept*, Syrinx June 2018). To provide context for design development presented in this report, a short summary of the underlying mechanisms driving the observed algae blooms is given below.

Neil McDougall Lake is a highly modified basin wetland. It was formerly part of a natural chain of wetlands and was historically a sumpland (seasonally inundated basin), interacting with groundwater. In 1995, the Lake was dredged to maintain permanent water levels, due to falling groundwater levels associated with the drying climate, and community desire for a permanent water feature.

Blooms of both *Lemna* and cyanobacteria are likely driven by the **high nutrient levels in the Lake** and the **poor water circulation** within the Lake.

Nutrients

The Lake water has been of poor quality for many years, with the surface water and sediments high in nutrients (both nitrogen and phosphorous). Nitrogen (N) is strongly dominated by ammonia which is likely indicative of a system lacking in oxygen, carbon (and possibly also alkalinity), so that the normal processes of nitrification and denitrification within the Lake are constrained.

The Lake sediments are highly overloaded with nitrogen and organics, which reflects the constant cycle of death and accumulation of algae and cyanobacteria. Stored N is 3 to 4 times higher than other Perth urban lakes which have some flushing mechanism (Syrinx data), indicating Neil McDougall Lake is a significant sink (and probably not a major source) of nutrients.

Whilst the storage of nutrients (N in particular) means the Lake is contributing to the improvement of water quality in the Canning River as far as nutrients are concerned, the Lake itself is unable to process and remove these nutrient loads fast enough, predominantly due to ongoing inputs to the system from stormwater. Hence, the system is unbalanced. The groundwater, while having slightly elevated nutrient levels, does not appear to be a large contributor to the system. Rather, stormwater inputs from the surrounding catchment, are the main ongoing source of pollutants.

Note, stormwater inputs into the Lake are largely untreated given there are no major upstream treatment interventions aside from a CDS® (Continuous Deflection Separation) gross pollutant traps installed on Henley Street near the DW4 inlet (pers. comm. Len Dalton, City Works & Services Coordinator, 18th January 2019). The greatest external input was measured in the stormwater entering via the Bickley St drain (DW1) in May 2018 and the Clydesdale St drain (DW3) in June 2019.

Lake Circulation

Hydraulically, the Lake has been identified as a 'wet infiltration basin', however it would appear there are few losses from the system, except where large storm events raise the lake water levels sufficiently to enable throughflow. The Lake is shallow and has no outflow to promote flushing. The poor movement of water within the Lake, in turn, affects the water temperature, one of the main drivers of chemical and biological processes in aquatic systems. Therefore, the hydraulic retention time of water within the lake is very long, and this stability enables the full completion of a cyanobacterial life cycle; this pattern is typical of many of the lakes in the Perth Metropolitan area.

1.3 DESIGN RESPONSES

Based on the understanding of the key underlying processes responsible for the re-occurrence of algal blooms, the integrated remedial solution developed by Syrinx integrates a range of initiatives aimed at addressing the specific system disbalances as follows:

1. Treatment of stormwater inflows (pre-treatment) – focused on nutrient removal. Control and management of both N and P levels in parallel is required with the focus on managing P to manipulate the molar TN/TP ratio in a way that disrupts algae growth.

2. Continuous in lake water improvements via recovery and treatment of Lake water in a treatment wetland external to the Lake.
3. Enhanced water circulation and mixing – this is needed for:
   i. Disruption of algae growth – increase in water movement and reduction of hydraulic retention time (HRT) within the Lake is a critical management strategy. Cyanobacteria are predicted to be greatly reduced from lakes irrespective of nutrient concentrations at hydraulic retention times of around 5-10 days. Whilst this is likely to not be feasible, reducing retention to 25 days could be sufficient to improve conditions to a satisfactory level. A flow rate of 0.05 meters per second (m/s) is also thought to be sufficient to prevent the persistent stratification and disrupt cyanobacterial growth.
   ii. Water oxygenation - needed to enable nitrification and removal of the high ammonia concentrations.
   iii. Engagement with the littoral zone of the lake, which is where the majority of biological processes occur, and which currently is dominated by cyanobacteria.
4. Shading – provision of in-lake shading for regulation of light intensity and temperature.
5. Revegetation and restoration of fringing vegetation to improve biotransformation processes and for habitat creation to support invertebrates which contribute to cyanobacteria control.

2.0 WATER QUALITY & FIELD INVESTIGATIONS (2018/19)

To manage the water quality and overall health of the Lake and control future blooms of *Lemna* and cyanobacteria, a comprehensive understanding of the key nutrient sources is needed.

2.1 SAMPLING METHODOLOGY

As part of the concept design process Syrinx undertook an initial field assessment in May 2018 (late autumn) which included i) sampling and water quality analysis of Lake water (surface water), stormwater inflows into the Lake and groundwater, as well as the Lake sediment analysis, ii) phytoplankton analysis in surface (Lake) water, iii) sediment analysis, and iv) groundwater flows.

In order to capture seasonal variations in the Lake condition and algae/cyanobacteria occurrence, an additional round of sampling was undertaken in September 2018 (early spring) as part of this preliminary design development phase.

Stormwater could not be sampled in September because the pipes discharging stormwater to the Lake were completely submerged, due to high spring water levels. An additional stormwater sampling event was undertaken on the 6th June 2019 during one of the first major rain events of the year (note, the pipes were not submerged during the sampling). This enabled capturing of the 'first flush' event, which typically carries the highest nutrient concentrations.

Together with the historic data, information obtained during May 20128 sampling event was used to firstly identify the main sources of nutrients driving the blooms in the Lake and other characteristics of the Lake that may be contributing to the problem, and to inform the remediation concept design. Information gathered during May 2018 sampling event is included in the Concept Design report (Syrinx, June 2018).

Information obtained during this September 2018 and June 2019 sampling events were used to refine and further progress the development of the integrated remediation solution.

June 2019 sampling was done following the same approach as in the May 2018 sampling round. The detailed sampling methodology is outlined in the Remediation Solution Concept report (Syrinx, June 2018) and also included in APPENDIX 1 within this report.

Sample site locations are shown in Figure 1; monitored parameters measured are listed in Table 1.

The results of the September 2018 field assessment and June 2019 stormwater sampling are summarised in sections below, with an emphasis on key changes in water levels, water quality and sediment quality since the May 2018 field assessment.

2.2 WATER QUALITY (WQ)

The full data set obtained in the September 2018 lake surface water and groundwater sampling and June 2019 stormwater sampling are included in APPENDIX 2; this data is summarised and discussed in sections below.

Physico-chemical water quality parameters measured *in situ* are summarised in Table 2, nutrient data is summarised in Table 3, Figure 2 and Figure 3, while metals are summarised in Table 4 and Table 5.

The summarised sediment data is presented in Table 7 and Table 8. Note, SP4 and SP5 are surface water samples taken by SERCUL as part of the City's annual surface water quality sampling program and are included for comparison (see Figure 1 for sites).

The water quality results have been compared to the water quality trigger values (WQTVs) discussed in Concept Design report (Syrinx, 2018) which align with the guidelines adopted by SERCUL and the DWER. It should be noted that the ANZECC and ARMCANZ (2000) guidelines for aquatic ecosystems have been recently revised (in 2018) and are in the processed of being replaced by the ANZG (2018) guidelines. However, the trigger values used in this water quality assessment have not changed with this 2018 revision. Therefore, for consistency and ease of comparison with the historic data, the ANZECC (2000) guidelines have been used in this latest assessment. It should also be noted that iron was compared to the ANZECC (2000) recreational guideline due to the absence of an appropriate ecological guideline.

Average concentration values from monitoring events undertaken in 2018 (Table 6) were used for predictive modelling of system performance (see Section 5.2.4).

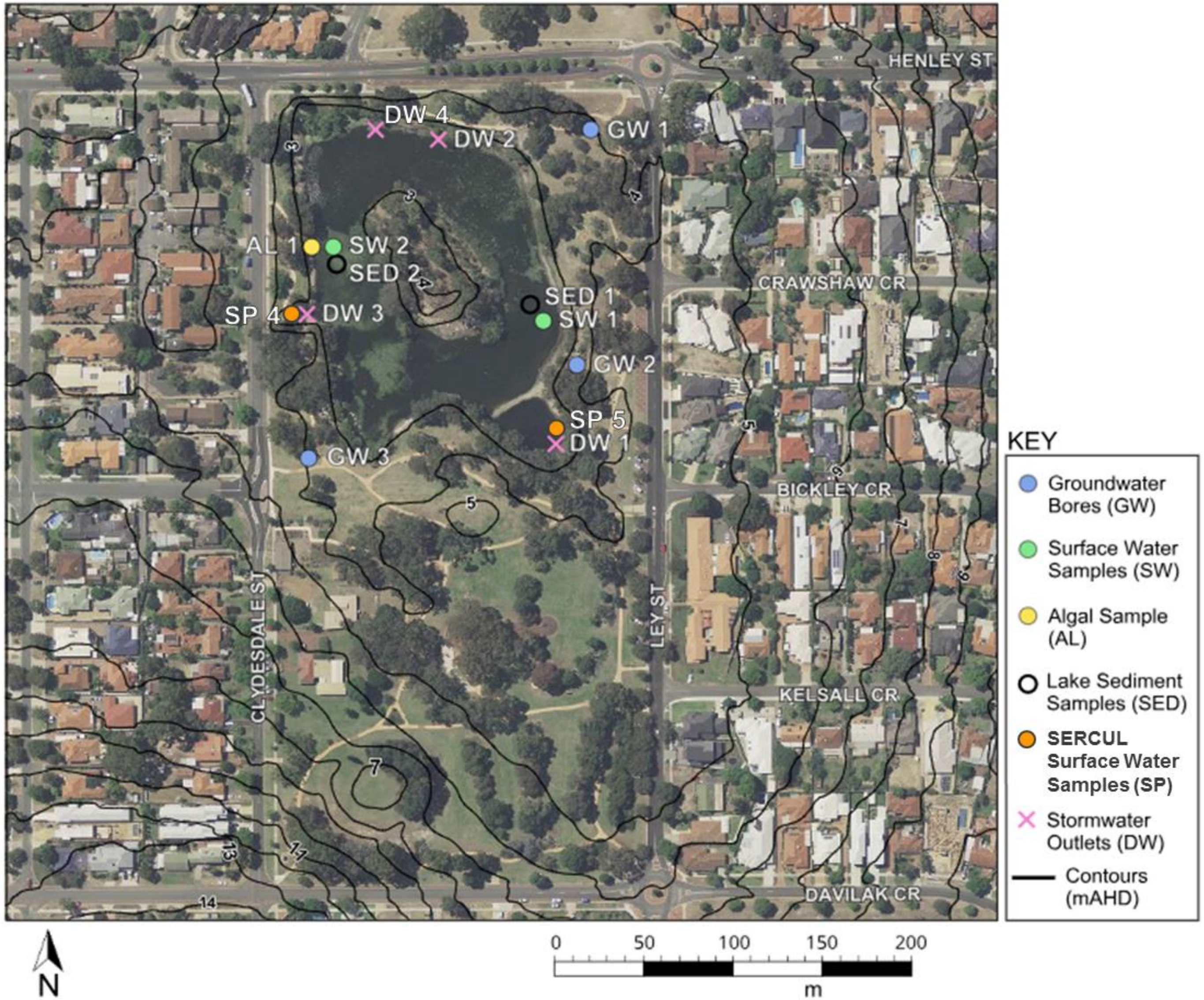


Figure 1 Syrinx sampling sites within Neil McDougall Park Lake.

Table 1 Water & sediment quality sampling programme, Neil McDougall Park Lake (2018 & 2019).

SAMPLE ID	LOCATION	SAMPLE DATE	TYPE OF SAMPLE	PARAMETERS TESTED
SW01	East side of the Lake	9/05/2018, 12/09/2018	Surface Water	**Field (*in situ*)-** pH, Dissolved Oxygen (DO), Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Oxidative Reductive Potential, Salinity and Secchi Depth. **Laboratory** Nutrients: Ammonia, Nitrate, Nitrite, NOx, Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), Total Phosphorus (TP), Reactive Phosphorus (SRP) Metals: Total and Soluble Aluminium (Al), Arsenic (As), Cadmium (Cd), Chromium (III) (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Zinc (Zn)
SW02	West side of the Lake	9/05/2018, 12/09/2018	Surface Water	
GW01	North-eastern bore	9/05/2018, 12/09/2018	Groundwater	
GW02	South-eastern bore	9/05/2018, 12/09/2018	Groundwater	
GW03	South-western bore	9/05/2018, 12/09/2018	Groundwater	
DW1	Bickley st inlet	25/05/2018, 6/06/2019	Storm Water	
DW2	Henley st inlet - east	25/05/2018, 6/06/2019	Storm Water	
DW3	Clydesdale st inlet	25/05/2018, 6/06/2019	Storm Water	
DW4	Henley st inlet - west	6/06/2019	Storm Water	
SED 1	East side of the Lake	9/05/2018, 12/09/2018	Lake Sediment	**Laboratory** Acid Sulfate Soil Potential (pHf, pHfox, reaction rate), Moisture Content (MC), Nutrients: Ammonia, Nitrate, Nitrite, Total Kjeldahl (TKN) Total Nitrogen (TN), Total Phosphorus (TP), Total Organic Carbon (TOC), Metals: Aluminium (Al), Arsenic (As), Cadmium (Cd), Chromium (III) (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Zinc (Zn)
SED 2	West side of the Lake	9/05/2018, 12/09/2018	Lake Sediment	

2.2.1 Lake Surface Water (SW)

In general, the quality of the Lake surface water (SW) was better in September 2018 compared to May 2018. As a result of winter rains, the electrical conductivity (EC) of the Lake water fell from approximately 590 µS/cm to 225 µS/cm between May and September (Table 2). This is considered fresh and within the range of WQTVs for EC.

The pH of the surface water was measured at 6.29 – 6.50. This is almost one pH unit lower than the pH recorded in May 2018 and just below the range of WQTVs for pH.

Dissolved oxygen (DO) concentrations measured *in situ* were lower than in May 2018 but still above those recommended for aquatic systems, with both sample sites exceeding 6 mg/L. The temperature of the SW was approximately 1 to 2ºC lower than in May and appeared to reflect the ambient temperature.

The nutrient concentrations in the Lake surface water were substantially lower compared to May 2018 but still exceeded the WQTV for total nitrogen (TN), ammonia, nitrite/nitrate (NOx), total phosphorous (TP), and SRP (a measure of orthophosphate) (Table 3). The observed reduction in nutrient concentrations from May to October sampling was significant; in October TN levels were ~70% lower and TP ~45% lower (Figure 2 and Figure 3).

The most significant change was observed for ammonium. In May NH_4-N levels were ~4 mg/L which represented ~70-90% of TN while in September the ammonium levels were about ten times lower (~0.45 mg/L) and accounted for ~30% of TN. This indicates that a significant portion of the observed TN reduction was caused by NH_4-N removal.

NO_x levels were similar to those recorded in the Lake in May 2018 and almost three times the recommended WQTV of 0.15 mg/L but only accounted for less than 4% of TN.

Despite dropping since May 2018, the TP levels in the SW of the Lake in September 2018 were nearly 20 times the WQTVs and the SRP was nearly 30 times. The most significant form of inorganic phosphorous is orthophosphate which is the form that is most readily taken up by plants and phytoplankton.

The metals in SW were generally lower than in May 2018 and all below the WQTVs. Metals in the Lake do not appear to be a factor that may inhibit the health of the aquatic biota.

In general, the quality of Lake surface water seems to have improved over the winter period. This is likely a consequence of the increased winter rainfall resulting in:

- Direct dilution of Lake surface water from rainfall.
- Progressive dilution of stormwater inputs throughout the winter period (as is characteristics of Perth winter stormwater).
- An increase in ammonia removal (nitrification) fostered by greater Lake water oxygenation in rain events (note, oxygen was not elevated during the September monitoring likely suggesting that it was spent in the process of ammonium biotransformation).
- Associated lower evaporation rates.

This winter pattern is similar to that observed in 2017 (Figure 2 and Figure 3).

Table 2. Physico-chemical WQ parameters measured *in situ*, Neil McDougall Lake (2018 & 2019)

Sample ID	Location Description	Sample Date	Temp. (°C)	pH (Field)	EC (µS/cm)	Salinity (ppt)	TDS (mg/L)	DO (mg/L)	DO (%)
ANZECC (2000)				*6.5-8.5*					*80-120%*
SW01	East side of Lake	9/05/2018	19.0	8.57	590.0	0.33	368.5	9.75	N/A
		12/09/2018	17.1	6.29	225.3	N/A	172.7	6.35	67.7
SW02	West side of Lake	9/05/2018	18.3	7.91	586.0	0.33	368.5	8.45	104.7
		12/09/2018	17.5	6.50	223.7	N/A	169.6	6.64	70.1
		average	**18.0**	**7.32**	**406.3**	**0.33**	**269.8**	**7.80**	**80.8**
		se	*0.4*	*0.55*	*104.9*	*0.00*	*57.0*	*0.80*	*12.0*
DW1	Bickley street inlet	25/05/2018	13.7	5.79	85.9	0.04	55.9	N/A	138.1
		6/06/2019	14.4	6.63	77.9	N/A	63.7	7.7	75.7
DW2	Henley street inlet	25/05/2018	14.6	7.07	121.4	0.06	78.7	N/A	91.0
		6/06/2019	13.1	7.21	48.9	N/A	41.0	9.5	90.2
DW3	Clydesdale street inlet	25/05/2018	14.9	6.72	117.5	0.06	76.1	N/A	67.8
		6/06/2019	13.9	6.99	78.4	N/A	64.4	7.4	71.3
DW4	Henley street inlet (west)	6/06/2019	13.7	7.02	121.9	N/A	100.8	7.9	75.2
		average	**14.0**	**6.78**	**93.1**	**0.05**	**68.6**	**-**	**87.0**
		se	*0.3*	*0.21*	*12.5*	*0.01*	*8.5*	*-*	*10.8*
GW01	North-eastern bore	9/05/2018	21.4	6.56	454.1	0.24	268.4	0.0	0.0
		12/09/2018	16.9	5.82	1110.0	0.66	858.0	0.5	5.2
GW02	South-eastern bore	9/05/2018	21.5	6.80	906.0	0.48	533.6	0.0	0.0
		12/09/2018	17.6	6.40	650.0	0.37	487.6	0.6	6.6
GW03	South-western bore	9/05/2018	19.6	6.52	442.2	0.24	271.7	N/A	0.0
		12/09/2018	15.6	5.42	373.0	0.22	295.8	1.9	19.2

Table 3. Nutrient data from lake surface water (SW), groundwater (GW) in May & September 2018 & stormwater (DW) in May 2018 and June 2019.

For Lake surface water and stormwater samples, cells shaded exceed the water quality trigger value (WQTV).

Sample ID	Sample Date	pH (Lab)	NH_4- N	Nitrite- N	Nitrate- N	NOx	TKN	Org. N (calc.)	% Org. N (calc.)	TN	TP	TN:TP molar ration	SRP	Particulate P (calc.)	% Particulate P (calc.)
		-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%	mg/L	mg/L		mg/L	mg/L	%
ANZECC (2000)		*6.5-8.5*	*0.04*			*0.15*				*1.2*	*0.065*		*0.04*		
SW01	5/09/18	8.06	3.77	0.18	0.25	0.43	5.20	1.43	26%	5.60	2.45	5.05	2.48	N/A	N/A
	9/12/18	7.32	0.45	0.07	0.35	0.42	1.20	0.75	47%	1.60	1.30	2.72	1.19	0.11	8%
SW02	9/05/18	8.02	3.95	0.14	0.19	0.33	4.90	0.95	18%	5.20	2.19	5.25	2.03	0.16	7%
	12/09/2018	7.40	0.48	0.08	0.36	0.44	1.30	0.82	48%	1.70	1.28	2.94	1.23	0.05	4%
SP4	26/07/18	-	1.50	-	-	0.38	3.50	2.00	51%	3.90	1.00	8.62	0.92	0.08	8%
	21/08/18	-	0.97	-	-	0.30	2.30	1.33	51%	2.60	1.20	4.79	1.00	0.2	17%
	27/09/18	-	0.09	-	-	0.09	1.80	1.71	90%	1.90	1.30	3.23	1.20	0.1	8%
	10/10/18	-	0.16	-	-	0.07	0.90	0.74	76%	0.97	1.30	1.65	1.10	0.2	15%
SP5	26/07/18	-	0.98	-	-	0.30	2.90	1.92	60%	3.20	0.74	9.56	0.68	0.06	8%
	21/08/18	-	0.89	-	-	0.30	1.70	0.81	41%	2.00	1.20	3.69	1.10	0.1	8%
	27/09/18	-	0.12	-	-	0.09	0.83	0.71	77%	0.92	1.10	1.85	1.10	0.00	0%
	10/10/18	-	0.18	-	-	0.08	1.10	0.92	84%	1.10	1.30	1.87	1.20	0.1	8%
	average	**7.70**	**1.13**	**0.12**	**0.29**	**0.27**	**2.30**	**1.17**	**56%**	**2.56**	**1.36**	**4.27**	**1.27**	**0.11**	**0.08**
	se	*0.20*	*0.39*	*0.03*	*0.04*	*0.04*	*0.44*	*0.14*	*0.1*	*0.46*	*0.14*	*0.74*	*0.14*	*0.02*	*0.01*
DW1	25/05/2018	6.98	0.04	0.01	0.05	0.06	1.30	1.26	90%	1.40	0.24	12.90	0.04	0.20	83%
	6/06/2019	6.61	0.10	0.02	0.07	0.09	1.30	1.20	86%	1.40	0.20	15.48	0.15	0.05	25%
DW2	25/05/2018	6.65	0.03	0.01	0.10	0.11	0.50	0.47	78%	0.60	0.16	8.29	0.08	0.08	50%
	6/06/2019	7.08	0.21	0.01	0.16	0.17	0.80	0.59	59%	1.00	0.13	17.01	0.12	0.01	8%
DW3	25/05/2018	6.77	0.04	<0.01	0.06	0.06	0.40	0.36	72%	0.50	0.10	11.06	0.08	0.02	20%
	6/06/2019	6.83	0.44	0.02	0.20	0.22	1.70	1.26	66%	1.90	0.23	18.27	0.20	0.03	13%
DW4	6/06/2019	7.06	0.40	0.02	0.12	0.14	1.30	0.90	64%	1.40	0.15	20.64	0.11	0.04	27%
	average	**6.85**	**0.18**	**0.01**	**0.11**	**0.12**	**1.04**	**0.86**	**74%**	**1.17**	**0.17**	**14.81**	**0.11**	**0.06**	**32%**
	se	*0.07*	*0.066*	*0.00*	*0.02*	*0.02*	*0.18*	*0.15*	*0.04*	*0.19*	*0.02*	*1.63*	*0.02*	*0.02*	*10%*
GW01	9/05/2018	6.92	0.24	<0.01	0.03	0.03	0.50	0.26	52%	0.5	0.060	18.4	0.06	0	0%
	12/09/2018	6.38	0.11	<0.01	<0.01	<0.01	2.70	2.59	96%	2.7	0.130	45.9	0.02	0.11	85%
GW02	9/05/2018	6.84	0.32	<0.01	<0.01	<0.01	1.10	0.78	71%	1.1	0.030	81.1	0.03	0	0%
	12/09/2018	7.09	0.30	<0.01	0.02	0.02	1.00	0.7	70%	1.0	0.070	31.6	0.01	0.06	86%
GW03	9/05/2018	6.80	0.13	<0.01	0.12	0.12	0.60	0.47	67%	0.7	0.450	3.4	0.48	N/A	N/A
	12/09/2018	6.46	0.04	<0.01	0.08	0.08	2.30	2.26	94%	2.4	0.450	11.8	0.25	0.2	44%

Table 4. Total metals measured in the Lake from lake surface water (SW), groundwater (GW) (2018) & stormwater (DW) (2018 and 2019). *For Lake surface water and stormwater samples, cells shaded exceed the water quality trigger value (WQTV)*

Sample ID	Sample Date	Al	As	Cd	Cr(III)	Cu	Fe	Pb	Hg	Ni	Se	Zn
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ANZECC (2000)		***0.055***	***0.024***	***0.0002***	***0.0033***	***0.0014***	***0.3***	***0.0034***	***0.0006***	***0.011***	***0.011***	***0.008***
SW01	9/05/2018	0.1	0.003	<0.0001	<0.001	0.001	0.08	0.004	<0.0001	<0.001	<0.01	<0.005
	12/09/2018	0.03	0.001	<0.0001	<0.001	<0.001	0.16	<0.001	<0.0001	<0.001	<0.01	<0.005
SW02	9/05/2018	0.1	0.003	<0.0001	<0.001	0.001	0.08	0.004	<0.0001	<0.001	<0.01	0.007
	12/09/2018	0.02	<0.001	<0.0001	<0.001	<0.001	0.14	<0.001	<0.0001	<0.001	<0.01	<0.005
SP4	26/07/2018	0.026	0.001	<0.0001	0.0003	0.0009	0.055	0.0007	<0.0001	<0.0005	<0.0002	<0.005
	21/08/2018	0.036	0.0009	<0.0001	0.0004	0.001	0.13	0.002	<0.0001	<0.0005	<0.0002	<0.005
SP5	26/07/2018	0.05	0.0008	<0.0001	0.0005	0.0018	0.064	0.0009	<0.0001	<0.0005	<0.0002	0.011
	21/08/2018	0.077	0.001	<0.0001	0.0006	0.0008	0.2	0.004	<0.0001	<0.0005	<0.0002	<0.005
	average	**0.05**	**0.001**	**<0.0001**	**0.0007**	**0.001**	**0.11**	**0.002**	**<0.0001**	**<0.001**	**<0.01**	**0.006**
	se	*0.01*	*0.0003*		*0.0001*	*0.0001*	*0.02*	*0.001*				*0.001*
DW1	25/05/2018	0.62	<0.001	<0.0001	0.003	0.024	0.77	0.032	<0.0001	0.002	<0.01	0.093
	6/06/2019	0.30	<0.001	<0.0001	<0.001	0.013	0.23	0.007	<0.0001	0.001	<0.01	0.046
DW2	25/05/2018	0.22	<0.001	<0.0001	0.001	0.013	0.26	0.003	<0.0001	<0.001	<0.01	0.033
	6/06/2019	0.20	<0.001	<0.0001	<0.001	0.008	0.16	0.002	<0.0001	<0.001	<0.01	0.019
DW3	25/05/2018	0.11	<0.001	<0.0001	<0.001	0.004	0.10	0.002	<0.0001	<0.001	<0.01	0.024
	6/06/2019	0.27	<0.001	<0.0001	<0.001	0.011	0.20	0.003	<0.0001	0.001	<0.01	0.039
DW4	6/06/2019	0.52	<0.001	<0.0001	0.002	0.017	0.62	0.006	<0.0001	0.001	<0.01	0.060
	average	**0.32**	**<0.001**	**<0.0001**	**0.001**	**0.013**	**0.33**	**0.008**	**<0.0001**	**0.001**	**<0.01**	**0.045**
	se	*0.07*			*0.0003*	*0.002*	*0.10*	*0.004*		*0.0001*		*0.010*
GW01	9/05/2018	0.89	0.005	<0.0001	0.004	<0.001	4.31	<0.001	<0.0001	<0.001	<0.01	0.006
	12/09/2018	1.05	0.008	0.0004	0.009	0.026	1.73	0.003	<0.0001	0.006	<0.01	1.52
GW02	9/05/2018	1.06	0.012	<0.0001	0.009	<0.001	3.92	<0.001	<0.0001	<0.001	<0.01	<0.005
	12/09/2018	1.12	0.032	<0.0001	0.007	<0.001	1.19	0.002	<0.0001	0.002	<0.01	<0.005
GW03	9/05/2018	0.22	0.004	<0.0001	0.002	<0.001	1.96	<0.001	<0.0001	<0.001	<0.01	0.013
	12/09/2018	1.75	0.003	0.0001	0.005	0.008	0.98	0.002	<0.0001	0.002	<0.01	0.034

Table 5. Soluble metals measured in the Lake from lake surface water (SW), groundwater (GW) & stormwater (DW).

Cells shaded exceed the water quality trigger value (WQTV).

Sample ID	Sample Date	Al	As	Cd	Cr(III)	Cu	Fe	Pb	Hg	Ni	Se	Zn
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ANZECC (2000)		*0.055*	*0.024*	*0.0002*	*0.0033*	*0.0014*	*0.3*	*0.0034*	*0.0006*	*0.011*	*0.011*	*0.008*
SW01	9/05/2018	0.03	0.003	<0.0001	<0.001	0.003	<0.05	0.002	<0.0001	<0.001	<0.01	<0.005
	12/09/2018	0.01	<0.001	<0.0001	<0.001	<0.001	0.09	<0.001	<0.0001	<0.001	<0.01	<0.005
SW02	9/05/2018	0.04	0.003	<0.0001	<0.001	<0.001	<0.05	0.002	<0.0001	<0.001	<0.01	<0.005
	12/09/2018	0.01	<0.001	<0.0001	<0.001	<0.001	0.08	<0.001	<0.0001	<0.001	<0.01	<0.005
SP4	26/07/2018	0.017	0.001	<0.0001	0.0003	0.0008	0.048	0.0006	<0.0001	<0.0005	<0.0002	0.009
	27/09/2018	0.016	0.0012	<0.0001	<0.001	0.0006	0.13	0.0006	0.00005	<0.005	<0.0002	0.008
	10/10/2018	0.015	0.0012	<0.0001	0.0007	0.0009	0.15	0.0006	<0.0001	<0.0005	<0.0002	0.008
SP5	26/07/2018	0.025	0.0008	<0.0001	0.0004	0.0014	0.046	0.0006	<0.0001	<0.0005	<0.0002	0.017
	27/09/2018	0.025	0.0015	<0.0001	<0.001	0.0006	0.23	0.0007	0.00006	<0.005	<0.0002	0.008
	10/10/2018	0.02	0.0014	<0.0001	0.0008	0.0005	0.21	0.0006	<0.0001	<0.0005	<0.0002	0.008
	average	**0.02**	**0.002**	**<0.0001**	**0.0008**	**0.001**	**0.11**	**0.001**	**<0.0001**	**<0.001**	**<0.01**	**0.008**
	se	*0.003*	*0.0003*		*0.0001*	*0.0002*	*0.02*	*0.0002*				*0.001*
DW1	25/05/2018	<0.01	<0.001	<0.0001	0.001	0.004	<0.05	<0.001	<0.0001	<0.001	<0.01	0.023
	6/06/2019	0.04	<0.001	<0.0001	<0.001	0.016	0.05	0.003	<0.0001	0.002	<0.01	0.051
DW2	25/05/2018	<0.01	<0.001	<0.0001	<0.001	0.006	<0.05	<0.001	<0.0001	<0.001	<0.01	0.022
	6/06/2019	0.02	<0.001	<0.0001	<0.001	0.007	<0.05	<0.001	<0.0001	<0.001	<0.01	0.013
DW3	25/05/2018	<0.01	<0.001	<0.0001	<0.001	0.002	<0.05	<0.001	<0.0001	<0.001	<0.01	0.021
	6/06/2019	0.02	<0.001	<0.0001	0.001	0.017	<0.05	0.002	<0.0001	0.002	<0.01	0.053
DW4	6/06/2019	0.03	<0.001	<0.0001	<0.001	0.008	0.09	<0.001	<0.0001	0.001	<0.01	0.032
	average	**0.02**	**<0.001**	**<0.0001**	**0.001**	**0.009**	**0.06**	**0.001**	**<0.0001**	**0.001**	**<0.01**	**0.031**
	se	*0.004*			*0.0000*	*0.003*	*0.006*	*0.0003*		*0.0002*		*0.006*
GW01	9/05/2018	0.03	0.005	<0.0001	0.002	<0.001	4.04	<0.001	<0.0001	<0.001	<0.01	<0.005
	12/09/2018	0.54	0.006	0.0004	0.007	0.015	1.17	0.002	<0.0001	0.006	<0.01	1.45
GW02	9/05/2018	0.07	0.012	<0.0001	0.006	<0.001	3.58	<0.001	<0.0001	<0.001	<0.01	<0.005
	12/09/2018	0.05	0.022	<0.0001	0.004	0.002	0.75	<0.001	<0.0001	0.002	<0.01	0.006
GW03	9/05/2018	0.04	0.004	<0.0001	0.001	<0.001	1.5	<0.001	<0.0001	<0.001	<0.01	0.008
	12/09/2018	0.38	0.002	<0.0001	0.002	0.005	0.43	<0.001	<0.0001	0.002	<0.01	0.029

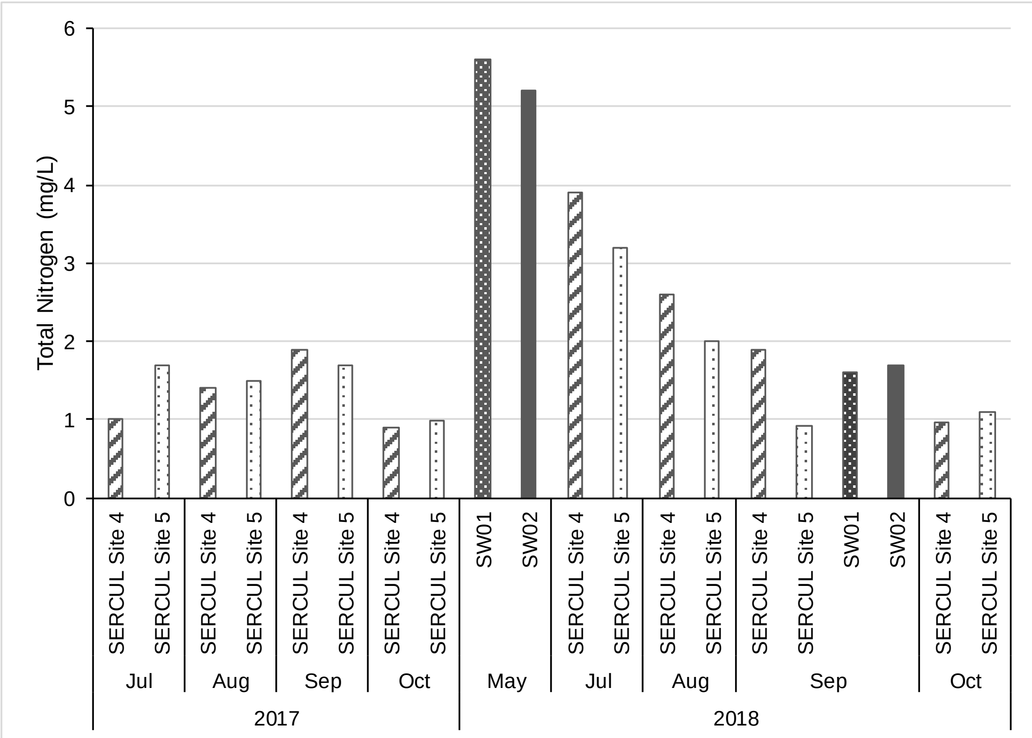


Figure 2 Total nitrogen in surface water, Neil McDougall Lake (2017 – 2018). Data from SERCUL (2017) (Site 4 & 5) and Syrinx (2018) (SW01 & SW02) sampling.

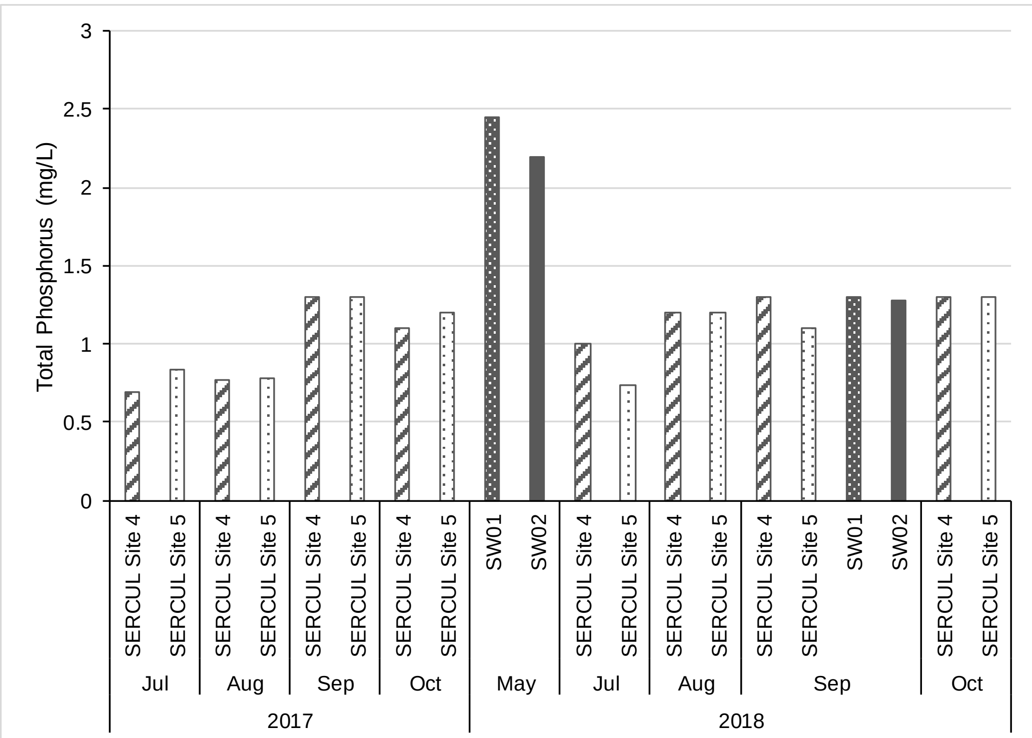


Figure 3 Total phosphorous in surface water, Neil McDougall Lake (2017 – 2018). Data from SERCUL (2017) (Site 4 & 5) and Syrinx (2018) (SW01 & SW02) sampling.

Table 6 Lake surface water quality 2018 values & stormwater quality 2018/2019 average values (se – standard error)

		Surface Water		Stormwater	
		average	*se*	***average***	*se*
Field Parameters					
pH	-	**7.32**	*0.55*	**6.78**	*0.21*
TDS	mg/L	**269.8**	*57.0*	**68.6**	*8.5*
DO	(%)	**80.8**	*12.0*	**87.0**	*10.8*
Nutrients					
NH_4- N	mg/L	**1.13**	*0.39*	**0.18**	*0.07*
NOx	mg/L	**0.27**	*0.04*	**0.12**	*0.02*
TN	mg/L	**2.56**	*0.46*	**1.17**	*0.19*
TP	mg/L	**1.36**	*0.14*	**0.17**	*0.02*
Total Metals					
Al	mg/L	**0.05**	*0.01*	**0.32**	*0.07*
Cu	mg/L	**0.001**	*0.0001*	**0.013**	*0.0024*
Fe	mg/L	**0.11**	*0.02*	**0.33**	*0.10*
Pb	mg/L	**0.002**	*0.001*	**0.008**	*0.004*
Zn	mg/L	**0.006**	*0.001*	**0.045**	*0.010*
Soluble Metals					
Cu	mg/L	**0.001**	*0.0002*	**0.009**	*0.003*
Zn	mg/L	**0.008**	*0.001*	**0.031**	*0.006*

2.2.2 Groundwater (GW)

Groundwater quality showed an opposite trend to surface water quality between the autumn and spring sampling event.

The GW was more saline in September 2018 compared to May 2018 (Table 2) but was still classified as fresh to marginal (below 1000 mg/L TDS). Concentrations of all other GW field parameters were similar to those measured May 2018. The field pH was recorded as slightly acidic at all sites (< 7). Laboratory measurements on the GW samples showed slightly higher readings but the values were still below 7. DO levels were either zero or very close to zero. The temperature across the sites was consistent with little variation recorded between wells.

Total Nitrogen TN values were approximately five times higher in GW1 and GW3 than in May 2018 and exceeded the WQTV by more than four times. The ammonia levels in the GW were slightly lower than in May 2018 but still exceeded the WQTVs guidelines with GW03 having the lowest levels and GW02 the highest (Table 3).

The most elevated TP concentrations were observed in the downgradient bore (GW3) which had TP values almost seven times above the WQTV). This was similar to the May 2018 results. However, TP was slightly higher in GW1 and GW2 compared to the May sampling with concentrations slightly above WQTV.

The concentration of zinc was 250 times higher in GW1 than in May 2018 and exceeded the WQTV by almost 200 times. The concentration of soluble aluminium in all bores was also elevated compared to May, particularly in GW1 and GW3 where concentrations were more than seven times above the

WQTV. Arsenic concentrations were slightly higher than in May with total values just above the WQTV in GW2. Cadmium concentrations were also higher in GW1 and just exceeded the WQTV.

One explanation for this change in GW quality is that, while the winter rains had a dilution effect on the Lake surface water, on the other hand it caused great leaching of nutrients, salts and soluble metals from the surrounding soil (park, lawns and gardens) to the groundwater.

2.2.3 Stormwater (DW)

Stormwater could not be sampled in September because the pipes discharging stormwater to the lake were completely submerged due to the high water levels. The pipes were still submerged during a site inspection almost two months later on 8th of November 2018. Hence, an additional stormwater sampling event was undertaken on the 6th June 2019 when the pipes were no longer submerged. This was the first major rainfall events of the year and the samples were collected when the drains first began flowing, therefore sampling is considered to capture a 'first flush' event, which typically carries the highest nutrient concentrations.

In general, and typical of urban settings, stormwater entering the lake system was found to be nutrient enriched and containing elevated concentrations of metals commonly present in fertilisers (Zn, Cu, Pb).

In general, the quality of the stormwater was worse in June 2019 compared to May 2018. This is likely because the sampling event occurred closer to the start of the rainfall event and after a longer dry period therefore was more representative of the first-flush event. DW3 had the highest nutrient levels in June 2019 but in May 2018 DW1 had the highest nutrient levels.

The pH of the stormwater was measured at 6.63 – 7.21 in June 2109. This was approximately half a pH unit higher and closer to neutral than the pH recorded in May 2018 and within the range of WQTVs for pH. The stormwater from DW1 had the lowest pH readings while DW2 had the highest value which was consistent with the May 2018 results.

The electrical conductivity (EC) of the stormwater was very fresh in June 2019 (48.9 µS/cm to 121.9 µS/cm) and the values recorded in DW1 to DW3 were approximately similar to those recorded in May 2018. However, the stormwater from DW2 had the lowest salinity despite being the most saline in May 2018. Stormwater from DW4, which was not sampled in May 2018, had the highest salinity.

Total Phosphorus TP values were more than two times higher in DW3 in June 2019 compared to May 2018 and exceeded the WQTV by more than 3.5 times. TP values were slightly lower in DW1 and DW2 compared to May 2018 and exceeded the WQTV by more than two times. The TP concentration in DW4 was similar to DW2.

Soluble Reactive Phosphorus SRP concentrations showed a similar trend to the TP values however SRP values were almost four times higher in DW1 compared to May 2018 and exceed the WQTV by almost four times. SRP values were more than two times higher in DW3 compared to May 2018 and exceeded the WQTV by five times. SRP values were slightly higher in DW2 compared to May 2018 and exceeded the WQTV by more three times. The TP concentration in DW4 was similar to DW2.

Total Nitrogen TN values were almost four times higher in DW3 in June 2019 compared to May 2018 and exceeded the WQTV by around 1.5 times. TN was almost two times higher in DW2 compared to in May 2018 but the value was still below the WQTV. TN in DW1 was the same as in May 2018 and only just exceeded the WQTV. The TP concentration in DW4 was similar to DW1.

Ammoniacal nitrogen NH_4-N was much higher in June 2019 compared to May 2018 and exceeded the WQTV in samples from all four drains. NH_4-N was highest in DW3 and was eleven times higher compared to May 2018 and exceeded the WQTV by 11 times. Nitrate-nitrite nitrogen (NO_x) was also higher in June 2019 compared to May 2018.

Soluble copper and soluble zinc exceeded the WQTV in all four of the drains and were generally higher in sample from June 2019 compared to May 2019. DW3 had the highest concentration of both soluble metals. The concentration of all other soluble metals in stormwater were below the trigger values.

2.3 SEDIMENT QUALITY

The sediment (SED) quality results are compared to the sediment quality trigger values (SQTVs) discussed in the Syrinx (2018) report. The SQTVs used are the default guidelines values from the ANZECC (2000) guidelines. These are the same as the Interim Sediment Quality Guidelines under DWER Contaminated Site Guidelines. The results of the pH(Fox) tests were assessed against assessment criteria for the identification of acid sulfate soils (DER, 2015).

The sediment sample collected on the eastern side of the Lake (SED1) had lower concentrations of nutrients in September, however the soil was of a sandier texture, so the change is more likely to be due to spatial variation in soils rather than a temporal change.

2.3.1 Nutrients

Although nutrients were slightly lower at both sites, levels were still relatively high at SED2 and nutrient composition was relatively similar, with almost all of the nitrogen in organic form (Table 7). The high organic N is likely caused by the decaying mass of dead algae, *Lemna* and cyanobacteria mats.

Table 7. Nutrient analyses of Neil McDougall Park Lake sediment (9/5/2018).

Sample ID	Sample Date	Ammonia as N	Nitrite as N (Sol.)	Nitrite + Nitrate as N (Sol.)	TKN	TN	TP	TOC
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
SED 1	9/05/2018	240	0.3	0.3	11 800	11 800	1040	12.8
	12/09/2018	<20	0.1	0.2	1620	1620	195	3.1
SED 2	9/05/2018	220	0.4	0.4	11 500	11 500	1250	14.6
	12/09/2018	80	<0.2	<0.2	8840	8840	1090	8.46

Note: The conditions within the lake that foster the release of nutrients from the sediment are more important than nutrient concentrations, as high fluxes stimulate phytoplankton and macrophyte blooms. Therefore, no general sediment quality trigger values (SQTVs) for nutrients have been set.

2.3.2 Metals

Metal concentrations were lower in SED1 compared to May 2018 but similar at SED2. Cd was slightly lower but As, Pb, Zn and Hg exceeded the SQTVs at SED2. Pb was particularly high (more than ten times) while As, Hg and Zn were just above the sediment quality trigger values (SQTVs) (Table 8).

When all sediments were rapidly oxidised during the pH (Fox) test, the resultant pH(Fox) values were highly acidic, (pH 3) and evoked slight to moderate reactions (Table 8). The pH change and reaction strength were not as extreme as in May 2018 however the results were still highly indicative of potential acid sulfate material as described in the *Identification and investigation of acid sulfate soils and acidic landscapes* by DER (2015).

Table 8. Sediment metal analyses, Neil McDougall Lake (May and September 2018). Shaded cells indicate exceedances for trigger values. Orange = ANZECC (2000), blue = DER (2015). (ASS = acid sulfate soils).

Sample ID	Sample Date	pH (Field)	pH (Fox)	pH(f)-pH(fox)	Reaction Rate	MC	Al	As	Cd	Cr	Cu	Fe	Pb	Ni	Se	Zn	Hg
		-	-	-	Reaction Unit	%	mg/kg										
ANZECC (2000)								20	1.5	80	65		50	21		200	0.15
DER (2015) - ASS		≤ 4	< 3	> 2													
SED 1	9/05/2018	6.9	1.6	5.3	3 - Strong	87.1	10,300	16	2	36	51	12 300	540	10	<5	302	<0.1
	12/09/2018	6.7	2.4	4.3	1 - Slight	49.8	1,420	<5	<1	4	5	1180	35	<2	<5	27	<0.1
SED 2	9/05/2018	7.1	1.6	5.5	3 - Strong	87.4	11,900	22	2	49	53	16 700	642	11	<5	321	<0.1
	12/09/2018	7.1	1.5	5.6	2 - Moderate	86.7	15,100	22	1	55	55	16900	672	10	<5	290	0.2

2.4 LEMNA & PHYTOPLANKTON

In September 2018 the *Lemna* mat that was removed the previous spring was observed to be growing back and one month later in October it had almost covered the entire Lake.

The two phytoplankton samples collected from SW01 and SW02 by Syrinx in September 2018 did not contain any cyanobacteria (Table 9) however the samples were generally low in diversity and abundance. These results are similar to the May 2018 results; however, the dominant species had changed from *Scenedesmus* species to large colonies of *Volvox*.

Table 9. Phytoplankton identified from sites SW01 and SW02, Neil McDougall Lake (September 2018). Enumeration in cells/mL.

Group	Taxon	SW01	SW02
		cells/mL	cells/mL
Bacillariophyta	*Cyclotella*	7	
	Fragillaria		128
	Gomphonema	7	7
	Navicula	7	20
	Synedra		
Cholorophyta	*Crucigenia*	13	
	Monoraphidium		
	Oocystis		
	Pediastrum	54	
	Scenedesmus	27	27
	Volvox		1330
	Cryptomonas		20
	Cryptophyte	88	61
Euglenophyta	*Euglena*	13	40

2.5 LAKE WATER AND GROUNDWATER LEVELS

The lake water level observed during the September field assessment was approximately 1 m higher than in May 2018. The water depth monitoring gauge was completely submerged and the flooded perimeter extended to some of the park benches and signs, indicating this was likely a wet year.

The depth to GW measured in the GW monitoring wells installed to the north-east (GW1) and east of the lake (GW2) was approximately 0.67 m bgl. The depth to GW in the monitoring well to the south west of the lake (GW3) was 1.10 m bgl (Table 10).

Table 10. Groundwater (GW) and lake water (SW) levels, Neil McDougall Lake (May 18). SWL = standing water level

Site	Top of PVC Pipe/ Wooden Stake Elevation (m AHD)	Date	Depth to SWL (m bToC/ToS)	SWL (m AHD)	Ground Elevation (m AHD)	Depth to SWL (m bgl)
GW1	3.755	5/9/2018	1.568	2.187	3.865	1.678
		9/12/2018	0.562	3.193		0.672
GW2	3.662	5/9/2018	1.548	2.114	3.787	1.673
		9/12/2018	0.540	3.122		0.665
GW3	3.884	5/9/2018	1.993	1.891	3.994	2.103
		9/12/2018	0.990	2.894		1.100
SW1	2.675	5/9/2018	0.570	2.105	-	-
		9/12/2018	stake submerged	-	-	-

3.0 EVOLVING THE CONCEPT

An early dialogue session was held with the City to progress the Neil McDougall Integrated Remediation solution from concept to preliminary design. This session was critical to ensure the final design fully meets the various project criteria and specific City requirements.

The first step in this engagement process was a workshop meeting which was held with the broader City project team early in the preliminary design process (27th of September 2018). The objectives of this meeting were to:

- Present the key elements of the Concept Design and explain the design principles;
- Provide a summary and discuss the proposed changes to the concept design;
- Incorporate and address all of the requirements and concerns of the City's team in the design process, and
- Discuss and progress an engagement process with the local community.

3.1 PROGRESSING THE CONCEPT DESIGN – INITIAL CHANGES

At the concept design stage, detailed survey data and drainage plans were unavailable.

Survey data for the project site was received from the City on 21st of September, and based on this data and additional site-specific information, Syrinx made several changes to the initial concept design. These changes included:

1. ***Inclusion of DW4 drain into the remediation solution.***

   A key new piece of information was understanding that the DW4 inlet along Henley Street (Figure 1) does discharge to the Lake. During the initial site investigations undertaken by Syrinx in May 2018, no stormwater discharge from DW4 was observed (it was not flowing during a rainfall event on 25th May 2018). Based on this it was originally concluded that this drain might have been decommissioned, and as such, it was not included in the Concept Design. Subsequent site visits and survey data revealed that this drain is not decommissioned; rather the survey revealed that DW4 is connected to an extensive network of drainage pipes towards the north (catchment ~ 21.5 ha) and was observed to be flowing during a rain event on the 6th June 2019.

2. ***Expanding the integrated remediation solution beyond the immediate Neil McDougall Park and using the Coolidge Reserve located north of the project site for locating specific treatment initiatives.***

   Following completion of the Concept Design, Syrinx met with the Client Project Manager (Yulia Volobueva) at the project site to discuss the proposed design and ways to progress the project. During this meeting Syrinx expressed concerns that the limited available area around the Lake could pose a challenge for the system design and its treatment efficiency, especially given the large volumes of stormwater being discharged to the Lake. One potential option for overcoming this space constraint that was discussed during this meeting was utilising the Coolidge Reserve to place treatment elements that would provide (pre)treatment of catchment D inflows (DW4, Figure 5), as described above. Alternatively, this reserve was also considered as a potential location for the main treatment wetland system.

The key benefits of utilising Coolidge Reserve for catchment D treatment include:

- The strategic location and existing ground levels of Coolidge Reserve serve as an ideal interception point for the existing drainage pipe under Baldwin Street. This pipe is connected to the broader upstream area of Catchment D. The Reserve also has sufficient area to provide effective stormwater treatment, and the existing topological surface levels already provide a natural hydraulic gradient.
- The stormwater from Manhole MH 01 with invert levels 5.73 mAHD can be intercepted and diverted to the park area with a designed invert level of 5.6 mAHD at its discharge point. Minimal earthworks will be needed.
- Leveraging on the existing drainage infrastructure, the treatment train's discharge point can at manhole MH 02 located south-west of the Park reducing the need for any additional drainage pipes or pits.

There are also limited amenities and infrastructure within Coolidge Reserve. It was understood from the City that the Reserve is not highly utilised, and is mainly used by local residents for dog walking. The reserve is not considered to have high conservation values, making it even more ideal for alteration and stormwater management purposes.

Figure 4 Proposed treatment train footprint at Coolidge Reserve

3. Reliance on roadside swales to provide treatment of inflow from DW1.

This design alternative proposed the use of road-side swales between the existing footpath and road kerb (~ 1.5 m wide and 0.2 m deep), to serve the adjacent road catchment. It includes modification of the kerbs/side entry pits to enable run-off directly from roads to be treated and then allowed to discharge through the existing drainage network. The swales would be densely vegetated with native rushes and sedges. The proposed area would be sufficient to ensure an adequate removal of sediments and achieve some nutrient stripping capabilities.

4. Minor changes to location of pre-treatment & treatment system components.

Detailed information regarding the above proposed changes to the Concept Design that were presented to the City for consideration are included in APPENDIX 3.

3.2 CITY'S RESPONSES TO PROPOSED DESIGN CHANGES

In addition to the presentation held on 21st of September, the proposed changes to the system design were also submitted to the City in a written form in order to obtain an official, agreed response from the entire broader City project group (APPENDIX 3). The City's position regarding the proposed changes can be summarised as follows:

- <u>Coolidge Reserve cannot</u> be included in the integrated treatment remediation solution. The system must be located within the available area in the Neil McDougall Park.
- In principle, the City does not have any issues with using the swales as treatment elements However, the following must be considered:
  - The swales are not to impact too much on access to the footpath.
  - Currently there is roadside parking and a bus stop along the southern side of Henley Street, and these must not be removed if swales are to be implemented.
  - The sections of the roadside kerb can be removed to facilitate discharge of road runoff into the provided swale, as long as it does not interfere with parking access etc.
  - The existing roadside gullies can be modified to facilitate discharge of treated stormwater from the swale.
- The City does not intend to address the upstream catchment as part of this project.

The City's response to the proposed design changes is also included in APPENDIX 3.

All of these inputs and requirements were considered and addressed in furthering the preliminary system design, as presented in the following Part 2 of this report.

PART 2: SYSTEM DESIGN

4.0 KEY DESIGN PRINCIPLES & INITIATIVES

4.1 DESIGN PRINCIPLES & REQUIREMENTS

As part of the concept design process a range of design principles were developed that best respond to the overall project aims and site context. These were used to further the system design to this preliminary stage and include:

- Capacity to provide an efficient, long term control of cyanobacteria and suppress visually persistent blooms.
- Capacity to efficiently deal with the key contaminants of concern (ammonia, total nitrogen, nitrate, phosphorous) in both stormwater and lake water.
- Continuous improvement in the overall lake water quality and ecological health.
- Low potential for by-products generation and potential contamination (including release of cyanotoxins).
- Capacity to efficiently deal with variable flows and pollutant concentrations (especially variable concentrations of nutrients in stromwater).
- Relative simplicity of operation and maintenance.
- Provision of opportunity for improvement of biodiversity and amenity values.

Field investigations undertaken by Syrinx on this project followed by the identification and characterisation of key factors and processes causing the issue of cyanobacteria and *Lemna*, indicate that the long-term remediation of Neil McDougall Lake requires an integrated approach. This should combine initiatives for:

i) Pre-treatment of all input water (stormwater, direct runoff).

ii) Improvement of in-lake recirculation/agitation of lake water.

iii) Modifications of the Lake to improve water quality and improve nutrient cycling and other treatment functions.

In addition to these, broader catchment initiatives that minimise the discharge of untreated stormwater to the Lake are also needed to support the success of this end of catchment remedial solution.

4.2 KEY DESIGN INITIATIVES

To address the key project principles and requirements, the following initiatives were developed as a basis of the integrated remedial solution design:

- **Sedimentation and gross pollutant** drop-out zones at stormwater inlet points.
- **Recirculation System** to improve in-lake circulation and enable extraction and treatment of Lake water.
- **Constructed Wetland** for the treatment of stormwater and continuous treatment of Lake water.
- **Restoration of Fringing and-In-lake Emergent Vegetation**

5.0 SYSTEM DESCRIPTION

The proposed integrated remediation system consists of treatment components designed to address the continuous inputs of polluted water to the Lake via stormwater, in-lake water quality issues, and poor water circulation.

In terms of stormwater inputs, there are four separate inlet points (DW, Figure 1). The proposed system allows for at least some level of pre-treatment of each of these flows. This is schematically presented in Figure 5 and Figure 6.

Individual treatment components are integrated within a wetland system which provides continuous treatment of Lake water aimed at progressive improvements of Lake’s water quality, while also enhancing the amenity and biodiversity values of the area.

A brief description of the proposed remediation system elements is provided in individual sections below. Key characteristics of individual treatment component are also summarised in Table 11.

5.1 CATCHMENT INPUTS

5.1.1 Catchments A & D

Treatment of Catchment D is constrained by the current drainage invert levels and the available space. The discharge pipe from Catchment D enters the Lake well below surface level, which makes daylighting of this pipe extremely complex within the boundary of the Neil McDougall Park. Daylighting of this pipe further upstream (assuming Coolidge Reserve is not available) would result in the creation of deep embankments in order to meet the invert of the drainage pipe, hence this approach would have little treatment benefit because most of the space would be required to form the embankments.

As such, the provision of a sedimentation basin (SDB3) at the discharge of DW1 within the footprint of the Neil McDougall Lake serves as the only feasible compromise solution.

Catchment A is also highly constrained with underground services, limited available area and again deep drain invert levels. To resolve this, runoff from this catchment will be diverted to a SDB1 (sedimentation basin) and vegetated filtration wetland (FW1) for sedimentation.

As such, SDB1 and FW1 will be used to treat stormwater runoff from both Catchment A and D.

5.1.2 Catchment C

The discharge pipe invert of 1.88 mAHD at outlet DW 2 is often submerged and influenced by backflow from the lake as the water levels frequently rise to levels above 2.5 mAHD. This will result in short-circuiting of the treatment system and compromises treatment efficiency if the treatment system was implemented at the pipe invert level. Raising the treatment system above the water level of 2.5 mAHD to improve this would require extensive earthworks and is not seen as a cost-beneficial solution considering that the treatment system would still continue to be affected by backflow during higher storm events.

As such, a similar approach to treating Catchment A and D is used for catchment C, which includes a sedimentation treatment basin (SDB2) and vegetated filtration wetland (FW2) for enhanced sedimentation and particle capture.

Based on the existing topography and configuration of the Lake, the available area allows construction of a larger sedimentation basin, thus sediment dropout performance of SDB2 is expected to be better than in SDB1.

5.1.3 Catchment B

Catchment B has the largest available area for treatment and is the least constrained catchment (Figure 5).

First flush and low storm event runoff volumes will be intercepted through the manhole via an orifice pipe along Clydesdale Street with invert level ~ 3.2 mAHD. This stormwater will discharge into sedimentation basin (SDB3). The remaining overflows will bypass the treatment system and continue its primary drainage route toward point DW3, discharging into the Lake. Water will pass from the sedimentation basin into the main treatment wetland (described below).

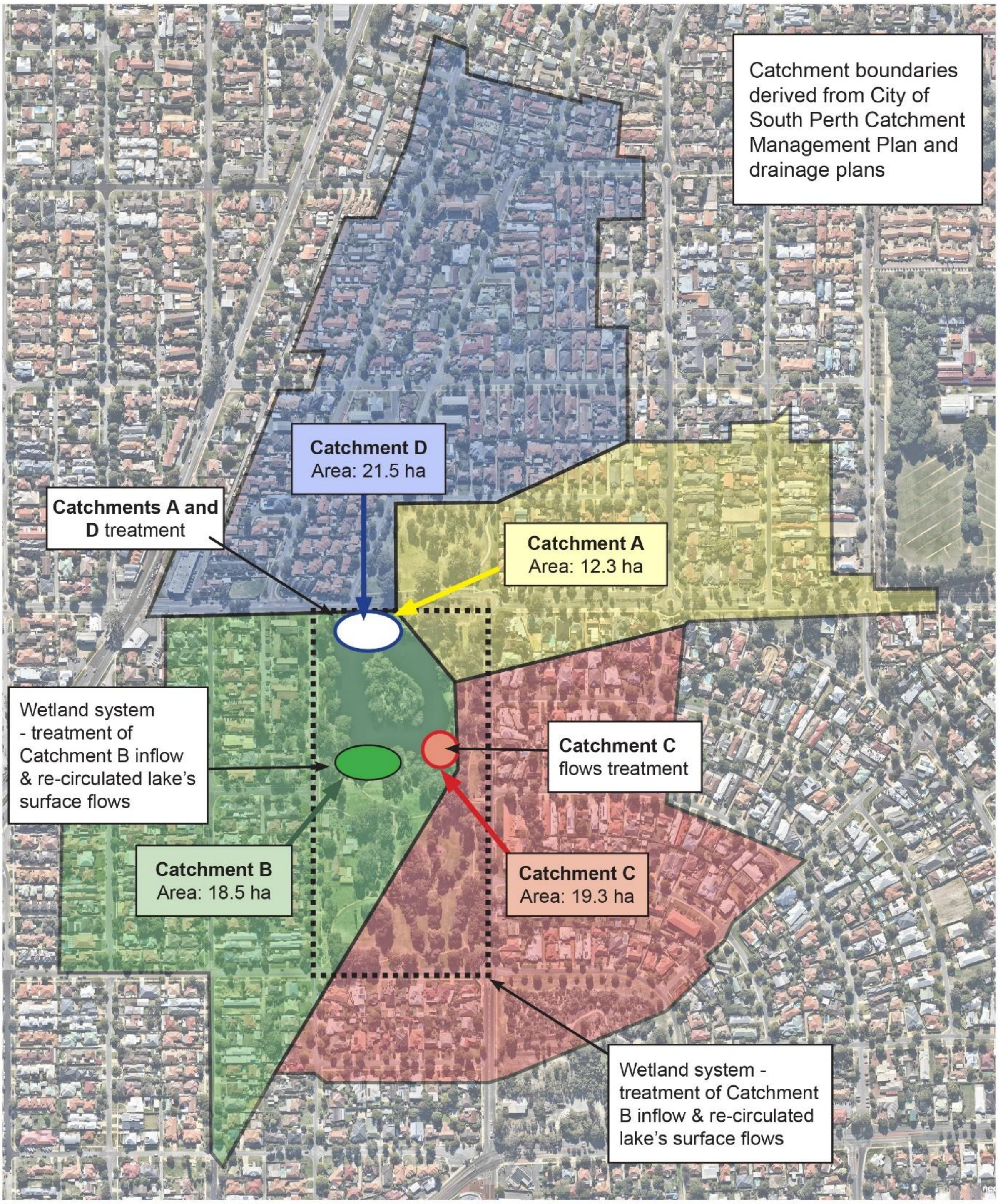
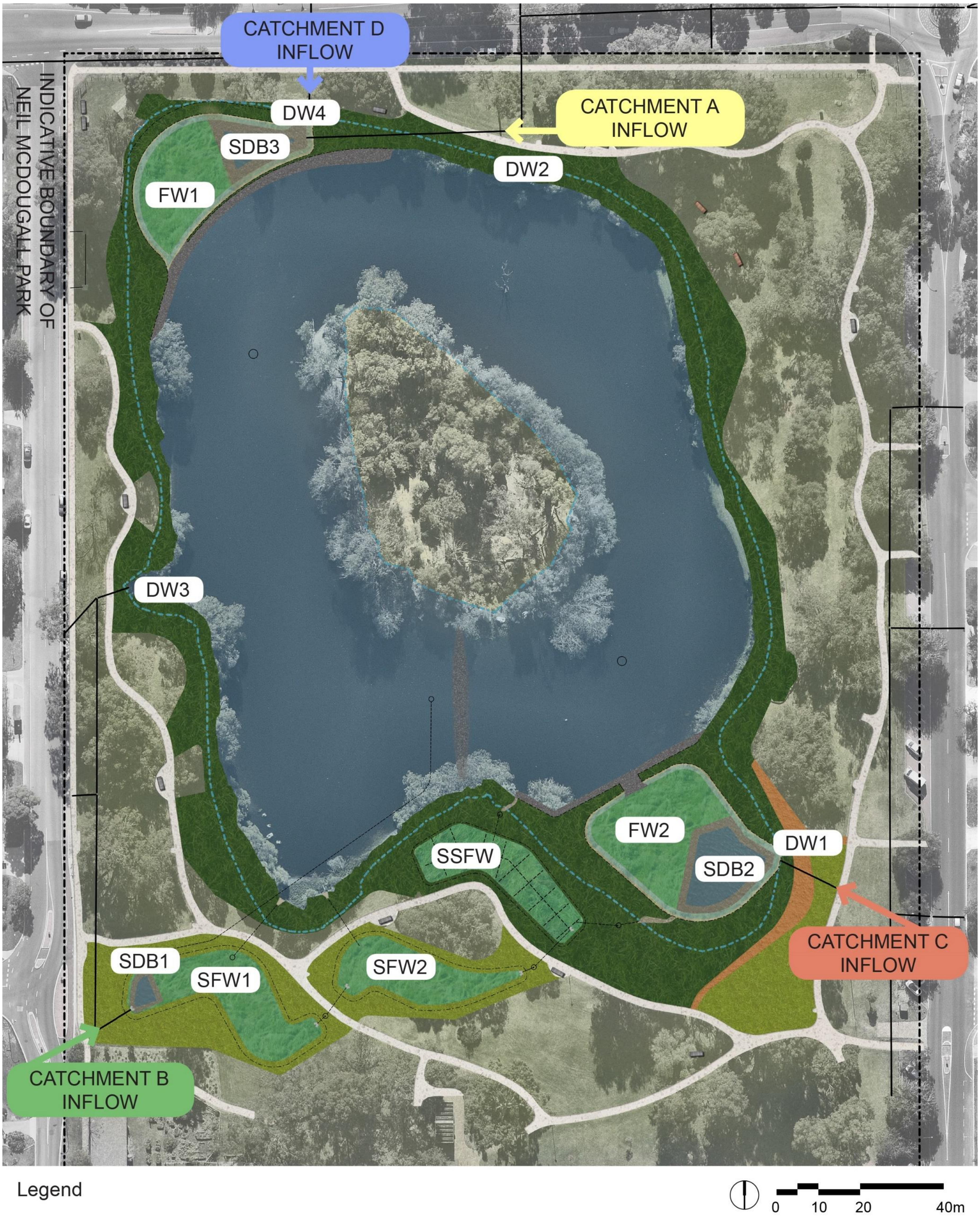


Figure 5 Proposed treatment approach – individual inputs & treatment elements



Legend

SDB - Sedimentation basin
SFW - Surface flow wetland
DW - Stormwater drain
FW - Filtration wetland
SSFW - Sub-surface flow wetland

Figure 6. Location and schematic of the proposed treatment elements

5.2 MAIN TREATMENT WETLAND

5.2.1 General Description

This wetland treatment system will serve as the Lake's primary treatment system. The system is intended to operate as a controlled permanent flow system, fed both by lake water via a pumped system in no rain events and by stormwater when flowing.

The wetland system is designed to provide filtration, sedimentation and biological removal of the following:

- ***Stormwater from Catchment B*** - during storm events.
- ***Lake water*** **-** continuous inflow (via the recirculation pipe and pump system) for most of the year (outside of storm events).
  This wetland system will serve as a 'kidney' enabling continuous filtration and treatment of lake water and ensuring progressive water quality improvements.

The proposed treatment wetland system will be a combination of surface and subsurface elements to maximise the removal of nitrogen (from organic N to N_2) and provide phosphorus uptake and retention. The system will be ~ 1300 m^2 (Table 11) and will be comprised of two consecutive treatment stages as follows:

1. ***Vegetated surface flow wetland (SFW)***
2. ***Vegetated subsurface flow wetland (SSFW)***

The proposed wetland treatment system is to be located adjacent to the Lake on the south-west side of the Park (Figure 6). The surface flow wetlands will serve a general water treatment function that includes sediment removal and nutrient transformation, while the subsurface flow wetland provides anaerobic conditions for denitrification processes.

Table 11. Key characteristics of the individual system components

	NEIL MCDOUGALL LAKE INTEGRATED REMEDIATION SYSTEM							
	CATCHMENT A&D PRETREATMENT		CATCHMENT C PRETREATMENT		MAIN TREATMENT WETLAND			
	Sedimentation Basin	Filtration Wetland	Sedimentation Basin	Filtration Wetland	Sedimentation basin	Surface Flow Wetland		Subsurface Flow Wetland
	SDB 3	FW 1	SDB 2	FW 2	SDB 1	SFW 1	SFW 2	SSFW1
Area (m²) (operating water level)	275	650	406	518	67	481	386	441
Total Depth (substrate & water) (m)	1.2	0.92	1.2	0.96	1.1	0.3 - 0.5	0.3 - 0.5	0.6 - 0.7
Substrate Type	Existing soils	Reinstated existing soils	Existing soils	Reinstated existing soils	Clay	Reinstated existing soils over 100mm clay	Reinstated existing soils over 100mm clay	Local stone over 100mm clay
Substrate depth (inc. liner) (m)	n/a	Varies subject to existing level (nom. 0.6m). FL to be equal to catchment inlet IL	n/a	varies subject to existing level (nom. 0.6m). FL to be equal to catchment inlet IL	0.1	0.4	0.4	0.7-0.8
Operating volumetric capacity (kL)	206	194	381	170	46	110 - 173	114 - 154	260*
Operating water depth (above substrate - est. high lake level) (m)	2.1	1.22	2.1	1.26	1	0.2-0.3	0.3-0.4	0.1

* denotes media volume (m³)

5.2.2 Vegetated Surface Flow Wetland (SFW)

Objective: Ammonia & total nitrogen removal, phosphorous removal

The SFW is a predominantly aerated system to promote ammonia removal, with anaerobic processes required for denitrification accommodated within the root zone of the vegetated filter zones.

This wetland consists of two cells in series: SFW1 and SFW2. Both of these are to be clay lined and planted with various emergent wetland plants with high root density and rooting depth. A diversity of wetland vegetation types provides high adaptability of the system to changing season and water quality conditions. The submerged portion of the plant stems, roots and rhizomes act as a substrate for bacteria and other microbes, which provides most of the water treatment functions.

The SFW will receive flows from the Lake's recirculation system (Section 6.0) as well as from Catchment B inflows during storm events.

Flows from the Lake will be pumped at a constant or near constant rate, and stormwater flows (Catchment B) will be gravity fed.

While passing through the surface flow component, key water pollutants (nitrogen, phosphorus, TSS) will be progressively removed from the effluent by physico-chemical processes and microbial action (nitrification / denitrification). A significant portion of nutrients are removed by sedimentation. The remaining suspended and soluble organic material is degraded by microorganisms attached to plant stems and roots.

General Specifications

Area: ~ 870 m^2

Depth: 0.3 to 0.5 m in vegetated areas; average depth 0.4 m

Operating volumetric capacity: ~240-350 m^3.

Finished Surface: 1.5mm clay liner, 300mm topsoil over liner in vegetated areas.

5.2.3 Vegetated subsurface flow wetland (SSFW)

Objective: Removal of nitrate & total nitrogen, further removal of metals, TSS.

The SSF wetland will be planted with various emergent macrophytes with high root density and rooting depth to maximise the extent of microbial attachment sites, and hence microbial transformation of pollutants. This zone will be a mix of aerobic (surface) and anaerobic conditions to foster denitrification. Media will be a mix of clean washed pebbles (gravel or similar) with zeolite and limestone incorporated to enhance ammonia and phosphorus removal.

This system will receive continuous flows from the outlet of the surface flow wetland. Flows will be distributed across the wetland via slotted pipes and will vertically flow through the media. A network of slotted pipes will collect treated water prior to discharge to the Lake.

This system will need to maintain sufficient flows to ensure sediments remain wet to prevent death of plants and microbes, hence should not be taken off-line for more than a few days at a time.

General Specifications

Area: ~ 450 m^2

Depth: 0.6 – 0.7 m; average depth of ~0.65 m to encourage denitrification

Volume: ~290 m^3.

Substrate material: clean, round gravel (or similar) rocks free of fine materials; zeolite.

5.2.4 Expected Treatment Performance

Approach

The key function of the Neil McDougall wetland system is to ensure continuous treatment of the Lake water, via a constant or near-constant pumped flow. As such, the system is atypical of stormwater treatment systems, which normally have variable flows, and is more akin to a wastewater constructed wetland. Consequently, the approach used to assess the performance of the proposed wetland system is based on the methodology generally employed in modelling of constructed wastewater treatment wetlands.

A modified rate constant sequential model was used, based on Kadlec and Wallace (2008). The model was run for the limiting parameters (total nitrogen, ammonium nitrogen, NO_x, total phosphorus), using a monthly rainfall and evaporation model. Removal was dictated by the inlet concentration, the surface area of the wetland, the inflow volumes as well as an empirically determined area rate constant (Kadlec and Knight, 2008). Modifications were made to reflect Syrinx actual performance data for similar systems and climates.

The following critical parameters and assumptions were used:

- A continuous flow is maintained throughout the system via lake water recirculation. This is particularly important for the subsurface component in order to prevent drying out and oxidation of media, which can compromise denitrification and result in nitrate export during first-flush events.

- To ensure an effective and complete denitrification process, hydraulic retention time (HRT) of the subsurface biofilter was set to be a minimum of 2 days. This critical criterion determined the flows that can be effectively treated through the system; this flow is 90 m^3/day.

- The mean concentration values for the Lake surface water obtained during the two 2018 sampling events (Table 6) were adopted to be representative of the wetland inflow water quality.

- TN and NH_4-N are assumed to be temperature dependent; a minimum temperature of 15-20°C is assumed during the cooler months and 20-25°C during the warmer months.

Modelling Outcomes – Predicted Performance

Modelled performance of the main wetland treatment system is summarized in Table 12.

As a result of combined aerobic and anaerobic processes occurring within the system, the main treatment wetland is expected to achieve a very high (>80%) removal of both nitrate nitrogen and ammonia nitrogen. Together with the sedimentation zone which contributes to the removal of particulate (organic) forms of nitrogen, ammonia oxidation followed by denitrification will result in high removal of total nitrogen (modelled to be >65%).

In terms of phosphorus, the system is modelled to achieve ~30% reduction in concentration. Given that the subsurface treatment wetland media will contain zeolite and limestone, overall P removal is likely to be higher than this.

Note, for the purposes of tracking success of the system over time, Table 12 also includes ANZECC/ARMCANZ (2000) water quality trigger values for physical and chemical stressors for slightly disturbed ecosystems of south-west Australia. While other studies of the Lake and broader City of South Perth area consistently use *lowland rivers* ecosystem type to discuss the water quality data (SERCUL and the DWER) given that the key receiving environments of CoSP catchments are Swan and Canning Rivers. However, in Table 12 default trigger values for *Freshwater lakes & reservoirs* ecosystem type are included as this better reflect the nature of Neil McDougall Lake. These lake-specific values are more conservative and unlikely to be achieved in the short-term. However, the overall goal of the integrated remediation system is to achieve a progressive, continuous improvement in Lake surface water quality (and overall health) and hence these trigger values should be considered as aspirational, long-term targets.

The TN concentrations expected in the treated water (effluent) that is discharged back to the Lake is 0.83 mg/L. This is somewhat over the ANZECC guidelines, however it is expected that these concentrations will progressively decrease with continuous recirculation and treatment. Notwithstanding this, somewhat higher TN levels in a system can be seen as advantageous in efforts to combat cyanobacteria growth. This is because, contrary to most other planktonic algae, some cyanobacteria are able to fix atmospheric nitrogen, and in a nitrogen-limiting situation this can lead to a lack of nitrates or of ammonia, and in turn to a dominance of N_2-fixing cyanobacteria. Hence, avoiding nitrogen-limited conditions should also help management of cyanobacterial blooms.

Table 12. Performance modelling of the proposed main wetland treatment system

				MAIN TREATMENT WETLAND PERFORMANCE		
				Pollutant Removal (median effluent conc. - cell outlet)		
Parameter	Unit	**Aquatic Discharge Targets (ANZECC freshwater guidelines)[1]**	**Influent concentrations (Lake surface water)**	**Surface Flow Wetland (SFW 1 & 2)**	**Subsurface Flow Wetland (SSFW) (effluent returns to the Lake)**	**% REMOVAL THROUGH THE SYSTEM**
Total Nitrogen (TN)	mg/L	0.35	2.6	1.0	0.83	**67%**
Nitrate Nitrogen	mg/L	0.01	0.27	0.12	0.05	**83%**
Ammonium Nitrogen	mg/L	0.01	1.1	0.3	0.18	**84%**
Total Phosphorus (TP)	mg/L	0.01	1.4	1.07	0.9	**32%**

[1] *Default trigger values applicable to southern Western Australia - Freshwater lakes & reservoirs ecosystem type*

6.0 LAKE RECIRCULATION & PUMPING SYSTEM DESIGN

6.1 OBJECTIVES

The key objectives of the recirculation system are to:

- Ensure adequate water movement to disrupt cyanobacterial growth and prevent stagnation.
- Ensure adequate turnover of water to oxygenate and enhance nutrient removal.
- Assist with aeration and prevent hypoxia in sediments.
- Pump water into the constructed wetland for continuous treatment and WQ improvements.

6.2 CIRCULATION MODELLING

Given the primary functions of this system are to ensure water mixing as well as to pump water from the Lake into the main wetland for treatment, a preliminary model of the Lake using the existing survey bathymetry was set up in AEM3D. The aim was to assess the influence that the pumping rates would have on the mixing of Lake surface water, determine the optimal pumping requirements and to assess if and how these requirements can be met.

Model Setup & Scenarios

AEM3D (Aquatic Ecosystems Model) is a 3D numerical modelling tool that applies hydrodynamic, thermodynamic and biogeochemical models to simulate the temporal behaviour of stratified water bodies with environmental forcing. It can be used to simulate the velocity, temperature, salinity, nutrients, and biogeochemistry in surface waters that are subject to forcing including meteorological forcing, inflows, withdrawals, and bubblers. Given that stagnation and stratification is a prevalent issue in Neil McDougall Lake, this model was determined to be appropriate to provide a better understanding of Lake circulation improvements through the given pumping scenarios.

The primary modelling setup included two pumping locations, one at the northern end and the other at the southern end of the Lake. This model was used to analyse and compare three pumping scenarios as follows:

1. SCENARIO 1 – Recirculation of Lake water to Wetland. Under this scenario, the pumps were set at ~200 mm above the bed of the Lake and configured to have a continuous pumping rate of 3 L/s each to supply a daily average of 90 m^3/day to the constructed wetland treatment train.

2. SCENARIO 2 – Internal Lake Recirculation, medium pumping rate of 10L/sec.

3. SCENARIO 3 - Internal Lake Recirculation, high pumping rate of 100L/sec. This scenario is an extreme rate and an unlikely scenario used for comparison purposes only.

The modelling results were delivered in a 2D (2 dimensional) coloured velocity plan view at 3 varying depths of interest. The depths were taken as follows:

- 0.1m from surface;

- 0.4m from surface; and
- 0.3m from bottom.

Modelled results of the three scenarios are provided in Figure 8.

It should be noted that the model setup was only preliminary, based on a fairly coarse bathymetry and does not consider meteorological forcing or quantitative Lake recharge from stormwater and groundwater. Further modelling through a more detailed setup would be necessary to achieve a higher accuracy level, and would need to include Lake circulation pumping scenarios to refine the specifications and proposed positions of the circulation pumps. This would only be necessary if modelling of alternative pumping methods or other physical processes in the Lake is required in the detailed design phase.

Model Results Discussion

The 3 L/s pumping rate (Scenario 1) was shown to be ineffective at creating adequate circulation within the Lake. The 2D horizontal cross sections show a large area of dead zones (marked black on images) where the Lake water was not influenced by the pumping rate at any of the analysed depths. As to be expected, increasing the pump rate to 10 L/s (Scenario 2) resulted in improved circulation, with most of the Lake water moving at 0.001 m/s to 0.002 m/s velocity at 0.4m depth and deeper. However, dead zones were still prevalent at the water levels closer to the surface.

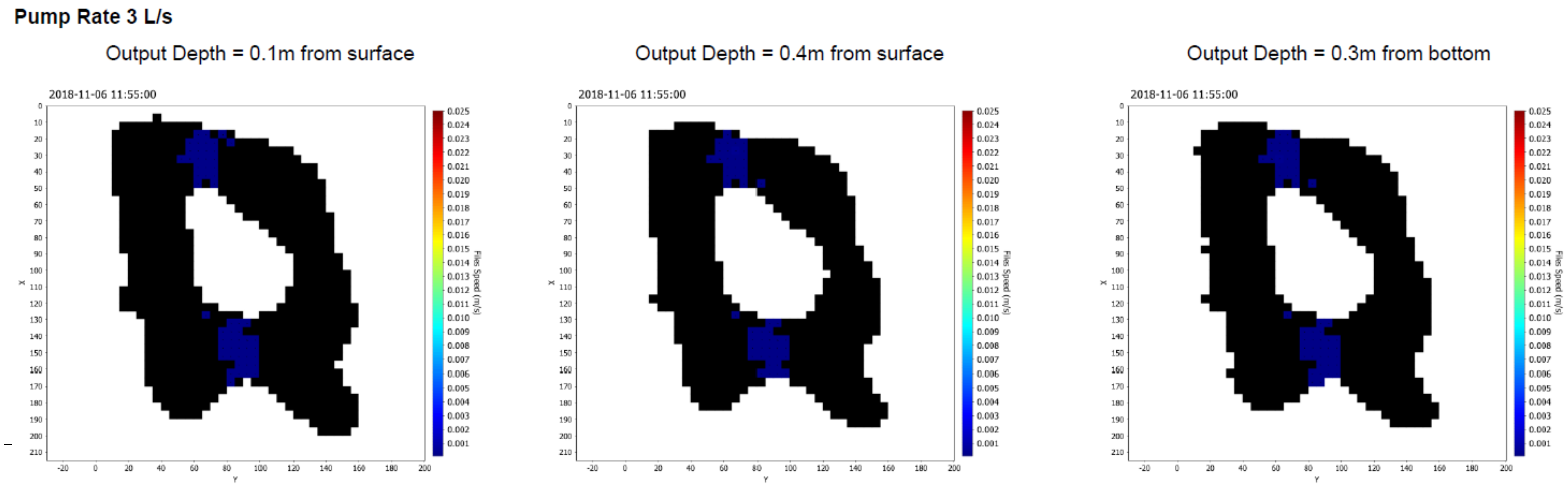
Additional circulation improvement was achieved with further increase in the pumping rates; at the 100 L/s pumping rates (Scenario 3) an optimal circulation scenario appears to be achieved with water moving at a consistent 0.004 m/s to 0.008 m/s velocity consistently throughout the Lake's water profile.

However, considering that average pumping capacity for most submersible pumps ranges between 1 L/s to 30 L/s, it would not be practical to provide a 100 L/s pump as it would be too energy intensive and expensive. In addition, a pumping rate of 100 L/s pump far exceeds the pumping requirements of the constructed treatment system.

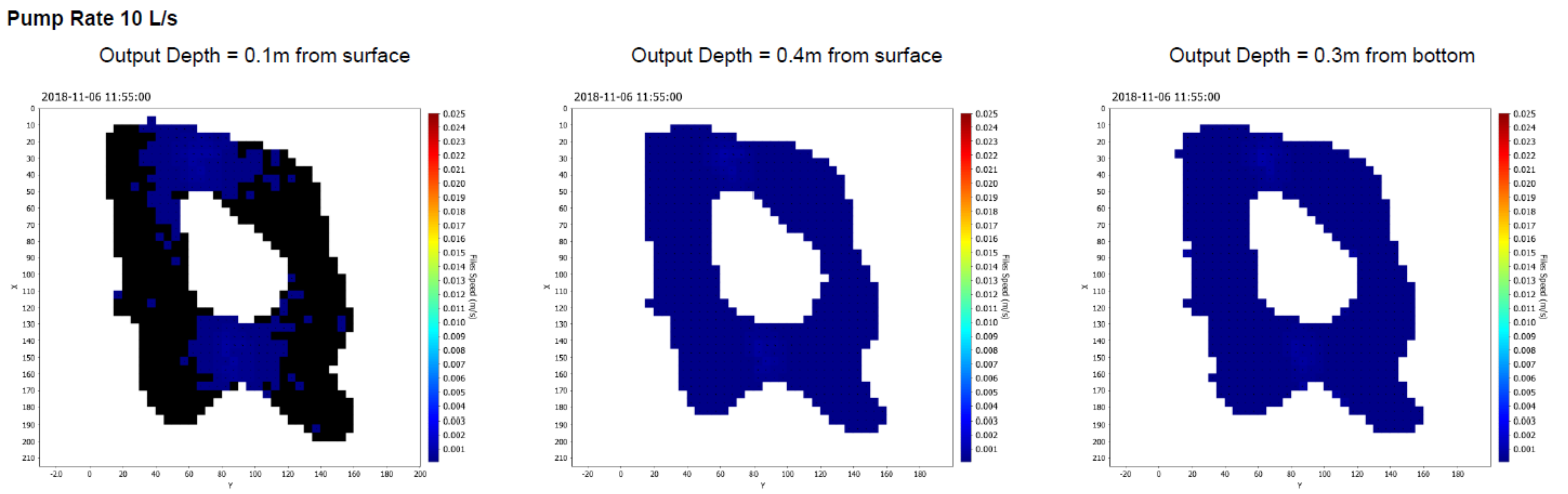
Hence, based on the modelling undertaken it appears that pumping alone is not the most effective and efficient way of achieving consistent Lake circulation. Rather an integrated approach is needed that combines pumping with the other best practice methods such as the use of aeration pumps, fountains, or specialised circulation pumps that involve pumping water from the waterbody and discharging it laterally across the water profile. These circulation pumps usually provide an aeration function as well as they discharge a mixture of air and water (Figure 7).

Figure 7 Example of an aeration circulation pump

SCENARIO 1: PUMPING RATE 3 L/s



SCENARIO 2: PUMPING RATE 10 L/s



SCENARIO 3: PUMPING RATE 100 L/s

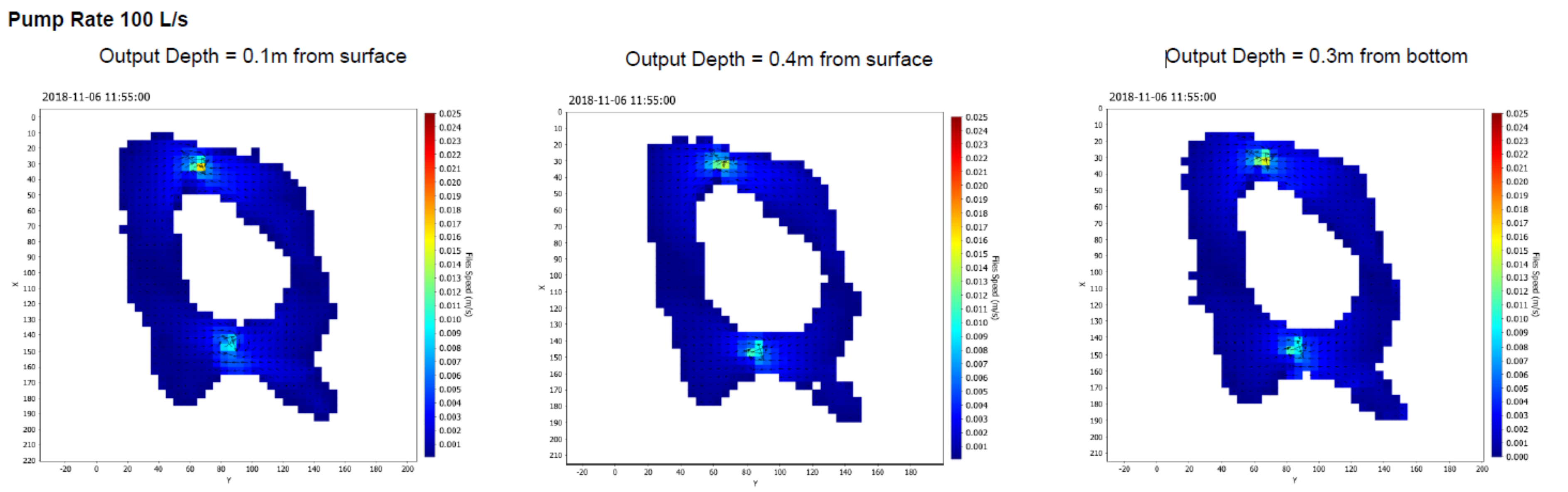


Figure 8 AEM3D modelling results for the three analysed pumping scenarios

6.3 SELECTED RECIRCULATION APPROACH

Taking into consideration results of Lake circulation modelling described above, it is proposed to separate Lake circulation requirement from the pumping rates needed to pump Lake water through the constructed treatment system.

Given there is an island in the middle of the Lake that effectively creates a separation between different sides of the Lake, at least two circulation pumps will be required at each side of the Lake for a sufficient circulation coverage (Figure 11).

A bund wall made of rocks will be positioned at the southern end of the Lake to create a flow separation. This separation will force the summer water levels to flow in an anti-clockwise direction from FW2 to the submersible pump location at the opposite side of the bund wall creating a healthy circulation flow path within the Lake.

One mobile aerator will also be installed in SDB3 (north western sedimentation basin) to facilitate aeration and mixing in this basin. The specifications and requirements of the mobile aerator will be provided in the detailed design.

6.4 PUMP REQUIREMENTS

The proposed design for Neil McDougall lake includes the implementation of 3 (three) pumps. One submersible pump for pumping the lake water into the constructed treatment system, and 2 (two) lake circulation pumps to provide disturbance to zones where water is likely to stagnate and cause health issues.

The specifications and requirements of the respective pumps to serve their intended purposes are provided below. The circulation pump requirements provided here were developed from a cost-effective perspective, and It should be noted that circulation can be improved further with the provision of more pumps if desired.

6.4.1 Pump Requirements for Lake Recirculation

The proposed circulation pump to be used will be a submersible type pump equipped with a 3 phase motor (recommended for operational longevity).

For the pump to adapt to the changing water levels within the Lake, the pumps will be mounted on a raft that enables it to float on the water surface. The depth of the pump should also have the ability to be positioned at variable depths below the water surface.

The motor axis should be adjustable up to 35º above and below the horizontal to configure the direction of influencing currents in any desired way to mitigate stratification of the lake as and when necessary. However, for the lake's application, given that the Lake tends to be only ~0.5 m deep during the summer, the motor axis should be adjusted above the horizontal axis toward the water surface in order to avoid sediment disturbance at the bed of the lake.

The pump will be secured to the bed of the lake with fitted concrete anchor blocks to prevent it from dislocating. The pump should also be easily relocatable if required to specific stagnant zones for treatment which is beneficial given the shape of the lake. The ability for the pump's position to be adjusted also gives the added advantage of fine-tuning to facilitate enhanced effectiveness at inducing lake circulation.

In regard to power supply, it is assumed that the supply source from the existing decommissioned pumping station will be made available and the proposed circulation pump will be supplied by this power source via a submersible cable. Solar power is also a viable option as it would not contribute to additional energy consumption. However, provision of a solar power source to supply the pump would be an additional cost. An above ground control cabinet will also be provided to operate the circulation pumps.

A circulation pump that meets the above criteria is the triple phase BRIO 1.0 water circulator. Specifications of this circulation pump are provided in APPENDIX 5; other equivalent pump systems can also be considered.

6.4.2 Pump Requirements for the Treatment System

The submersible pump provided to pump water through the treatment system needs to ensure a steady and constant supply of 90 m^3/day. This objective is assisted with a header tank that will have an orifice of ~50 mm internal dia. that discharges from the header tank to the treatment system at a rate of 1 L/s. For the purposes of deriving a suitable pump requirement, the effective volume in the header tank has been assumed to be at least 8 m^3. The volume of the header tank is not fixed at this stage and can be increased later during the detailed design, however, the volume should still be at least 8 m^3 as decreasing the volume would drastically affect the pumping requirements and treatment system operation.

The water in the header tank will thereafter, be gravity fed through the treatment system, before discharging back into the lake at the treatment system outfall as treated effluent.

The pump will need to be lifted off from the bed of the lake by at least 200 mm with a wire cage, raised platform or equivalent (to be developed during detailed design). This will reduce the risk of clogging and maintain the pump’s operational longevity. Unlike the circulation pump, this pump can be positioned at a fixed location and does not need to be movable. The pump will also need to have sufficient power and pressure to pump a distance of ~100 m and vertical head of at least 5 m to reach the top of the header tank.

The total required pump head specification based on the pump performance requirements above is provided in Table 13.

Table 13. Pump specifications based on pumping requirements

Pumping Requirements			**Pump Specifications**		
Maximum Flow rate	3	L/s	Flow velocity	0.37	m/s
Total Pipe length	100	m	Pipe headloss	0.15	m
Nominal Pipe Diameter	0.1	m	Fittings headloss	0	m
Total Pump lift	5	m	Vertical lift	5	m
Misc. Head Loss	0.3	m	Misc. Head Loss	0.3	m
			Total Required Pump Head	5.5	m
Number of Pipe fittings					
45 Elbow	0	no.			
90 Elbow	1	no.			
Tee	0	no.			

The submersible pump operation will be controlled with a float switch in the header tank, and shall be configured to start when the water volume in the header tank is less than 1 m^3, and stop when it is over 7 m^3 full with a freeboard of 1 m^3 (~15% freeboard of total tank volume, consistent with best management practices for designing freeboard).

At a pumping rate of 3 L/s, it is expected that the pump will only be activated for ~50 to 60 mins continuously each time. The pump will stop operation at for approximately 1.5 hrs between each pumping interval, thus resulting in the pump being activated ~9 to 10 times a day.

The pump operational routing graph that presents the inflow and outflow discharge hydrographs are presented in Figure 9 and the effective volume in the header tank based on this operation is presented in Figure 10. The pump operational routing table resulting in both figures are provided in APPENDIX 4.

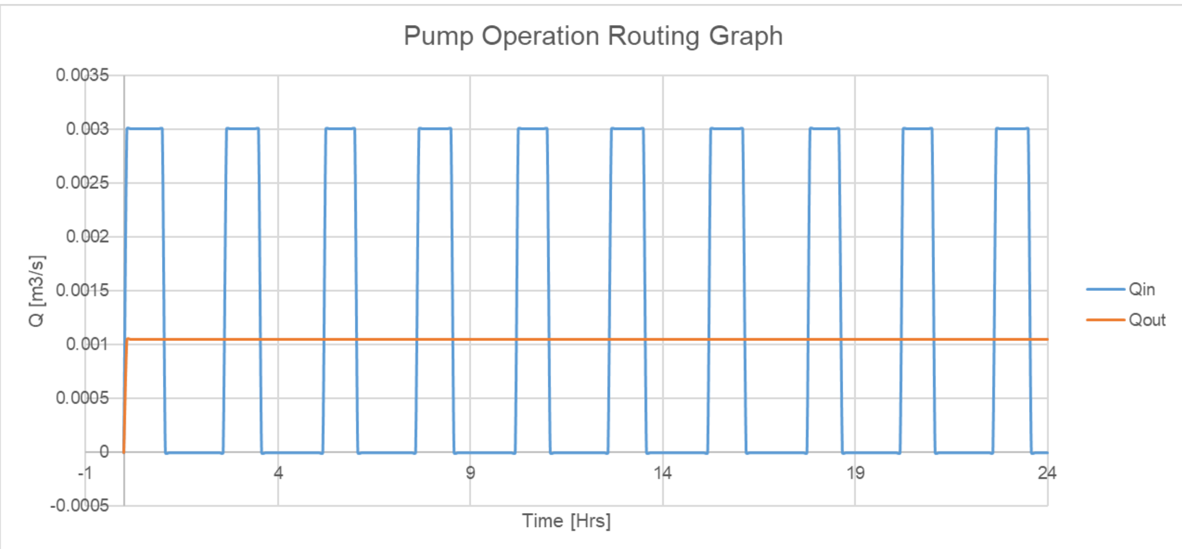


Figure 9 Pump Operational Routing Graph based on 3 L/s pumping rate and 8 m^3 header tank

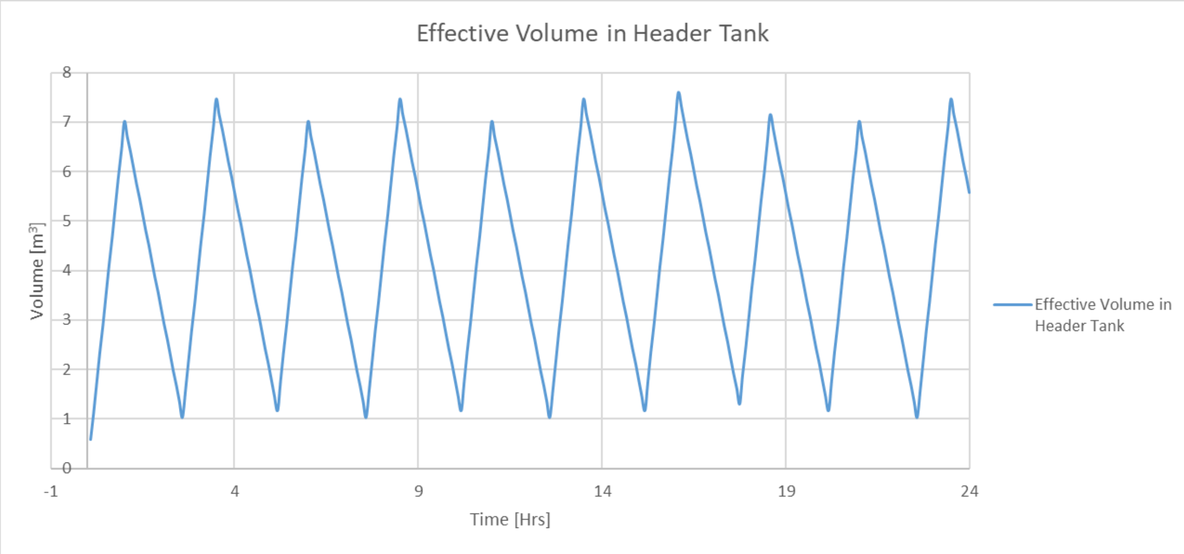


Figure 10 Effective volume in header tank based on indicated pumping operation

Similar to the power supply source of the circulation pumps, this pump is also expected to be supplied by the existing supply source from the decommissioned pumping station.

A submersible pump that meets the above criteria is the Tsurumi 50C4.75 three phase non-clog submersible pump. Specifications of this pump are provided in Appendix 6; other equivalent pumps with similar specifications can also be considered later in the design.

If solar power is to be considered later in the design, it should be noted that solar powered submersible pumps usually would not be able to pump more than 2 L/s, and sourcing for a suitable solar powered pump may be difficult, and the cost to supply the pump may not be beneficial. Nonetheless, lower pumping rates can be considered to accommodate the provision of a solar pump. In this situation, the routing table and operational graphs will need to be amended to suit the revised pumping rates accordingly. This can be further developed and refined during the detailed design phase.

Figure 11 Proposed measures for Lake circulation

7.0 STORMWATER SYSTEM DESIGN

7.1 CATCHMENT ANALYSIS

From the preliminary site inspection meeting with the City, and review of the feature survey, Neil McDougall Lake was found to be served by 4 (four) sub-catchment areas through 4 separate discharge points (DW1 to DW4).

The sub-catchment boundaries and respective area of each catchment were derived from the following information provided by the City:

- Existing drainage network plan;
- City of South Perth Catchment Management Plan;
- City of South Perth Integrated Catchment Plan;
- City of South Perth provided feature survey; and
- Aerial imagery from Near Maps.

The characteristics of all four catchments are relatively similar and consist typically of low rise residential land use developments, with several sections of public open space area (POS). Neil McDougall Park itself and the Coolidge Reserve contributes significantly to the total POS area.

A runoff coefficient (C-Factor) of ~0.8 is typically used for residential areas, and ~0.4 for POS areas, or turf areas (generally areas that are not developed and permeable). For this level of preliminary design and catchment characteristics, a composite C-factor of 0.7 was used for all four sub-catchments and was deemed to be sufficient to quantify the amount of runoff generated by the catchment.

A catchment plan indicating the area and boundaries of the sub-catchment areas are shown in Figure 12.

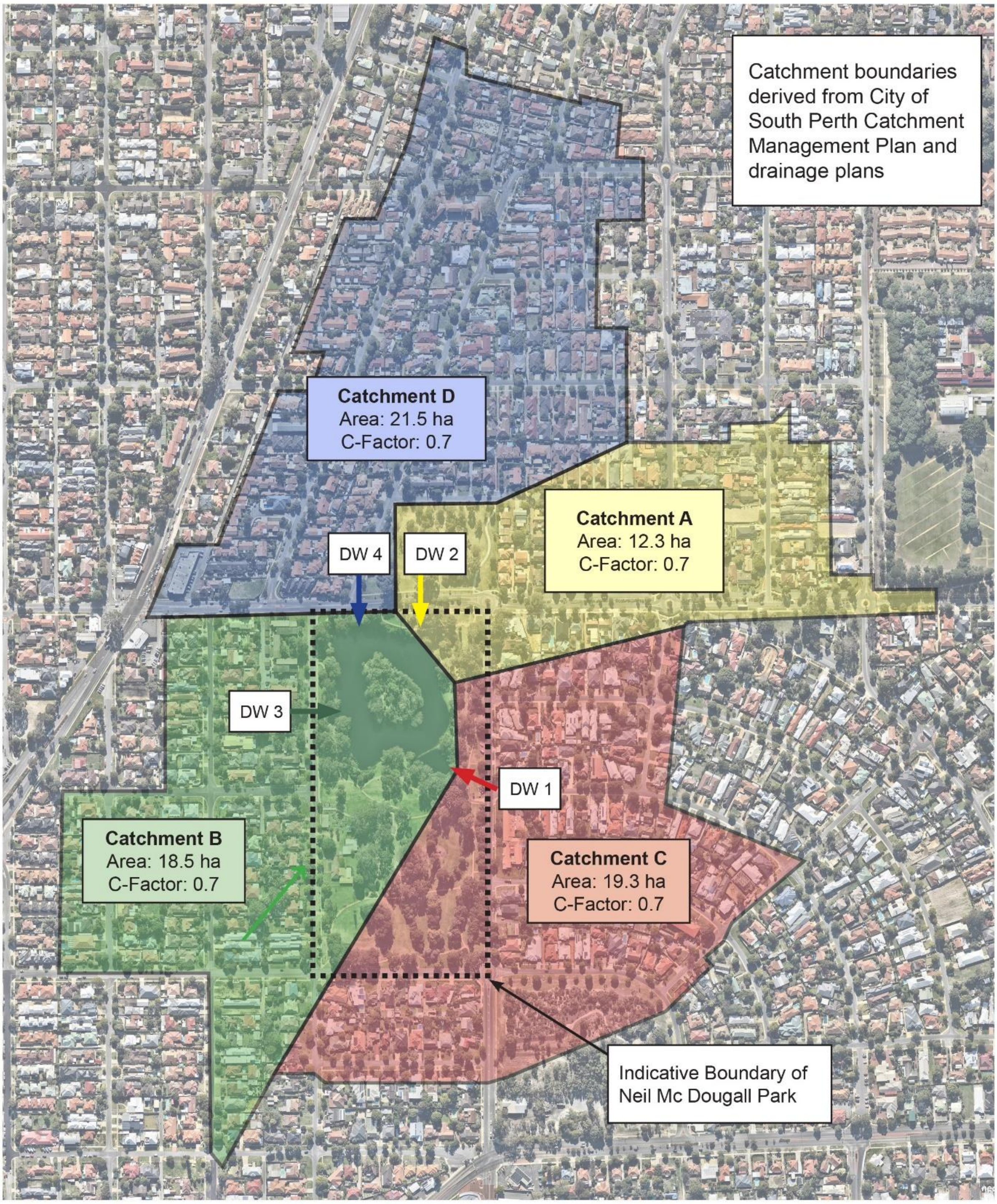


Figure 12 Catchment plan and boundaries of Neil McDougall Lake

7.2 TREATMENT VOLUME CALCULATIONS

Department of Water and Environmental Regulation (DWER) recommend treatment of a 15 mm rainfall event in bio-retention areas. This recommended 15 mm criterion replaced the previous 1-year, 1-hour ARI rainfall event criterion as it resulted in over-sized systems for water quality management for areas in the north-west and north of Western Australia (DWER 2017).

Table 14 indicates the volumetric treatment requirements from the respective contributing catchments based on this 15 mm sizing guide. However, given the constraints regarding the available area, the presence of existing services, and deep existing drainage invert levels, none of these volumetric requirements could be achieved.

Table 14 Achieved and required treatment volumes

<table>
<tr><th>Catchments</th><th>Area [Ha]</th><th>Treatment Volume Required (15 mm rainfall, C-factor: 0.7) [m³]</th><th>First flush volumes of 15 mm [m³]</th><th>Treatment Nodes</th><th>Achieved treatment volume [m³]</th></tr>
<tr><td>A</td><td>12.3</td><td>1,293</td><td>129</td><td>SDB3, SFW4</td><td rowspan="2">376</td></tr>
<tr><td>D</td><td>21.5</td><td>2,259</td><td>228</td><td>SDB3, SFW4</td></tr>
<tr><td>B</td><td>18.5</td><td>1,947</td><td>195</td><td>SFW1,SFW2,SSFW1</td><td>380</td></tr>
<tr><td>C</td><td>19.3</td><td>2,067</td><td>207</td><td>SDB2,SFW3</td><td>575</td></tr>
</table>

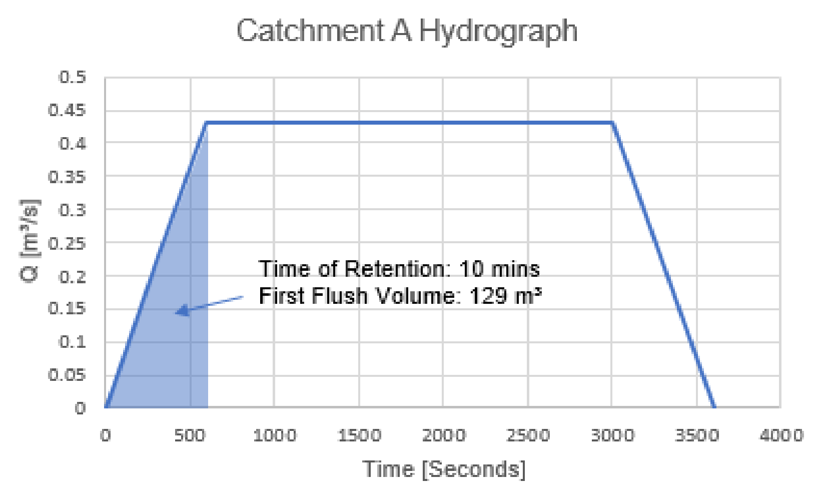
In order to maximise treatment efficiency, the treatment systems were sized to be as large as possible. The achieved treatment volumes through this approach as indicated under the “Achieved treatment volume” column of Table 14 appear to be significantly smaller than the actual required volumes. Nonetheless, these achieved volumes were verified to be sufficient to capture and treat the first flush effects of the 15 mm rainfall event which typically accounts for the highest concentration of pollutants.

The first flush volumes were calculated by plotting a 1-hour duration design rainfall hydrograph with an assumed time of concentration of 10 mins. Given the catchment sizes, the actual time of concentration would be expected to be much longer. Assuming a shorter time of concentration is considered to be a more conservative approach as these are often associated with more intense rainfall events. With the absence of actual catchment flow data and discharge pipe flow rates, this approach is seen to be the most appropriate, especially at this level of preliminary design.

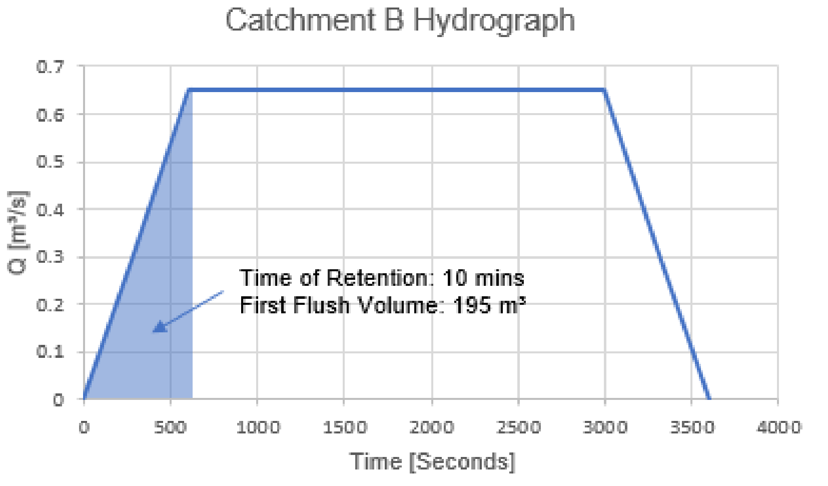
Through the plotted hydrograph, the first flush volumes are then determined via area under the hydrograph up to the end of the time of concentration (10 min point) which is the point where the runoff is expected to have flowed across the full catchment length picking up pollutants and contaminants in the catchment along its way.

The design hydrographs for the respective catchments are shown in Figure 13.

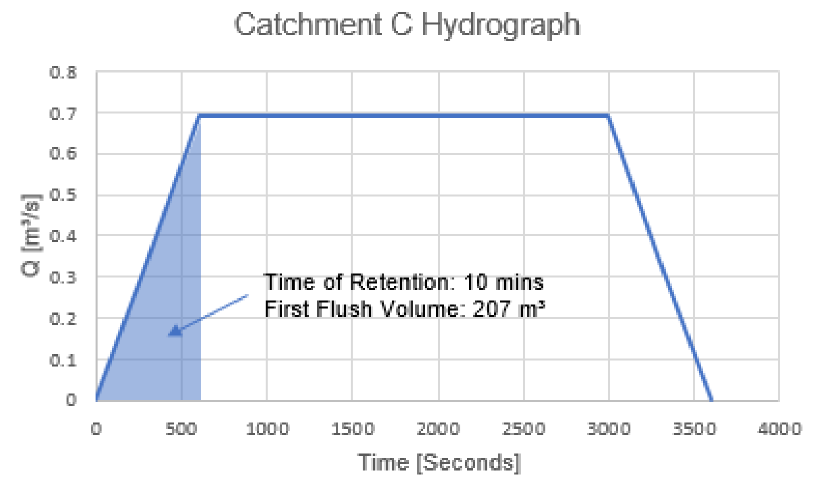
Design Hydrograph Catchment A [15 mm]				
Time [Min]	Time [s]	Time [s]	Q [m³/s]	Volume [m³]
0	0		0	0
5	300	300	0.22	66
10	600	300	0.43	129
15	900	300	0.43	129
20	1200	300	0.43	129
25	1500	300	0.43	129
30	1800	300	0.43	129
35	2100	300	0.43	129
40	2400	300	0.43	129
45	2700	300	0.43	129
50	3000	300	0.43	129
55	3300	300	0.22	66
60	3600	300	0	0
			TOTAL:	1293



Design Hydrograph Catchment B [15 mm]				
Time [Min]	Time [s]	Time [s]	Q [m³/s]	Volume [m³]
0	0		0	0
5	300	300	0.32	96
10	600	300	0.65	195
15	900	300	0.65	195
20	1200	300	0.65	195
25	1500	300	0.65	195
30	1800	300	0.65	195
35	2100	300	0.65	195
40	2400	300	0.65	195
45	2700	300	0.65	195
50	3000	300	0.65	195
55	3300	300	0.32	96
60	3600	300	0	0
			TOTAL:	1947



Design Hydrograph Catchment C [15 mm]				
Time [Min]	Time [s]	Time [s]	Q [m³/s]	Volume [m³]
0	0		0	0
5	300	300	0.34	102
10	600	300	0.69	207
15	900	300	0.69	207
20	1200	300	0.69	207
25	1500	300	0.69	207
30	1800	300	0.69	207
35	2100	300	0.69	207
40	2400	300	0.69	207
45	2700	300	0.69	207
50	3000	300	0.69	207
55	3300	300	0.34	102
60	3600	300	0	0
			TOTAL:	2067



Design Hydrograph Catchment D [15 mm]				
Time [Min]	Time [s]	Time [s]	Q [m³/s]	Volume [m³]
0	0		0	0
5	300	300	0.37	111
10	600	300	0.76	228
15	900	300	0.76	228
20	1200	300	0.76	228
25	1500	300	0.76	228
30	1800	300	0.76	228
35	2100	300	0.76	228
40	2400	300	0.76	228
45	2700	300	0.76	228
50	3000	300	0.76	228
55	3300	300	0.37	96
60	3600	300	0	0
			TOTAL:	2259

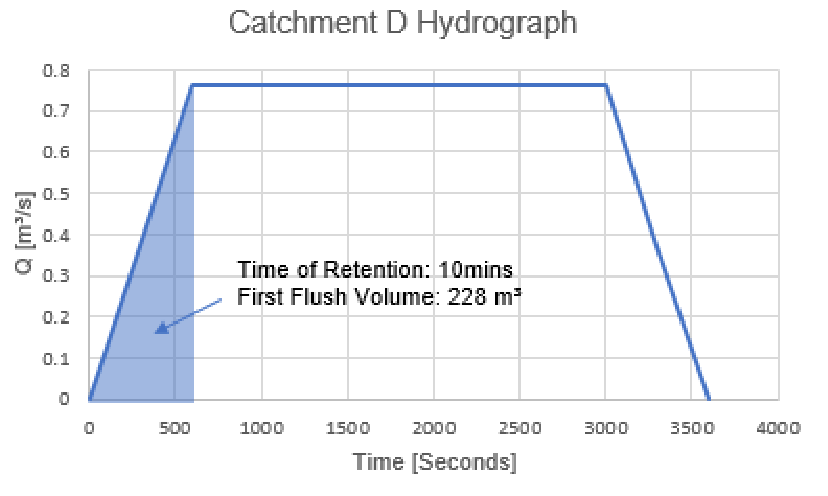


Figure 13 Hydrographs for Catchments A, B, C and D.

7.3 TREATMENT FLOW PATHS & TREATMENT NODE SIZING

7.3.1 Sedimentation Basin (SDB) Sizing

All sedimentation basins included in the integrated solution were sized using the Fair and Geyers equation expression for sedimentation basins with permanent pools (Fair, Geyer and Okun, 1966). The expression calculates the required surface area of the basin, permanent pool depth, storage depth, and extended detention depth, through the inflow discharge rate (Qin), and expected dropout efficiency rate of particles ranging from 125 um to 2000 um.

In the Fair and Geyers equation, a hydraulic efficiency (alpha) of 0.5 for basin flow configuration was used. In principle, the higher the alpha value, the more efficient the sedimentation basin will be at dropping out sediments. The alpha values increase accordingly with longer flow paths, and with the provision of more obstructions along that flow path (e.g. boulders, meanders, bunds, etc.) and can be further increased later if any of these components are included in the design during the detailed design phase.

A typical permanent pool depth of 1 m was used for all sedimentation basins in the Lake with the exception of SDB1 that is outside the lake. As compared to the other basins, SDB1 has a shallower depth of ~0.8 m deep because not as much sediment is expected to be experienced in SDB1 given the treatment systems offline configuration from its served catchment. This means that the primary flow path of the catchment does not need to flow through SDB1, and only the design flows will be intercepted and diverted into SDB1 via a control weir, orifice pipe, or a combination of both. This thus reduces the volume of flows intended to be discharged into SDB1, and the size of SDB1 can be reduced to prioritise more area to facilitate other forms of treatment.

7.3.2 Surface Flow Wetland (SFW) and Subsurface flow (SSFW) Sizing

The maximum achievable surface flow wetland volumes without resorting to highly intrusive works have been provided. Nonetheless, these volumes are sufficient to treat the first flush volumes of the 15 mm storm events.

In order to ensure that these wetland flow volumes are effectively utilised to their maximum capacity, the interconnecting drainage infrastructure such as pipes, orifices, and weirs need to be strategically sized to ensure optimal functional performance of the treatment system. This means that the inflow and outflow pipes need to be optimised to ensure that the full capacity of the wetland is frequently engaged without unnecessary bypassing of catchment flows.

At this design stage, the modified rationale method (MRM) was used to determine the inflow and outflow discharge rates of the wetland system required for the wetland operate at its full capacity. Interconnecting pipes and orifices were sized using orifice flow calculations and manning's open channel principle formulas.

It is recommended that 1D hydraulic modelling be carried during the detailed design stage to refine the interconnecting pipe sizes to ensure that the nodes within the proposed treatment trains function cohesively, and optimally with each other.

7.3.3 Treatment Flow Paths

Catchment A & D

Although Section 7.2 above indicated that the maximum discharge rate from Catchment D is 0.76 m^3/s, the 0.6 m dia. pipe culvert at DW4 only has a maximum discharge rate of ~0.38 m^3/s and would likely be operating with a higher headwater resulting in partially submerged to fully submerged pipe flow conditions. The remainder of the stormwater volumes would be temporarily stored within the existing drainage network until the network has fully discharged into the lake.

The first flush runoff volumes will discharge from Catchments A and D into sedimentation basin SDB3 (Figure 14). Catchment D connects to SDB3 in an online configuration, whereas catchment A connects to SDB3 in an offline configuration, where only first flush runoff volumes associated with the 15 mm rainfall event will be intercepted from DW1 and diverted to SDB3 via an orifice pipe.

Flows in SDB3 will then naturally overflow into the adjacent filtration wetland (FW1) where residual particles are captured, and nutrients are stripped from the wetland via microbial transformation and vegetation uptake. The combined retention time of SDB1 and FW1 cannot be determined exactly as the retention time is critically influenced by the amount of available storage in the treatment system which would frequently be compromised by backflow from the Lake, and groundwater interception.

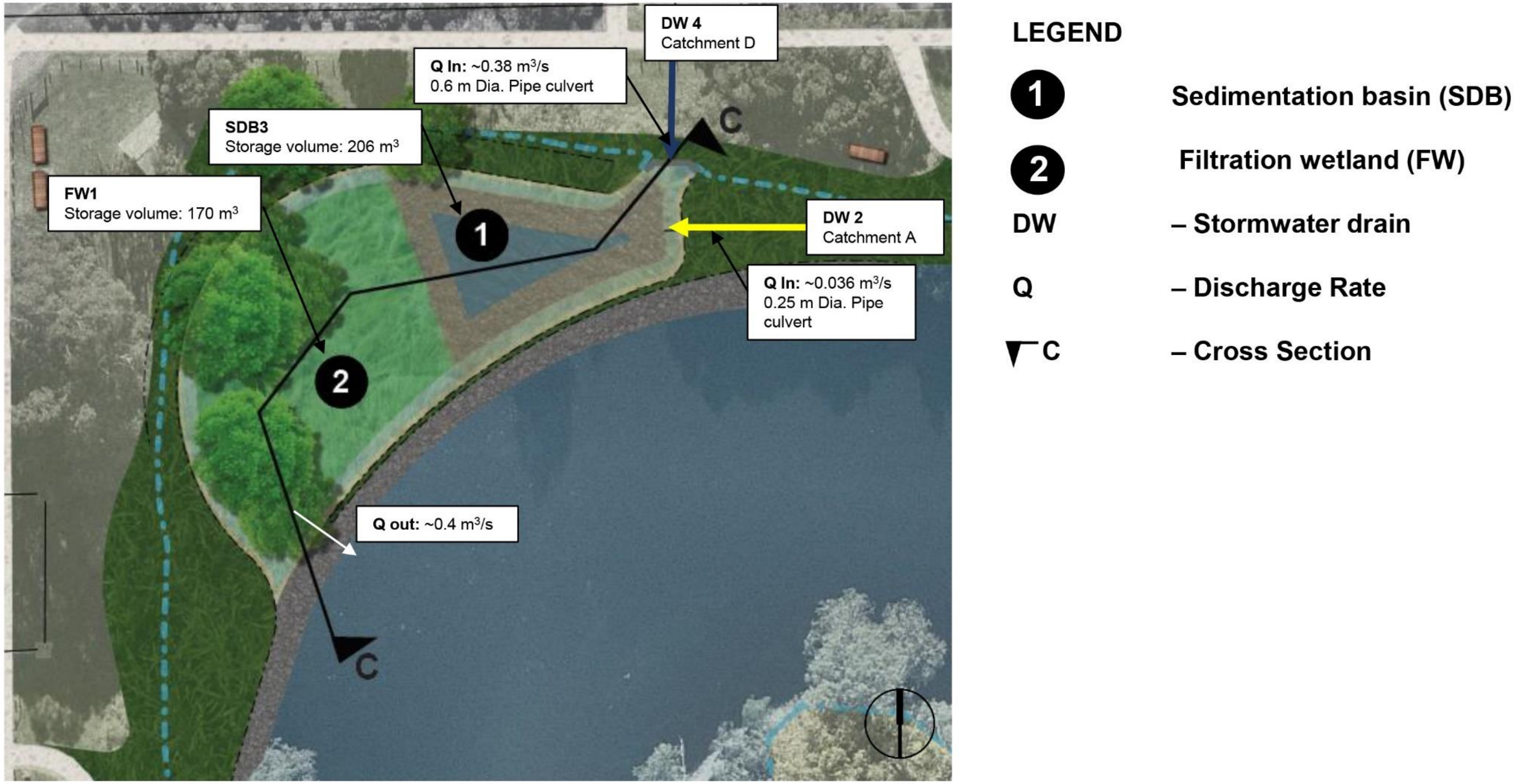


Figure 14 Design flow path for Catchment A and D treatment system

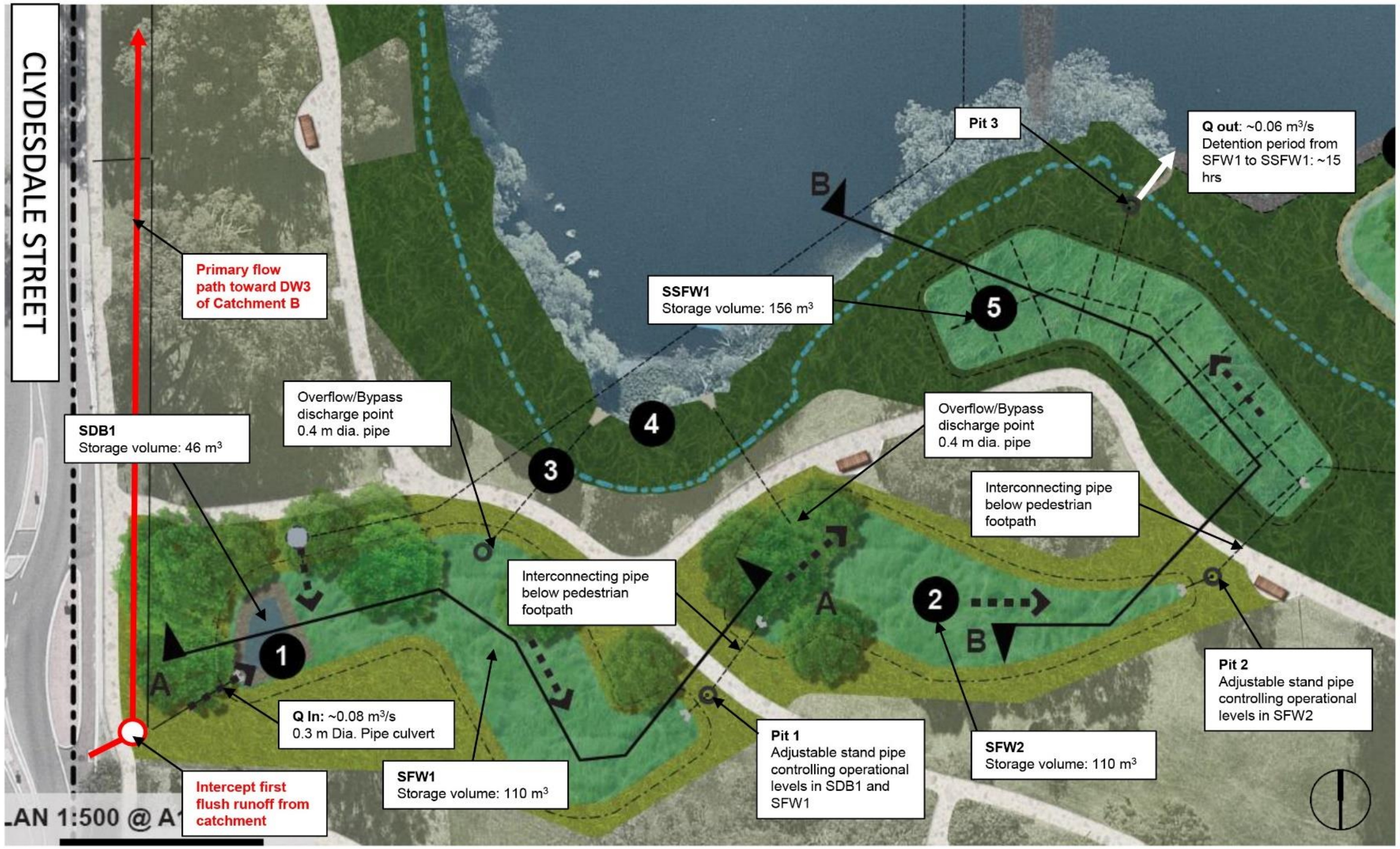
Catchment B

Catchment B's treatment system is a 3 tier treatment system that has an offline configuration where only the first flush volumes associated with the 15 mm storm events will be intercepted for treatment. The interception will be carried out with the provision of a pipe orifice from the drainage pit along Clydesdale Street into sedimentation basin SDB1.

Flows from SDB1 will then overflow via gravity into the adjacent surface flow wetland (SFW1) where generally nutrient stripping and enhanced particle removal will be carried out by the wetland microbes and vegetation (Figure 15). The operating levels of SDB1 and SFW1 will be maintained to a depth of 0.5 m to 0.6 m by an adjustable standpipe in the downstream pit 1. Maintaining a constant water depth in the wetland will provide the plants with the appropriate conditions for effective treatment performance. a 0.4 m dia. standing pipe overflow is also provided in SFW1 to allow a flow bypass in the event that higher than design volumes flow into the wetlands, or to prevent flooding of the adjacent park facilitates such as footpaths in the event that a connecting pipe gets choked.

From SFW1, the flows will continue into the next surface flow wetland (SFW2) through a pipe laid under the existing pedestrian footpath. Similar treatment processes in SFW1 will take place in SFW2 to facilitate further refinement treatment. For similar purposes of SFW1, the operating levels in SFW2 will also be maintained but with a deeper depth of 0.6 m to 0.7 m by an adjustable standpipe in pit 2 downstream of SFW2. The depths in SFW2 are only deeper because of the lower ground levels at which the wetland is situated on.

Flows from SFW2 then flow into an anaerobic sub-surface treatment wetland (SSFW1) where de-nitrification of the water takes place. SSFW1 will be covered with surface planting, while the effluent flows vertically down through the filter media via gravity, and laterally through a series of perforated pipes before discharging into the lake via a bubble up pit at pit 3.



LEGEND

1 Sedimentation basin (SDB)
2 Surface flow wetland (SFW)
3 High flow bypass
4 Cascade outlet
5 Sub-surface flow wetland (SSFW)
DW – Stormwater drain
Q – Discharge Rate
A/B – Cross Section

Figure 15 Design flow path for Catchment B treatment system

Catchment C

The maximum runoff discharge rate from Catchment C was calculated to be 0.69 m^3/s in Section 7.2. However, the 0.6 m dia. pipe culvert at DW2 only has a maximum discharge rate of ~0.38 m^3/s, thus creating the similar scenario experienced in catchment D.

The treatment system for Catchment C is similar to that which serves catchments A and D and comprises of a sedimentation basin (SDB2) for sediment dropout, and a surface flow wetland (FW2) for enhanced particle capture and general nutrients stripping. Catchment C connects to the treatment system in an online configuration.

Leveraging on the existing footprint provision in the lake, a larger treatment area was able to be achieved in this treatment system which contributes potentially to better treatment results as compared to the smaller systems.

In addition to receiving runoff from Catchment C, SDB2 also receives a small amount of flow from SSFW1. However, the discharge from SSFW1 does not require further treatment but serves to create flow disturbance in SDB2 to reduce issues that may arise with water stagnation.

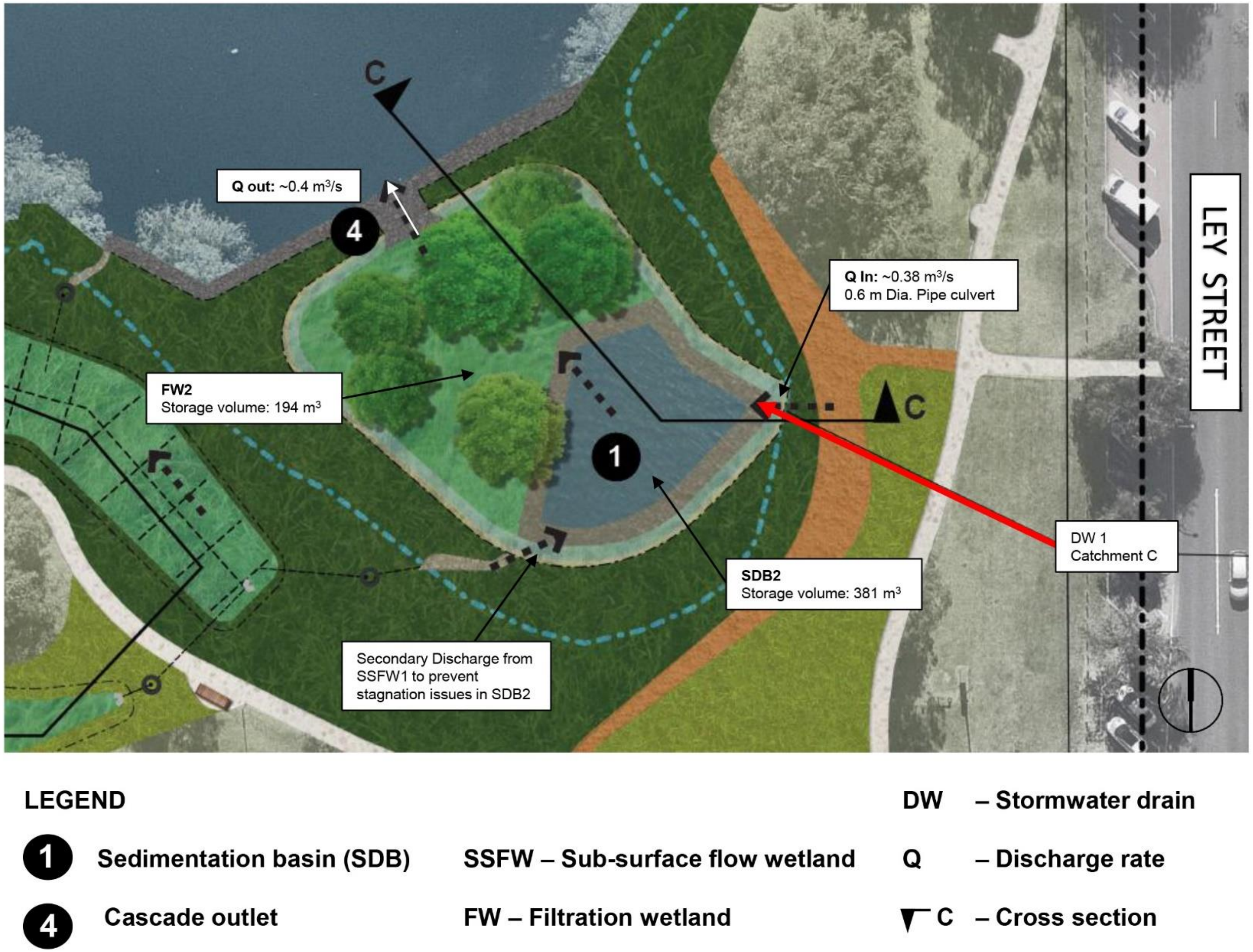


Figure 16 Design flow path for Catchment C treatment system

8.0 CIVIL DESIGN

The required civil works for the stormwater and lake recirculation system components are derived from the principles and requirements discussed above:

- Segmentation of treatment components;
- Orientation of the treatment areas within the available space and existing vegetation
- Requirement for even distribution of flow, and optimal plug flow;
- Type of drainage structures to be provided;
- Earthwork considerations and potential issues; and
- Site preparation and considerations.

8.1 SITE INVESTIGATIONS AND PREPARATION

The high groundwater tables, live stormwater network and acid sulfate soil risks mean this treatment system should be constructed during the dry season in late summer to minimise logistical challenges and costs.

Acid Sulfate Soils (ASS) Investigation & Management

The Perth Groundwater Atlas indicates that the Neil McDougall Lake site has moderate to high risk of ASS disturbance for excavations less than 3 m from the surface. ASS investigations according to DER guidelines were completed in April 2019 to establish the quantity of required treatment, and necessary dosing rates for ASS management during the construction process as detailed in Section 13.

The appointed contractor will need to prepare an Environmental Management Plan describing in detail, the appropriate ASS management measures to be implemented.

Dewatering

Relative to the surrounding surface levels and lake top water levels, the invert levels of the existing drainage network are considered deep, and the inverts of the treatment systems will be even deeper considering the need for gravitational operation. Available space within the Park is also a constraint as there is little benefit to allocating space to accommodate a long and deep embankment for the purpose of intercepting the deep drainage network for treatment. To work around these constraints, best-compromised location for these treatment systems (in particular Catchment A, D, and C) had to be within the lake body itself.

The City has also advised through previous meetings that the Lake does not dry out completely, hence water to a certain depth is expected to be encountered year-round. Deep inverts of the treatment systems also increase the risk of groundwater interception while conducting excavation works.

Taking all these factors into consideration, it is expected that dewatering will be inevitably be required to facilitate construction works of the treatment systems within the lake. Options of cofferdams or the application of sandbags can be explored to isolate the dewatering area.

As detailed in Section 13 an Acid Sulfate Soil and Dewatering Management Plan was prepared for the works in April 2019. The appointed contractor should provide details of how this will be implemented within their Construction Management Plan.

Surface Water Management

The treatment systems are serving active catchments and the existing drainage network should continue to be functional without any obstruction to stormwater discharge throughout the duration of construction works.

Surface water management of the offline treatment system at Catchment B is less complicated as the existing drainage network discharging toward DW3 does not need to be obstructed during construction. The pipe to divert flows from the drainage network can be constructed later upon completion of the Catchment B treatment train. However, pit modification works to facilitate the pipe connection needs to have a surface water management plan as this is expected to affect the operation of the existing drainage network.

Online treatment systems (particularly at DW2 and DW4) will need a stormwater management plan for flows to be diverted away from the dewatered construction site. Options of flat hoses or other forms of temporary piping can be considered to bridge the discharge point across the construction site to be discharged directly into the lake. Considerations of construction work obstruction and invert levels need to be made while exploring these options.

The appointed contractor shall provide details on the surface water management strategy to be implemented and to ensure that the functional integrity of the catchment’s drainage network is maintained.

Tree Removal

Only selected trees within the proposed footprint of the treatment systems will be removed. All trees within the rest of Neil McDougall Park that are not affected by the proposed works will be retained.

8.2 EARTHWORKS

All earthworks should be carried out to the various gradients, batters, dimensions, levels, and extents as shown in the Drawings with allowances provided for compaction and settlement.

Based on the preliminary design, it is expected that excavation to existing levels will be required to SDB1, SDB2, SDB3, SFW1, SFW2, and SSFW1. Fill will be required to construct FW1, and the separation bunds in the lake. No major earth works will be required for FW2 as the existing levels are already relatively consistent with the required design levels.

Table 15 below presents the preliminary cut and fill volumes for each treatment feature, and it has been estimated that ~1000 m^3 of fill would need to be removed from site. These volumes are indicative only, and were not derived from a civil cut and fill model. More accurate volumes will need to be calculated through cut and fill modelling during the detailed design phase.

Table 15. Indicative earthworks cut and fill volumes

	SFW1	SFW2	SSFW1	SDB1	SDB2	SDB3	FW1	Total
Cut	368	387	761	116	508	248	43	2431
Fill	132	154	0	0	0	0	22	711
total spoil	156	179	673	116	508	248	22	1902
Clean fill (minus ASS)	156	179	673	93	407	199	22	1728
Total for disposal of clean unusable fill								657
ASS 20% of SDB's and SSFW			135	23	102	50		309.2

	Total clean fill needed			
	FW2	Separation bund FW2	Separation bund FW:	Total
Cut	0	0	0	
Fill	404	262	405	
total spoil				
				1071

In the cut to fill volumes, it was assumed that on site excavated material will be suitable for re-use in the construction of the FW1 and separation bunds without treatment.

If excavated material is deemed to be unsuitable for re-use, then contingency to treat the material to achieve sufficient quality for re-use purposes will be necessary. In the event that the material cannot be salvaged for reuse, then arrangements for importing of clean fill to compensate the loss of material will need to be made. Unsuitable material shall also be disposed off-site accordingly.

8.3 LINERS

The treatment wetland (surface and subsurface flow components) will be clay lined to reduce the risk of groundwater intrusion that may reduce the treatment capacity and compromise the performance of the treatment system, and prevent the need for underdrains to prevent bulging of HDPE (high-density polyethylene) or similar liners. The objective of the liner is to minimise rather than fully exclude groundwater interception and should enable the penetration of tree roots into the groundwater to assist with evapotranspiration, and improve shading and biodiversity of the wetlands.

A clay liner will also allow the treatment system to dry down but remain moist in the unlikely event of in-operation removing the unnecessary risks of water stagnation.

8.4 WETLAND MEDIA

8.4.1 Surface Flow Wetland

Surface flow wetlands will comprise 250 - 300mm of soil won from site over the liner to support plant growth. Material will need to be free of weeds and deleterious material.

8.4.2 Subsurface Flow Wetland

The filter media for the Sub-Surface flow wetland (SSFW1) will consist of a 2 tier media profile with the top layer being zeolite, and a bottom layer of rounded gravel or similar.

The nominal diameter of the gravel sizes should be 10 mm but is subject to detailed design depending on required hydraulic conductivity, and saturation flow rate. The gravel should be poorly graded, and more rounded than angled for good hydraulic conductivity.

8.5 CIVIL STRUCTURES

Rock Revetment

Rock revetment shall be constructed with the specified rock riprap and placed over a sheet geotextile. The geotextile will serve as a separator between the rock riprap material, and the sand, or fill material to reduce the effects of erosion and loss of material that contributes to stability. The rock revetment will help the treatment systems retain its shape during its ongoing operations and sets a defined perimeter around the sedimentation basin (SDBs) for dredging purposes.

The Rock revetments should have an embedded rock toe to prevent slumping at the bottom and have a gradient no steeper than 1 in 1.5. Rock revetment thickness would typically be twice the nominal rock diameter (D50) but is subject to detail design development.

The rocks used for construction should be a rock type that is preferably native to the Neil McDougall site. Rock material should also be able to withstand long periods of submersion in water and resistant to chemical weather.

Separation Bunds

The objective of the separation bunds is to create an operational boundary between the treatment nodes and define a designated flow path for the treatment system.

The separation bunds can be shaped using excavated material on site unless excavated material is deemed to be unsuitable, then the use of clean infill would be the next option. Rock revetment underlaid with geotextile shall be placed on the embankments of the separation bunds for stability improvement. The top of the separation bunds will be planted for added stability and visual aesthetics purposes.

Lake Bund

A Lake bund is provided at the southern end of the lake to create a defined anti-clockwise directional water movement for circulation of the lower water level flows.

The lake bund will be constructed with similar rock material types and grades as the rock riprap used for rock revetment and would be installed by laying rocks directly into the lake through machinery, or manually without the need for dewatering.

The lake bund can remain leaky, as the objective of the bund is not to prevent water from flowing through, but only to encourage a certain flow direction within the lake. Similar to typical rock revetment installation, the lake bund will also have a layer of geotextile laid underneath to reduce the risk of settlement due to under wash.

8.6 HYDRAULIC STRUCTURES

Headwalls

All outlets to treatment systems will be provided with headwalls. Headwalls should be purchased from reputable suppliers such as Rocla and Humes. The headwall should be installed with a suitable compacted subgrade as according to the product supplier's specifications and as according to the installation guidelines.

Pits

All pits to be installed at this preliminary design stage should be concrete. This is because most of the pits within the park area appear to be located close to vegetated areas and will be more resistant to root wedging damage. Concrete pits are also able to withstand pedestrian loading, which is an important consideration given that many of the pits are located close to footpaths. This enhances the operational longevity of the wetland system.

Pit sizes should be minimally 600 mm Dia. to enable easy maintenance access.

All drainage pits should be provided by a reputable supplier such as Rocla or Humes. The pits should be installed with a suitable compacted subgrade as according to the product supplier's specifications and as according to the installation guidelines.

Pipes

As all interconnecting and drainage pipes are to be gravitationally operated. The pipe materials should either be concrete, or UPVC. UPVC is generally BPA free, and does not contain phthalates which is seen as a more environmentally considerate option as compared to regular PVC. UPVC is also more rigid making it less susceptible to settling, and more ideal to perform gravitational flow functions.

Leaky Weir

Discharge points from the treatment systems into the lake will be carried out through a leaky weir. The rock weir will create a slight backup of headwater within the treatment system creating a distinct flow path from the treatment system into the lake during an actual flow event.

The leaky weir will be constructed from the similar rock type as the rock revetment, but rocks selected for the leaky weir construction shall be poorly graded, with fewer variations in sizes. The poor grade of the leaky weir will result in higher hydraulic conductivity, and be less susceptible to clogging.

Similar to typical rock revetment installation, the leaky weir will also have a layer of geotextile laid underneath to reduce the risk of settlement due to under washing.

9.0 PLANTING & LANDSCAPE DESIGN

9.1 PLANTING OF TREATMENT WETLANDS

Selection of plant species for the main wetland has been based on those native to the Perth area and those proven as suitable for treatment systems dealing with nutrient enriched effluent. A diverse range of indigenous plant species will:

- Optimise nutrient uptake: Providing a diversity of species with different seasonal growth physiology to optimise nutrient uptake by ensuring some species are actively consuming nutrients in all seasons.
- Provide system resilience: A range of species will exhibit different tolerances to different site conditions. Thus, changes to site conditions will not result in system failure.
- Enhance biodiversity & fauna habitat: Diversity in plants will support and encourage habitat for fauna.

The surface flow wetland is expected to experience varying inundation and water depths. Hence, the species selection for this treatment system component involved matching plant requirements and thresholds to site conditions including: nutrient loads, water depths, rooting depth and turbidity.

In terms of the subsurface wetland, water levels are relatively constant hence species have been selected that tolerate these conditions.

9.2 PLANTING OF FILTRATION WETLANDS

The filtration wetlands are part of the sedimentation basin design, which contain vegetation in strips perpendicular to the flow path. Water discharging out of the open basins will still carry fine sediments, hence the planted sections will assist in trapping sediments within the root and stems. Plants in these zones will be densely planted emergent sedges and rushes that can tolerate deeper water. In shallower edges that intermittently dry out, trees (*Melaleuca rhaphiophylla*) will also be incorporated to provide shading and habitat values.

9.3 PLANTING OF FRINGING VEGETATION

A key part of the remedial strategy is the revegetation of a wider emergent macrophyte zone around the lake (shoreline), continuing the current efforts the City is making in this regard. Additionally, extending the fringing vegetation and incorporating a wider range of species with variable rooting depth, will assist in managing surface run-off and intercepting nutrients in groundwater. Whilst no fertiliser is apparently used on the grassed areas surrounding the lakes, there is significant bird activity and droppings around the lake perimeter, as well as grass clippings, and these run-off into the lake with little intercepting vegetation or mulched controls.

The key functions of fringing vegetation are as follows:

- Improve interaction and biotransformation of nutrients;
- Increase shading to reduce water temperatures; and
- Intercept and treat any direct runoff prior its inflow into the Lake.

Planting is proposed within the following zones:

1. In-lake vegetated filtration zones (permanently wet), which act to trap and filter finer particles, provide shading to improve water quality, and provide enriched habitat to assist in increasing refuge sites for native aquatic predators important to water quality.
2. Outer perimeter fringing macrophyte zone (permanently moist) to filter surface run-off and subsurface flows within the 1m below surface level zone, and increase aquatic refuges.
3. Specific paperbark forest zone north of the site to intercept groundwater flows passing through Coolidge Reserve (future residential).

Planting appropriate native fringing (riparian) vegetation such as sedges, rushes and submerged species in the perimeter of the Lake and island will act as a nutrient trap (buffer strip) to control nutrient and organic inputs from the surrounding grassed areas to the Lake. Furthermore, this fringing vegetation will help shade the water, creating less favourable conditions for algal growth and blooms. It will also provide fauna habitat, particularly for macroinvertebrates that predate on algae, which will further improve the health of the Lake.

Given that the local residents are attached to the current appearance of the Lake and in particular the open vistas and water reflections, it is proposed that this fringing vegetation is mostly comprised of low rushes and sedges and small shrubs, with discrete woodland zones, so as not to interrupt views. In areas that are considered difficult or not ideal to plant, a minimum 5m mulched edge should be installed, except in those areas where beaches are to be retained.

9.4 PRELIMINARY PLANTING SPECIFICATIONS

As can be seen in Table 16, in total an area ~9,200 m^2 is proposed to be planted as part of the integrated remediation system. When completed, these areas will contain ~~70 different species totalling 23,000 plants. This number of plants will provide an average density of 3-4 plants/m^2.

Planting will occur in strips perpendicular to the flow. Typically, only 70% of the surface flow wetland will be planted. The fringing vegetation allowance should be sufficient to balance the existing vegetated areas, and allow for access (beach) zones to maintain public interaction along shore sections.

Table 16 Planting specifications

Total Planted Area (m^2)	**9,204**
Main Treatment Wetlands	1,740
Filtration Wetlands	1,110
Fringing Vegetation	6,354
Total No. of Plants	**23,000**
Main Treatment Wetlands	6,960
Filtration Wetlands	3,330
Fringing Vegetation	12,708
Proposed Planting Density (plants / m^2)	
Main Treatment Wetlands	4
Filtration Wetlands	3
Fringing Vegetation	2

SPECIES No.	
Trees	6
Shrubs	36
Rushes & Sedges	13
Herbs	12
Total	**67**

The species selection for each planting area (main treatment wetland, filtration wetlands, fringing vegetation and landscape integration areas) is presented in Table 17. The location and the extent of planting areas are provided in the concept design drawing presented in APPENDIX 8.

The species number for each planting mix will be determined as part of the detailed design stage and will depend on the final levels and positioning of hard structures like weirs, pipes and rock riprap.

Table 17. Species list

Species Name	Common Name	Average Plant Height	PLANTING MIX 1 Fringing Vegetation	PLANTING MIX 2 Vegetated Filtration Wetlands	PLANTING MIX 3 Surface Flow (SF) and Sub-Surface Flow Wetlands	PLANTING MIX 4 Landscape Integration Planting
Trees						
Banksia littoralis	Swamp Banksia	10				
Eucalyptus rudis subsp. *rudis*	Flooded Gum	25				
Melaleuca preissiana	Moonah	10				
Melaleuca rhaphiophylla	Swamp Paperbark	10				
Shrubs						
Acacia applanata		0.4				
Astartea scoparia	Common Astartea	1.5				
Bossiaea eriocarpa	Common Brown Pea	0.4				
Calothamnus lateralis		1.5				
Calytrix fraseri	Pink Summer Calytrix	1				
Euchalopsis linearis		0.5				
Eremaea pauciflora		1				
Eutaxia virgata		1.5				
Gastrolobium capitatum		0.5				
Gompholobium tomentosum	Hairy Yellow Pea	0.5				
Hakea varia	Variable-leaved Hakea	2				
Hardenbergia comptoniana	Native Wisteria	climber				
Hibbertia racemosa	Stalked Guinea Flower	0.5				
Hypocalymma angustifolium	White Myrtle	1.5				
Hypocalymma robustum	Swan River Myrtle	1				
Lechenaultia floribunda	Free-flowering Leschenaultia	0.5				
Macrozamia riedlei	Zamia	2				
Melaleuca lateritia	Robin Redbreast Bush	2				
Melaleuca seriata		0.7				
Melaleuca teretifolia	Banbar	3				
Melaleuca viminea	Mohan	3				
Pericalymma ellipticum	Swamp Teatree	1.2				
Philotheca spicata	Pepper and Salt	1				
Scholtzia involucrata	Spiked Scholtzia	0.5				
Verticordia densiflora	Compacted Featherflower	1				
Xanthorrhoea preissii	Grass tree	1				
Sedges and Rushes						
Baumea articulata	Jointed Rush	2				
Baumea juncea	Bare Twigrush	0.8				
Baumea preisii		1				
Baumea vaginalis	Sheath Twigrush	1				
Dielsia stenostachya		0.4				
Isolepis cernua var. setiformis		0.2				
Lepidosperma longitudinale		0.7				
Leptocarpus scariosus		1				
Schoenoplectus tabernaemontani	Lake Club-rush	2				
Herbs						
Anigozanthos manglesii	Mangles Kangaroo Paw	0.7				
Conostylis aculeata	Prickly Conostylis	0.3				
Dampiera linearis	Common Dampiera	0.2				
Dianella revoluta	Blueberry Lily	0.3				
Kennedia prostrata	Scarlet Runner	0.2				
Lobelia anceps	Angled Lobelia	0.2				
Patersonia occidentalis	Purple Flag	0.3				
Thysanotus multiflorus	Many-flowered Fringe Lily	0.3				

9.5 PLANTING REQUIREMENTS

Sourcing Plants for Revegetation

Local provenance seed and vegetative material should be used whenever possible to generate the required plant stock. Local provenance stock will have better adaptation to local conditions resulting in higher plant survival. Vegetative material (cuttings, rhizomes or roots) and seeds from the foreshore reserves within the City of South Perth would be considered most appropriate. Failing this, the Swan Coastal Provenance seed and vegetative material should be used.

Plants should be ordered at least 6 to 12 months prior to planting to allow adequate growth time for stock.

Size of plant stock and hardening off prior to planting

Tube stock (50 x 50 x 125mm) will be suitable for propagation of most plants; however, it is recommended that larger stock is used within the filtration wetlands due to water depths. Use of small 140mm pots for some fringing vegetation shrubs and trees is also recommended.

Establishment

For the wetland to function correctly when operational, the correct sequence and timing of events must be adhered to during wetland commissioning. Factors such as storm events and water levels must be carefully managed to ensure that plants are not compromised by initial and subsequent water level increases and changes in water quality.

The wetlands and fringing vegetation should be planted in late spring or summer to maximise growth and establishment success. Upland fringing vegetation should be planted in winter so as to avoid the need for irrigation. From experience, planting the wetland in a single phase is the most effective way to ensure plant establishment and survival. Once planting is complete, a growth period of three months is required prior to commissioning of the wetland.

Supplementary planting after this phase may be required as part of the long-term site maintenance for the treatment areas. Supplementary planting and/or seeding may be required in areas with poor plant growth/germination to minimise the possible impact of weed growth or erosion.

Surface flow wetlands and fringing vegetation in areas where the root zone is dry <u>should be irrigated</u> prior to commissioning to maximise plant establishment. The subsurface flow wetland should have water levels at operational depth prior to planting.

10.0 OPERATIONAL, MANAGEMENT & MAINTENANCE REQUIREMENTS

10.1 OPERATION & MAINTENANCE

The wetland system will largely operate with minimum intervention, however routine maintenance is essential for longevity and performance. Ideally, an operator is required for preventative checks on a weekly or fortnightly basis to minimise any issues and costs associated with remedial works.

The treatment wetland will have adjustable operating depths to facilitate management of variable flows, mosquito and plant health maintenance. In general, operating depths should be adjusted once or twice a year to accommodate changes in storm flows. The lake recirculation pump may need to be moved periodically to address stagnant pockets.

A combination of routine and scheduled maintenance activities is critical to the life and performance of the Neil McDougall system. Routine (ongoing) maintenance tasks are those tasks which should be undertaken on a regular (weekly, monthly or quarterly) basis. Scheduled maintenance tasks are those tasks which should be undertaken annually or periodically (3 to 5 yearly). These activities will very for different system components.

Note, maintenance activities can be undertaken by City personnel with appropriate training. A detailed maintenance plan will be produced as part of the detailed design (Operating and Maintenance Manual). Operators Inspection Checklist (to be prepared as part of the Operating Manual) needs to be completed after each maintenance activity and any issues recorded and actioned.

Main Treatment Wetland & Filtration Wetlands

These wetlands are predominantly passive systems and hence maintenance is expected to be minimal. However, routine maintenance is still necessary to ensure correct function and longevity of the system.

The maintenance tasks for the integrated system can be divided into two categories as follows:

- Softworks: This includes the main wetland and filtration wetlands, open water zones and vegetation on bunds and embankments.
- Hardworks: This includes all civil structures such as rock inlets, outlet structures and all related pipework.

Typical maintenance activities are outlined below.

- Balance tank maintenance.
- Checking inlet/outlet structures and pipework – these should be checked for leaks and blockages weekly or monthly and following peak events. Pipes need to be cleaned periodically to ensure they are free of any obstructions which have the potential to cause clogging.
- Equipment (pumps) – to be inspected and maintained as per manufacturer’s specifications, and as part of routine maintenance quarterly or biannually and after peak rainfall events.

- Vegetation maintenance – checking plant health and replacing plants if necessary to ensure healthy plant cover;
- Weed-control - to be undertaken on a quarterly or bi-annual basis throughout the wetland.
- Plant health, density and diversity – to be monitored on a bi-annual basis throughout the wetland, and appropriate management measures undertaken to replace plants, or apply soil conditioners etc. if required.
- Sediment aeration – to be undertaken via wetland draw down and removal of excess accumulated biomass every 3 to 5 years; and
- Supplementary planting – if required.

Note, specific harvesting of wetland plants is not proposed as part of this design, since plant uptake is not the primary removal mechanism.

The functional life span of treatment wetlands is unlimited, however certain components (e.g. pumps, pipework, headwalls) will require a replacement schedule.

All maintenance can be undertaken by the City personnel who have been given appropriate training. A detailed maintenance plan will be produced as part of the detailed design (Operating and Maintenance Manual).

Sedimentation Basin

- Regular sediment removal - to be done every two years as a minimum.

Recirculation System

- Regular recirculation equipment (pumps) maintenance – to be inspected and maintained as per manufacturer's specifications.

10.2 MONITORING

A regular water quality monitoring program will need to be undertaken during the commissioning and operation of the integrated system, at least for the first two years regularly and thereafter periodically (e.g. prior to irrigation in summer only) to:

- Determine the quality of the Lake and assess cyanobacteria-related risks. If required (i.e. if cyanobacteria are detected) this information will be used to trigger corrective management measures,
- Enable assessment of the treatment performance of the proposed integrated system.

Note, a detailed Sampling and Monitoring Plan will need to be produced in later stages. The following will need to be considered in development of water quality sampling program:

- The current sampling of the Lake water and groundwater (sampling location, frequency of sampling and parameters) will remain unchanged.

- Individual components of the integrated solution (treatment wetland, filtration wetland) will be included in the program as follows:

    - Testing of influent and effluent quality for each component (surface flow, subsurface flow) – to ensure these components are efficient and are contributing to the water quality improvements of the Lake. This should be done on a regular basis (e.g. monthly) during the system commissioning.
    - Ad hoc testing of water quality through individual elements of treatment wetland (SF, SSF) - to test their operational capacities enabling detection and correction of any potential issues at an early stage.

Water quality parameters should be aligned with the current monitoring program and will need to include testing for physical and chemical parameters and algae sampling and identification. The proposed additions to this include testing for:

- Nitrogen (total nitrogen and nitrogen species) and phosphorus.

- Metals (total and dissolved) – to be included in commissioning sampling as a minimum.

- Biochemical Oxygen demand (BOD).

The monitoring program will be complemented by ongoing visual checks of vegetation health, inspection of hydraulic components and mechanical components.

Once the system is operational and the *Lemna*/cyanobacterial blooms are under control, monitoring should be limited to a standard suite for the Lake and at the wetland outflow.

11.0 COSTING

Order of magnitude cost (OMC) for construction and operating cost estimates have been undertaken and have been provided as APPENDIX 7 to this report.

Construction components include earthworks, hydraulic features, mechanical, electrical, and planting costs.

The site is considered to have a moderate to high risk of ASS disturbance, as such, a provisional sum for ASS investigation and management has been included in this cost estimate. Dewatering has also been provided as a provisional sum.

As detailed in Section 13, an Acid Sulfate Soil Investigation and Management Plan was prepared in April 2019 and the costs of implementing this plan will need to be further validated during the detailed design phase.

12.0 COMMUNITY CONSULTATION

The concept design for the integrated remediation system was presented to the community on signs that were installed in the park surrounding the Lake in February 2019. These design information panels are included in APPENDIX 8.

The community was also informed about the project and given the opportunity to provide their feedback via the online platform that was open for comments from 25th of February till 17th of March 2019. A summary of the concept design outlining projects aims, drivers, and key elements of the proposed treatment system was prepared by Syrinx, and uploaded to the City's web portal for public viewing.

The concept design was also presented at a community consultation meeting which was held on 7th of March 2019 at the Neil McDougall park. During this meeting community members were given an opportunity to provide comment on the design.

Stakeholder engagement feedback and outcomes are provided in APPENDIX 8.

The community feedback was predominately positive, with majority of survey responders strongly supporting the project and the proposed remediation design. Most of the comments reflected residents desire to be provided with more technical information regarding the proposed system and its broader impacts and benefits. Some of the common concerns included:

- Potential issue of the increase in midges and mosquitoes around the Lake;
- Issue of mature trees removal; and
- Exposure of the rock bund during dry periods which may allow access by cats or other predators and unauthorised human access to the island which may disrupt bird nesting sites.

All of these concerns have been addressed in the system design. Specifically, the preliminary design has minimised the removal of mature trees where possible noting that none of these trees are native.

A separate memo outlining specific mosquito management measures incorporated in the system design was also prepared and issued to the City.

Other comments relevant to the design included:

- A suggestion for the inclusion of beach areas around the Lake;
- A query regarding current location of Gross Pollutant Traps (GPTs) and whether these should be maintained on all of the drainage inlets; and
- A query regarding the effectiveness of the aerator.

One resident also asked what steps will be taken to provide a sanctuary to the birdlife in the park during construction. This comment is relevant to the construction phase of the works and should be addressed in the preparation of a Construction and Environmental Management Plan (CEMP) for the works.

All questions and comments from the community will be considered in detail and addressed where necessary in the detailed design phase and/or preparation of a CEMP for the works.

The summary of the key community comments and how these were addressed either in the system design or via broader City's efforts are summarised in *the Stakeholder engagement feedback and outcomes* report prepared by the City (APPENDIX 9).

13.0 ACID SULFATE SOIL INVESTIGATION & DEWATERING MANAGEMENT PLAN

In April 2019 Syrinx prepared an Acid Sulfate Soil Investigation and Management Plan and a Dewatering Management Plan (ASSIDMP) for land disturbance works during construction of the integrated remediation solution.

The ASSDMP concluded that if the integrated remediation solution is constructed according to the preliminary design ASS would be disturbed through both excavation and dewatering at the site. However, the potential impacts of disturbance of ASS can be effectively managed so <u>there was no need to modify the preliminary design based on the findings of the ASS investigation</u>. The findings of the ASSDMP will be considered further and addressed if necessary in the detailed design.

The results of the investigation and key conclusions and recommendations are summarised below:

- The proposed disturbance works are likely to disturb both ASS and groundwater on-site, through excavation activities and/or partial lowering of the water table (soil dewatering).
- Where ASS is disturbed at the site through excavations and/or as a result of lowering of the water table and where it is not appropriately managed, release and mobilisation of acidity and contaminants could occur and there may be unacceptable risks to both ecological and human receptors, both on-site and off-site.
- All lake sediments that will be excavated during the construction of the two treatment basins within the lake (SDB02 and SDB03) will require ASS management.

- Given the baseline groundwater chemistry and results of the baseline soil results (ASS detected), dewatering effluent must be managed (monitored and potentially dosed with carbonate) to reduce the potential impacts from ASS oxidation.

An ASS and Dewatering Management Plan (ASSDMP) was developed which outlines strategies to manage potential impacts of development works that are likely to disturb ASS and groundwater. In addition, the DMP outlines expected dewatering rates, duration of pumping and groundwater modelling which were used to determine the effect of dewatering to off-site receptors.

The ASSMP included the following site-specific management and monitoring actions:

- On-site and off-site options for the management and treatment/reuse or disposal of ASS during the construction of the two treatment basins within the lake.
- Management of exposed excavations in ASS (application of a 100 mm thick limestone layer).
- A strategy for treatment of dewatering effluent (retention/sedimentation basin and allowance for a lime dosing unit if water quality exceeds action criteria).
- Options for disposal of treated dewatering effluent (on-site infiltration is the preferred option).
- Method for decommissioning and remediation of all ASS treatment areas.
- Method for decommissioning and remediation of any dewatering effluent and infiltration areas.
- Monitoring program for dewatering effluent quality, water levels and groundwater and surface water quality before, during and post-construction works.
- Trigger values for water levels, dewatering effluent quality and groundwater and surface water quality and contingency actions should trigger values be exceeded.
- Recommendations for closure reporting following completion of the works.

REFERENCES

ANZECC and ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 2 Aquatic Ecosystems - Rationale and Background Information, Australian and New Zealand Environment and Conservation Council, Agricultural Resource Management Council of Australia. and New Zealand, Canberra.

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines.

City of South Perth (20014). City of South Perth Integrated Catchment Management Plan, September, 2004

SERCUL (2017) Water Quality in the South Perth Catchments: Winter – Spring 2016. South East Regional Centre for Urban Landcare Inc.

Syrinx (2018). Neil Mcdougall Lake Park: Design of Integrated Management & Remediation Solution (Concept Design). Prepared for the City of South Perth, July 2018.