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Response to EDQ- Water Quality

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Response to EDQ- Water Quality

Prepared for:	Pacifiq Communities
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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1 Introduction

1.1 Preamble

This section of the report describes the proposed Flinders Master Planned Community, Precinct 1 Lake, and the objectives of the report.

1.2 Proposed Development

The Flinders Master Planned Community (hereafter referred to as 'Flinders') is a 4,000 hectare landholding being developed by Pacifiq Communities. Flinders is located in Undullah, south west of Logan City.

Flinders includes an area of approximately 1,000 hectares known as 'Precinct 1', which is located within the Greater Flagstone Priority Development Area. Precinct 1 is proposed to ultimately accommodate approximately 18,000 residents in 7,282 dwellings.

It is proposed that a lake will be integrated into Precinct 1 to enhance amenity for the benefit of the local community and to provide recreational opportunities for future residents. The lake is proposed to be located in the south-east corner of Precinct 1 at the headwaters of an unnamed creek.

1.3 Lake Description

The lake is intended to be constructed in the lowest area of the site as shown in Figure 1-1. It is to be formed by constructing a dam across the unnamed tributary upstream of the southern site boundary. The lake is comprised of one larger waterbody, with an approximate area of 22.2 hectares and a smaller waterbody located upstream, with an area of approximately 3.7 hectares. Both waterbodies will have an average typical water depth of the order of 4 metres. Note that although the lake is made up of two waterbodies, for the purposes of this report they will be referred to as 'the lake'.

The volume of the lake at full supply level is estimated to be 915 ML.

1.4 Report Objectives

A development application for a material change of use was submitted to Economic Development Queensland (EDQ) for the proposed Flinders development. Subsequent to the submission and review of the application, in a letter dated 29 May 2017 EDQ identified a number of Further Issues to be addressed.

A copy of the Further Issues letter is provided in Appendix A. Of the Further Issues, Point 2 and Point 3 relate to the management of water quality.

Point 2 and Point 3 from the letter are reproduced below. A response to each point is provided in Section 6.

Water quality management

2. Undertake a preliminary analysis to determine the likely lake water quality obtained from the inflow streams and any management measures necessary to maintain the required water quality objectives. It is accepted that detailed analysis is not required at this time, however the preliminary water quality analysis, combined with scenario testing of outcomes, will be a way to provide sufficient confidence in the likely outcomes.

3. Please confirm the preferred management measures for lake water quality i.e. is this by recirculation through upstream waterways; is it by the use of a water treatment plant; or is it both or some other measures. If a water treatment plant is preferred its operating parameter and likely process should be defined.

In order to address these items, a preliminary water quality assessment was completed. To gain an understanding of the level of treatment that is practicable using a water treatment plant (in addition to natural systems), a concept option was developed with respect to the treatment of lake water. This provided a sound basis for the water quality assessment.

However, it is stressed that while one option for the treatment of lake water was considered for this report, alternate options may be available for the treatment of runoff and it is intended that the most efficacious and appropriate system will ultimately be defined as part of further design. This work will include additional soil testing to provide increased knowledge with regard to the soils on the site and the measures required to maintain water quality in the lake in the long term.

Further, it is necessary to recognise that the focus of the analysis was on confirming that water quality could be guaranteed in the long term through treatment. As a consequence, the analysis considered the most conservative case and did not consider internal lake treatment processes to remove nutrients (for example floating wetlands, fringing vegetation, emergent macrophytes). Future design will consider such options (in addition to the recirculation of water through the stormwater quality control devices built for the treatment of site runoff) to maximise the use of natural processes and consideration could even be given to reducing the size of the lake. The inclusion of these elements in addition to detailed water quality modelling will determine the level of additional treatment and rate of pumping that is required for the lake.

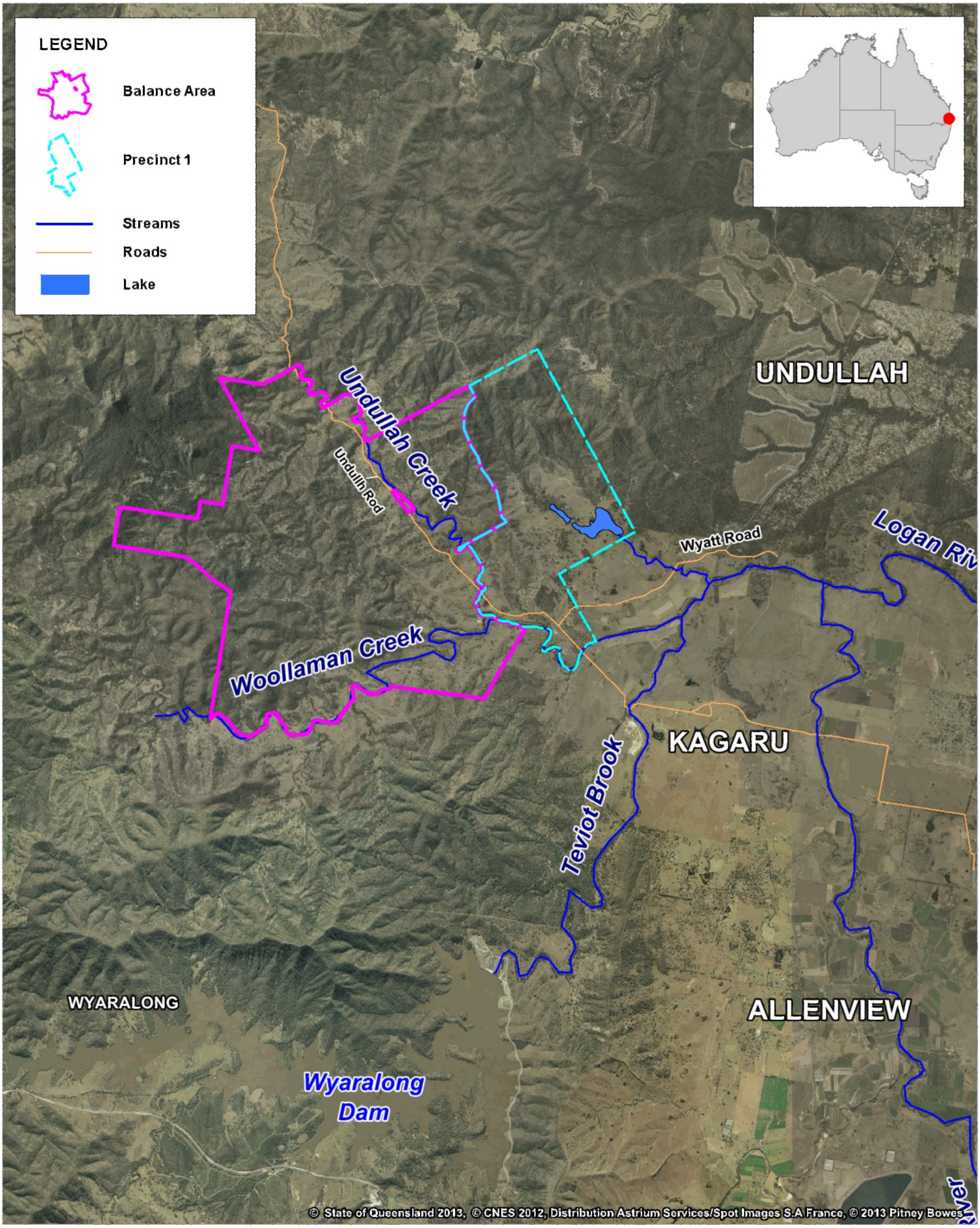
Point 7 of the letter relates to maintenance and operational costs.

‘7. *Please provide further detail with respect to the costs of the maintenance and operations of the lake. This should include considerations of the costs of:*

- *Aquatic weed harvesting;*
- *Invasive pests: fish, snails;*
- *Riparian edge maintenance;*
- *Lake edge treatments;*
- *Water quality monitoring;*
- *Recirculation pumping;*
- *Water Treatment Plant;*
- *Upstream waterway maintenance;*
- *Destratification;*

- *Main embankment / Dam;*
- *Fish kill response;*
- *Top up water from Lake Wyaralong; and*
- *Proposed structures ie jetties, pontoons, boat ramps etc.'*

The relationship between this report and the ability to accurately define costs at this point is discussed in Section 6.



Title:
Location of Site

Figure:
1-1

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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2 Source of Lake Water

2.1 Preamble

This section provides an overview of water balance modelling undertaken to provide an understanding of the inflow streams to the proposed lake during the main development phases.

2.2 Water Balance Modelling

A customised water balance model has been developed for the proposed lake to provide an understanding of anticipated water inputs and outputs and water level variation. The methodology and detailed results of the water balance modelling are contained in the *Flinders Precinct 1: Concept Lake Management Plan* (BMT WBM 2017a). In summary:

- There are three main phases of the lake development which each have different proportions of inflow streams, including:
  - (a) Lake fill
  - (b) Pre-development
  - (c) Post-development
- The lake will most likely be filled by water from Wyaralong Dam. The water is proposed to be discharged to Teviot Brook, and subsequently extracted and pumped to the lake. The proposed extraction point is at the confluence of Teviot Brook and Woollaman Creek.
- Once the lake is filled the majority of water inputs to the lake are predicted to be from catchment flows.
- Prior to the proposed development of the contributing catchment (to the proposed lake), additional sources of water are anticipated to be required to prevent unacceptable water level variation. The water balance modelling indicates that the predicted required daily average top-up water will be 500m^3/day. This required 'top-up' volume would reduce as the catchment is developed.
- For developed catchment conditions (with the proposed development of the site), the predicted water level variation for the proposed lake achieves the set performance criteria with no additional 'top-up' from any source. However, additional 'top up' water of 314 m^3/day has been included for the purposes of irrigation.
- Direct rainfall also comprises a significant volume of water entering the lake per day.

As outlined above the source of water for the lake will vary over the lifetime of the lake. Table 2-1 outlines the estimated proportion of water from the three sources over the three main stages of the development.

Table 2-1 Sources of Inflow Lake Water

Stage	Average Daily Volume of Water entering lakes (m3)			
	Wyaralong Dam via Teviot Brook	Catchment Runoff	Direct Rainfall	Total
Lake Fill	0.9GL* (100%)			
Pre Development	500 (21.4%)	1193 (51.0%)	645 (27.6%)	2338
Post Development	314 (8.7%)**	2671 (73.6%)	645 (17.8%)	3630

*Note that this value is the full volume of the lake.

**A small proportion of water from Wyaralong Dam is included in the 'post development' phase. This water is included for irrigation purposes and is not expected to be required to maintain lake water levels.

3 Lake Inflow Water Quality

3.1 Preamble

As outlined in Section 2 lake water will be made up of three main sources, including water released from Wyaralong Dam, catchment runoff and direct rainfall onto the lake. This section will outline the estimated water quality from each of these sources.

3.2 Fill and 'top up' water from Wyaralong Dam

3.2.1 Description

Wyaralong Dam is located 6 km south-west of the Flinders development. Outflows from the dam discharge into Teviot Brook and flow in a north easterly direction past the south east corner of the site. It is proposed that water from Wyaralong Dam will be released and pumped from Teviot Brook to fill and 'top up' the proposed lake.

3.2.2 Method

Three samples have been collected from Teviot Brook during releases from Wyaralong Dam. The samples were collected on the following dates:

- 21 March 2017
- 22 March 2017
- 17 May 2017

3.2.3 Results

The average of the three results have been summarised in Table 3-1. Appendix B contains all three sets of results.

Table 3-1 Water Quality Monitoring Results, Wyaralong Dam via Teviot Brook

Parameter	Unit	Value
Total suspended solids	mg/L	20
Total phosphorus	mg/L	0.072
Orthophosphate	mg/L	0.025
Total dissolved phosphorus	mg/L	0.029*
Total nitrogen	mg/L	1.2
Nitrate and nitrite	mg/L	0.11
Ammonia	mg/L	0.041
Total dissolved nitrogen	mg/L	0.86*

*Only one sample was analysed for total dissolved nitrogen and total dissolved phosphorus on 17 May 2017

3.3 Catchment Runoff

3.3.1 Description

Three stages in the development have been assessed to provide an understanding of the catchment runoff. These are:

(1) **Undeveloped catchment (prior to significant development)** – when the lake is first constructed the existing catchment upstream of the proposed lake will be comprised of large tracts of land being actively grazed by cattle. However, this land use is generally confined by the steeper topography of the Teviot Range, which is the upper catchment to the lake. The upper catchment is undeveloped and features open forest woodlands.

(2) **Partially developed catchment** – once development has occurred the lake catchment will contain a number of land uses, including residential development, open space, and environmental protection zones.

Runoff from residential areas will be treated to meet the water quality objectives defined in the *State Planning Policy* (DILGP). The stormwater quality management strategy for the development area includes the construction of bioretention basins which will be integrated into the open space areas immediately downstream of areas proposed for development.

For the assessment, it was assumed that 50% of the development has occurred with stormwater management measures in place to treat runoff. Runoff from undeveloped parts of the catchment was assumed to be as per the undeveloped catchment to reflect the fact that catchment management practices to reduce erosion in open space areas will be under establishment as development proceeds.

(3) **Developed catchment** – once development has occurred the lake catchment will contain a number of land uses, including residential development, open space, and environmental protection zones.

Similar to the partially developed catchment case, runoff from residential areas will be treated to meet the water quality objectives defined in the *State Planning Policy* (DILGP).

As this scenario reflects the long term condition of the catchment, the scenario includes the soil rehabilitation and erosion protection works that will be undertaken in currently disturbed open space areas.

The results of modelling of developed catchment conditions presented in this report is contingent on both the treatment of runoff from urban areas and the rehabilitation of disturbed open space areas.

3.3.2 Method

To determine the water quality from catchment runoff, two sources of data were reviewed, including:

(1) Baseline water quality monitoring

(2) Predictions from water quality modelling.

3.3.2.1 Baseline Water Quality Monitoring

Baseline water quality was monitored at four locations within Precinct 1 of the Flinders development. Three of these sites (Sites A, B and D) are located within the proposed lake catchment as shown in Figure B-1. The majority of monitoring at Sites B and D has been undertaken with rising stage samplers; whilst the greater part of monitoring at Site A has been undertaken through grab sampling during runoff events.

Undeveloped catchment scenario: Site A is located at the approximate site of the proposed lake and provides a good representation of inflow to the proposed lake from the undeveloped catchment.

Partially developed and developed catchment scenario: Runoff water quality from the urbanised portion of the 'developed' catchment can only be estimated using water quality modelling. However, Sites B and D, are located in the upper catchment of the proposed lake. As the results collected at both sites reflect the current condition of the upstream catchment, the results are conservative with respect to open space areas as management practices (e.g. sediment basins, dispersive soil management, bank stabilisation) will improve water quality for the developed case. Consequently, and the water quality results obtained at Sites B and D are used for guidance only.

3.3.2.2 Predictions from water quality modelling

Version 6.1 of the MUSIC modelling software was used to assess the generation and transportation of flows and pollutant loads from Precinct 1.

- ***Undeveloped catchment scenario:***

  Based on a review of current catchment landuse, for the purposes of modelling it was assumed that the undeveloped (prior to significant development) land use is equivalent to the 'rural residential' land use defined in the *MUSIC Modelling Guidelines* (Healthy Waterways, Version 1, 2010).

  Although it is anticipated that management practices (e.g. management of dispersive soils, bank stabilisation, sediment basins) will be incorporated to improve the quality of runoff from the catchment, the practices will be progressively implemented. When the lake is first filled, it is expected that management practices will not be fully in place. Consequently, a conservative assumption was made with respect to land use for conditions prior to significant development.

- ***Partially developed catchment scenario:***

  The developed catchment scenario (refer below) was revised to reflect only 50 percent of the development being completed (with treatment measures in place). For this scenario, it was conservatively assumed that the catchment management practices intended for open space areas will be in the establishment phase and consequently the land use adopted for the undeveloped case (i.e. rural residential') was retained for this case.

- ***Developed catchment (long term) scenario:***

  The urban development was previously modelled as part of the *Flinders Precinct 1: Stormwater Quality Management Plan* (BMT WBM, 2017b). This model was expanded to include the full catchment area draining to the lake (i.e. areas upstream of the urban development area).

  To account for management practices in the upper lake catchment which will reduce sediment and nutrient loads, for the purposes of modelling it was assumed that half of the upstream land use is 'rural residential' and half is 'forested' according to the land uses defined in the *MUSIC Modelling Guidelines* (Healthy Waterways, Version 1, 2010).

3.3.3 Results

3.3.3.1 Baseline Water Quality Monitoring

The results of the baseline water quality monitoring are presented in Table 3-2. Appendix B contains details of all the water quality monitoring results.

Table 3-2 Baseline Water Quality Monitoring Results, Precinct 1

Parameter	Unit	Water Quality Objective	Average concentrations		
			Site A	Site B	Site D
Total suspended solids	mg/L	-	676	192	92
Total phosphorus	mg/L	0.075	0.086	0.16	0.13
Orthophosphate	mg/L	-	0.016		
Total nitrogen	mg/L	0.7	1.4	1.6	1.3
Nitrate and nitrite	mg/L	-	0.10		
Ammonia	mg/L	-	0.032		
No. of samples		-	*5*	*6*	*4*

The above results can be summarised as follows:

- The concentration of total suspended solids is higher at Site A than Site B and Site D. This is due to the one sample with a particularly high TSS concentration of 3,500 mg/L collected on 22 February 2016, and the dispersive soils that are found on the site.
- On average, the concentration of Total Phosphorus is higher at Sites B and D than Site A.
- The concentration of Total Nitrogen is similar across all three sites.
- The average concentration of Total Phosphorus and Total Nitrogen at all sites is higher than the proposed water quality objectives (WQOs) for the lake.

3.3.3.2 Predictions from water quality modelling

The results of the MUSIC modelling are outlined in Table 3-3. The average water quality concentrations have been calculated using the total average annual load and flows. This would represent the average water quality concentration of ‘pollutants’ entering the lakes.

Table 3-3 Modelled Water Quality Results, Average Concentrations

Parameter	Unit	Average concentrations		
		Undeveloped	Partial Development	Developed
Total suspended solids	mg/L	239	178	112
Total Phosphorus	mg/L	0.20	0.19	0.17
Total Nitrogen	mg/L	1.6	1.6	1.4

The results outlined above highlight that there is predicted to be an improvement in the average water quality concentration from catchment runoff with development, which will include stormwater management measures (e.g. bioretention basins) and management measures to improve the undeveloped portion of the lake catchment (e.g. management of dispersive soils, bank stabilisation, sediment basins).

3.3.3.3 Comparison of Monitored and Modelled Results

A comparison of the monitored and modelled water quality results highlights the following:

- The average concentration of total suspended solids varies from 92mg/L at Site D to 676mg/L at Site A. The modelled results for both the ‘undeveloped’ scenario and ‘developed’ scenario fell between these two monitoring results.
- The average measured concentration of Total Phosphorus and Total Nitrogen was similar to the modelled results, with the exception of Site A. The average measured concentration of Total Phosphorus at Site A was approximately half of the modelled results for Total Posphorus.

3.4 Anticipated Water Quality Concentrations

Table 3-4 provides a summary of the anticipated water quality concentrations for all inflow streams based on an analysis of both the water quality monitoring and water quality modelling results. It also includes an estimate of the water quality from rainfall in south-east Queensland (BMT WBM, 2003).

Table 3-4 Summary of Water Quality Concentrations from all Potential Inflow Streams

Parameter	Average concentration			
	'Top up' water from Wyaralong Dam	Catchment Runoff from Undeveloped catchment*	Catchment Runoff from developed catchment*	Rainfall**
Total Suspended Solids	20	239	112	0
Total Phosphorus	0.072	0.20	0.17	0.006
Orthophosphate	0.025	-	-	-
Total Dissolved Phosphorus	0.029	-	-	-
Total Nitrogen	1.2	1.6	1.4	0.4
Nitrate and Nitrite	0.11	-	-	-
Ammonia	0.041	-	-	-
Total Dissolved Nitrogen	0.86	-	-	-

*Results in table are those derived from MUSIC modelling

**Rainfall event mean concentrations sourced from Barry et al. (2004).

4 Estimated Lake Water Quality- No Treatment

The catchment model was first used to provide an estimate of the lake water quality that would occur without treatment measures in place. Modelling considered three stages of lake development:

- Lake fill, when the quality of water in the lake will be dominated by the quality of water drawn from Wyaralong Dam;
- Undeveloped catchment, which reflects conditions when only limited urban development has commenced; and
- Developed catchment, which reflects the long term water quality in the lake based on established management and treatment measures in urban and open space areas.

The lake water quality calculations were based on the inflow volumes outlined in Section 2 and the water quality results summarised in Section 3.4. It should be noted that no in-lake processes were accounted for and as a result Total Suspended Solids concentrations will be overestimated.

The results of the analysis are shown in Table 4-1.

Table 4-1 Estimated Lake Water Quality

Stage	Average Concentration (mg/L)		
	Total Suspended Solids	Total Phosphorus	Total Nitrogen
WQOs*	NA	0.07	0.75
Lake Fill	20	0.072	1.2
Undeveloped catchment	126	0.12	1.2
Developed catchment	84	0.13	1.2

*Recommended lake water quality objectives (WQOs) (BMT WBM 2017a).

As previously discussed, catchment runoff from the ‘undeveloped catchment’ stage was assumed to be from a land use equivalent to the ‘rural residential’ land use defined in the *MUSIC Modelling Guidelines* (Healthy Waterways, Version 1, 2010). For the ‘developed catchment’ it was assumed that land management practices (e.g. management of dispersive soils, bank stabilisation) and/ or downstream management practices (e.g. sediment basins) will be incorporated to ensure the water quality from the upstream catchment is improved prior to runoff entering the lake. Therefore, the catchment runoff from the undeveloped portion of the lake catchment was assumed to be 50 percent ‘rural residential’ and 50 percent ‘forested’ land use in the MUSIC model.

For all scenarios, the average water quality does not comply with the adopted water quality objective. Consequently, a treatment system will be required to ensure lake water quality objectives are maintained.

5 Lake Water Quality Treatment

5.1 Preamble

The quality of water within the proposed lake at Flinders Precinct 1 will be important to the ecological, amenity and recreational values of the lake. The design, construction, establishment and management of the lake must be appropriately undertaken to protect lake water quality. This section describes two potential management measures for protecting the lake water quality.

5.2 Natural treatment of lake water

5.2.1 Description

In accordance with *State Planning Policy* (DLGIP 2017), all new development (greater than 2500m^2 that results in an impervious area greater than 25 percent of the net developable area or 6 or more dwellings) are required to achieve minimum reductions in mean annual stormwater pollutant loads relative to unmitigated development (see Appendix 3 of the *State Planning Policy*).

It is subsequently necessary for stormwater management measures to be appropriately integrated within the development to comply with the aforementioned requirements. The most likely suitable measures for the site are bioretention systems and, potentially, wetlands. The treatment measures will be integrated into the open space areas downstream of development areas. In addition to providing treatment to achieve regulatory requirements, these systems have the potential to provide additional treatment/polishing to recirculated lake waters.

5.2.2 Method

The preliminary feasibility of treatment via natural systems was completed in terms of treatment of recirculated lake waters. Water By Design (2013) cites that bioretention systems can be used in a waterbody recirculation system. However, it is anticipated that individual bioretention cells would need to be 'rested' periodically to dry (and not be continually loaded with recirculated water), to avoid algal growth on the filter media and subsequent blockage. For the purposes of assessing this option, the maximum hydraulic loading rate for bioretention systems was assumed to be 200mm/day (one tenth of the average saturated hydraulic conductivity of bioretention filter media).

As part of this assessment it was assumed that all stormwater management measures flowing to the Precinct 1 lake were available to be used to treat recirculated lake waters.

Based on and to be consistent with the water quality treatment plant detailed in Section 5.3, nominal 60 and 90 day lake residence times were considered. In reality, it is expected that a longer turnover period could be generally adopted and it is intended that the plant will be operated to respond to water quality in the lake.

5.2.3 Results

The results of the assessment are summarised in Table 5-1.

Table 5-1 Summary of Assessment of treating lake waters through bioretention systems

Parameter	Unit	Value
Lake volume (upper and lower lake)	m^3	915,297
Pumping to achieve a 60-day residence time	m^3/day	15,255
Pumping to achieve a 90-day residence time	m^3/day	10,170
Average post-development inflow to lake	m^3/day	3,630
Assumed maximum loading rate to bioretention	m/day	0.2
Approx. bioretention area required to achieve water quality objectives defined in *State Planning Policy*	m^2	21,098
Approx. maximum hydraulic loading rate of potential bioretention	m^3/day	4,220

Key findings from the above analysis include the following:

- The predicted maximum hydraulic loading rate for potential bioretention systems is approximately 4,220m^3/day, which is well below the rate of pumping (and associated treatment) required to achieve a 60 or 90 day turnover, providing 28 percent and 40 percent respectively of the required treatment.
- The predicted maximum hydraulic loading rate for the bioretention systems is greater than the average post-development inflow to the lake.

The results indicate that the bioretention systems are not sufficient in size to ensure a nominal 60 to 90 day residence time in the lake. However, the water quality in the lake has the potential to be maintained by recirculating lake waters through the bioretention systems, thus minimising the requirements of a lake water treatment plant.

It should also be noted that some recirculation of lake waters through the treatment devices will be likely to improve the function, amenity and ecological values of the treatment devices – by providing a supply of water in extended dry periods (to ensure the systems don't "dry out"), reducing any potential for vegetation die-back (due to lack of water) and associated reduced treatment performance.

While it is intended that natural systems will be used wherever and to as great an extent as practicable, it is recognised that the bioretention area required for the treatment of runoff will not be sufficient to also cater for the treatment of recirculated lake water. Although consideration was given to adopting a larger area for bioretention systems (and will continue to be considered as part of detailed design), given the need to ensure water quality in the lake and the desirability to adopt a treatment system where the rate of treatment can be readily increased or decreased to suit actual conditions, the option of including physical treatment of lake water was developed and assessed.

5.3 Physical treatment of lake water

As discussed previously, it may be necessary to have an additional physical treatment system for the lake water. There are a number of mechanisms that this can be provided. For the purposes of this report Simmonds and Bristow were engaged to provide specialist advice in relation to treatment options.

In particular, care was taken to ensure that the removal rates adopted for treatment options reflected the fact that the influent water quality was stormwater rather than wastewater. In the latter case, the higher influent concentrations of nutrients in particular allow higher removal efficiencies to be achieved for a given treatment systems. The significantly lower influent concentrations associated with stormwater result in a lower relative removal efficiency for a given treatment system.

5.3.1 Description

For concept planning, advice was provided by Simmonds and Bristow in relation to a system that would be suitable for the treatment of lake water.

The system consequently assessed for this report consists of the following units:

- Nitrifying trickling filter: nitrification (conversion of ammonia nitrogen to nitrate and nitrite)
- Denitrification media filter: denitrification (conversion of nitrate and nitrite to ammonia gas)
- Chemical phosphorus removal: coagulation with Alum
- Cloth media disk filtration: removal of coagulated phosphorus and suspended solids (including algal cells).

Initial treatment process modelling, based on the likely variation in water quality in the lake, was undertaken by Simmonds and Bristow to determine the removal rates and effectiveness associated with the concept system. The resultant removal rates are presented in Table 5-2.

Table 5-2 Predicted Pollutant Removal Rates, Treatment Plant

Parameter	Value	Notes
Total Phosphorus	80%	Estimated based on modelling
Total Nitrogen	35%	Estimated based on modelling
Total Suspended Solids	13%	Assumed based on filter performance and coagulant dosing

The above removal rates generally represent the lower removal rates calculated during the modelling process, providing a more conservative test of the system and rates that are applicable across the likely range of sediment and nutrient inflow concentrations. It is also noted that the concept system identified by Simmonds and Bristow represents one option for the treatment of lake water, and is only intended to demonstrate that appropriate lake water quality can be achieved.

The configuration of the actual treatment system will be the subject of subsequent detailed design. In particular, the treatment system assumes that no other treatment (other than sedimentation) will occur. In reality, the recirculation system will make use of stormwater treatment measures that will treat site runoff to as great an extent as practicable and, as part of further design, consideration will be given to options for maximising in-lake treatment processes (for example floating wetlands or other areas of fringing vegetation). Further, the lake will include a number of missing and de-stratification measures that will promote good water quality in the lake.

The adopted removal rates also reflect the coagulant load required to treat Total Nitrogen and Total Phosphorus. With respect to Total Suspended Solids, it was determined that a considerably greater coagulant load would be required to remove additional sediment and lower turbidity. The inclusion of such additional treatment was not considered to be justified given the large residence time afforded by the lake and the resultant ability for particulate matter to settle.

Although there is some uncertainty associated with the amount of sedimentation that will occur in practice (as the rate of settlement is dependent on particle size and therefore the composition of soils within the catchment and the nature of erosion that occurs), available data provides a reasonable starting point for the consideration of lake settlement. For the purposes of this report, based on a review of sedimentation rates and residence times the mass balance assumed that sedimentation within the lake would reduce the Total Suspended Solids concentration by 80 percent. This is similar to the expected removal rate given by Fletcher et al. (2004) of 60 to 85 percent for a pond, dependant on particle size distribution. It was also assumed that the lake would not provide any treatment with respect to nutrients.

As the MUSIC program only considers sediment and nutrient loads, it was not possible to model the turbidity of runoff or its treatment. While the reduction in sediment load derived from MUSIC was able to be calculated using the mass balance model, a water quality objective was not defined with respect to sediment because concentration-based water quality objectives (other than for construction sites) for water bodies typically refer to turbidity.

Given this, it was necessary to assume a conversion factor between Total Suspended Solids and turbidity in order for the efficacy of the treatment system to be assessed. Based on typical relationships, a fixed conversion factor of two was assumed (i.e. turbidity is equal to twice the Total Suspended Solids concentration) for runoff entering the lake. It is acknowledged that the relationship between turbidity and Total Suspended Solids is variable, and further consideration of this issue will be required as part of subsequent design. It is envisaged that this further consideration will involve additional soil sampling and testing, and the evaluation of the load reduction that will be afforded by the adoption of soil conservation measures.

Noting that turbidity is typically associated with finer particles which settle at a significantly slower rate to larger soil particles, consideration was given to whether the adopted removal efficiency with respect to sediment would provide an unrealistic reduction in turbidity. Advice was sought from erosion and soil specialists Wholistic Environment in relation to the issue of turbidity. As noted in their response to soil issues raised by EDQ (Wholistic, July 2017), the level of salinity in runoff entering the lake, although relatively low compared to a fully saline environment, would be sufficient to result in the coagulation of fine particles and the ability for the heavier resultant combined particles to settle in the lake.

Based on this advice, for the purposes of modelling the same conversion factor was applied to derive turbidity levels following the reduction in Total Suspended Solids afforded by treatment and settlement.

5.3.2 Assessment

For the purposes of this report mass balance water quality modelling was undertaken to demonstrate the expected water quality achieved in the lake with the inclusion of a physical treatment system. The mass balance was undertaken using the MUSIC model and a customised water quality mass balance model over a 10-year period.

A combination of scenarios was assessed, including three stages of the development, and three treatment rates to represent different residence times. A variation in residence time (or treatment rates) was assessed to determine the variation in water quality and time taken to recover from high nutrient and sediment loads. Based on this assessment and expected requirements with respect to treatment, residence times of 60 and 90 days were adopted for this report to reflect anticipated conditions under normal operation.

The analysis also considered a shorter residence time to reflect the more rapid improvement in water quality that could be achieved if a lower residence time were to be adopted for a short period to address a poor water quality event in the lake. In such a situation, the main and standby pumps used under normal circumstances would all be used.

For the short term rapid turnover case, a residence time of 20 days was considered based on the *Mackay Engineering Design Guidelines: Constructed Lakes* (Mackay City Council, 2008). However, based on the water quality modelling presented in this report and experience with other lakes, it is considered that the 20 day residence time nominated in the Mackay guidelines is not directly relevant to Flinders lake. Consequently, although a residence time of 20 days was considered for the emergency pumping scenario, the actual emergency pumping rate will be determined as part of further design.

The scenarios assessed are detailed below.

Lake Development Stages

(1) **Prior to significant development** – approximately 50% of the water in the lake is from catchment runoff, with the land use assumed to be 'rural residential' to reflect the previous activity within the catchment and the reality that the catchment management practices to be adopted for the development will be implemented as part of the development. The remaining lake water is made up of direct rainfall and 'top up' water from Wyaralong Dam.

(2) **Partial development** – 50% of the development is assumed to have occurred with stormwater management measures in place to treat runoff. The remaining catchment is assumed to be 'rural residential'. This scenario is considered to be slightly conservative as catchment management practices will be well underway by this stage of the development.

(3) **Post development** – Full development is assumed with stormwater management measures. The remaining upstream catchment is assumed to be 50% 'forest' and 50% 'rural residential' to account for catchment management measures in place (e.g. sediment basins, dispersive soil management, bank stabilisation). This scenario reflects the long term condition of the lake.

Residence Times

(1) Nominal **60-day** residence time, which is equivalent to a treatment rate of 180 L/s through the WTP

(2) Nominal **90-day** residence time, which is equivalent to a treatment rate of 120 L/s through the WTP

(3) Rapid short term turnover **(20-day)** residence time, which is equivalent to a treatment rate of 540 L/s through the WTP

5.3.3 Results

The results of the water quality mass balance modelling are presented in Figure C-1 to Figure C-3 and show the time taken for the treatment system to return to an acceptable water quality following elevated levels increases as the turnover rate is decreased. These results do not take into account any combined benefit of the natural treatment systems described previously in this report.

The median water quality was calculated and compared to the relevant water quality objective (WQO) and is shown in Table 5-3 (with values exceeding the WQOs shaded). As expected, the figures show the time taken for the treatment system to return to an acceptable water quality following elevated levels increases as the turnover rate is decreased.

It should also be noted that the water quality modelling was undertaken for Total Phosphorus, Total Nitrogen and Total Suspended Solids.

The following key points can be made regarding the results of the lake water quality mass balance modelling:

- Total Phosphorus water quality objectives are met for all development stages and at all the lake residence times analysed.
- Total Nitrogen water quality objective is met for the 60-day lake residence time for all development stages, however the water quality objective is not met when the residence time is 90 days for the pre and partial development cases. For these cases, a residence time closer to 60 days may be necessary.
- There is no water quality objective for total suspended solids. The median concentration of Total Suspended Solids in the lake decreases as the development proceeds, with the lowest median concentration at the post development stage.
- The turbidity water quality objective would only be met during the post development phase with the use of the short period residence time. However, the calculated median concentration for longer residence times is only slightly greater than the water quality objective. With the inclusion of the treatment afforded by the use of natural systems and depending on the actual performance of the lake, it is expected that a longer residence time can be adopted in periods when significant catchment runoff is not occurring, with the option of using a reduced residence time for limited periods if necessary.

Table 5-3 Estimated Median Water Quality in Proposed Lake with Physical Treatment Only

Lake Residence Time	Estimated Median Water Quality in Proposed Lakes		
	Pre Development	Partial Development	Post Development
Total Phosphorus (mg/L)			
Rapid for short period (20 days)	0.01	0.02	0.02
60 days	0.03	0.04	0.04
90 days	0.05	0.06	0.05
WQO	0.07	0.07	0.07
Total Nitrogen (mg/L)			
Rapid for short period (20 days)	0.24	0.27	0.28
60 days	0.65	0.68	0.60
90 days	**0.92**	**0.88**	**0.75**
WQO	0.75	0.75	0.75
Total Suspended Solids (mg/L)			
Rapid for short period (20 days)	17	11	7
60 days	36	22	12
90 days	41	26	14
WQO	NA	NA	
Turbidity (NTU)			
Rapid for short period (20 days)	**33**	**22**	14
60 days	**72**	**44**	**24**
90 days	**83**	**52**	**27**
WQO	20	20	20

5.4 Operation in Practise

Although the modelling results presented in Section 5.3.3 consider fixed turnover rates (nominally 60 to 90 days or longer), in practise the turnover rate would be set based on prevailing lake conditions. With a treatment plant in place there is considerable flexibility with respect to residence time compared to a natural system. The treatment plant would be designed to allow for a more rapid turnover for short periods in the event of a significant reduction in water quality occurring (for example as a result of a major runoff event). However, under more standard conditions, the maintenance of water quality in the lake would be achieved via circulation through the natural (bio-retention) treatment systems together with a reduced rate of circulation to maximise operational efficiency.

Based on the results obtained from the mass balance modelling, it is expected that appropriate water quality will be achieved by a system with a typical residence time of between 60 and 90 days and the ability to reduce residence time for short periods if necessary.

6 Response to Water Quality Matters in Further Issues Letter

Two matters relating to water quality management were raised in the Further Issues letter from EDQ dated 29 May 2017 (refer Appendix A). Modelling was completed to address the matters. The results of the modelling, which are presented in the preceding sections of this report, allow the following responses to be made in relation to the two matters.

2. *Undertake a preliminary analysis to determine the likely lake water quality obtained from the inflow streams and any management measures necessary to maintain the required water quality objectives. It is accepted that detailed analysis is not required at this time, however the preliminary water quality analysis, combined with scenario testing of outcomes, will be a way to provide sufficient confidence in the likely outcomes.*

   The likely lake water quality associated with the water quality from inflow streams (initial fill water, top up water, and catchment runoff) without any treatment measures in place and discounting any water quality improvement afforded by the lake is detailed in Section 3 and Section 4. Without treatment, it is expected that water quality in the lake will not meet the adopted water quality objectives.

   Modelling of natural treatment systems (recirculating lake water through the stormwater treatment devices used to treat runoff from the developed parts of the catchment) indicated (refer Section 5.2 and the response to Item 3) that the use of natural systems will provide some of the required improvement in lake water quality.

   The remainder of the required treatment could be achieved via a dedicated treatment plant. Based on the results obtained from MUSIC and mass balance modelling for one treatment scenario, it is expected that appropriate water quality will be achieved by a system with a nominal residence time of between 60 and 90 days and the ability to reduce residence times significantly for short periods if necessary (eg. 20 days).

3. *Please confirm the preferred management measures for lake water quality i.e. is this by recirculation through upstream waterways; is it by the use of a water treatment plant; or is it both or some other measures. If a water treatment plant is preferred its operating parameter and likely process should be defined.*

   The preferred management measure is to rely on recirculation through natural systems to as great an extent as possible. The calculations presented in Section 5.2 suggest that the bio-retention systems provided to treat local catchment runoff could achieve between 28 and 40 percent of the required recirculation for residence times of 60 days and 90 days respectively.

   However, it will not be practicable to provide a treatment system that is fully based on natural systems due to the area required and the difficulty in providing a system that is capable of dealing with a residence time that can vary between 60 and 90 days and be reduced significantly (eg. 20 days) if a more rapid turnover is required for a short period. To provide the ability to adjust the residence time in the lake based on the variation in water quality in the lake over time, a formal treatment plant is considered as part of the solution to meeting Water Quality Objectives.

For the report, one option for the treatment of lake water was considered to confirm that adequate water quality can be guaranteed in the long term. This option was conservative as it did not consider internal lake treatment processes to remove nutrients (for example floating wetlands, fringing vegetation, and emergent macrophytes). Future design will consider such options (in addition to the use of stormwater quality control devices for the treatment of site runoff) to maximise the use of natural processes together with alternate options for the treatment of runoff.

As a result of this future design, the pump rate appropriate to the lake (under both normal and emergency situations) will be defined together with the relevant treatment processes. The objective for the design will be to derive a system with operational and maintenance costs that are optimised and generally similar to the costs associated with an embellished park and the maintenance of the watercourses that would otherwise be required if the lake were not to proceed.

To this end, the requirement of Point 7 of the EDQ letter is relevant

‘7. *Please provide further detail with respect to the costs of the maintenance and operations of the lake. This should include considerations of the costs of:*

- *Aquatic weed harvesting;*
- *Invasive pests: fish, snails;*
- *Riparian edge maintenance;*
- *Lake edge treatments;*
- *Water quality monitoring;*
- *Recirculation pumping;*
- *Water Treatment Plant;*
- *Upstream waterway maintenance;*
- *Destratification;*
- *Main embankment / Dam;*
- *Fish kill response;*
- *Top up water from Lake Wyaralong; and*
- *Proposed structures ie jetties, pontoons, boat ramps etc.’*

Based on the above discussion, the estimation of reliable maintenance costs (that would not either grossly over or under estimate actual costs) is not possible at this point and there is a concern that the consideration of costs that either over or under estimate actual costs would be counter-productive in the long term when future ownership of the lake is discussed.

It is proposed that greater investigation is warranted when the general potential for successful operation of the lake is accepted. With this acceptance in place, there would be sufficient confidence for the completion of detailed modelling and further design which in turn would allow the costs to be defined with sufficient rigor.

To this end, the previously proposed condition of approval for the development with respect to the lake would be of relevance. The proposed condition with respect to the preparation of a Lake IMP, which is reproduced below, could be used to ensure that maintenance costs are detailed as part of further design.

To allow for the full consideration of treatment options, it is also proposed that the requirement for the submission for the Lake IMP would be as part of a submission in support of development that would require construction of the lake. As at least the initial precinct does not involve construction of the lake, development could commence without the IMP being in place.

Lake

(a) Submit for compliance assessment an Infrastructure Master Plan for the lake which is generally consistent with the *Flinders Precinct 1: Concept Lake Management Plan*, revision 4, dated 24 April 2017, prepared by BMT WBM.

(b) The Infrastructure Master Plan must:

i. Identify the intent of the lake (e.g. amenity, recreation) and water quality objectives that match the intent for the lake.

ii. Identify guiding principles for the design, construction, establishment and operation of the lake that will augment the realisation of the stated intent.

iii. Identify key risks associated with the lake and its operation, and outline associated performance criteria and strategies to demonstrate that risks will be appropriately managed and minimised. In particular, key performance criteria and conceptual design verification must be provided for issues related to lake water quality and sedimentation.

iv. Detail proposed means to consistently achieve acceptable water quality within the lake, particularly during periods of low rainfall.

v. Provide a concept water quality monitoring program, including (if appropriate) pre-development, construction and operational phase monitoring.

vi. Provide a concept lake maintenance plan, outlining the maintenance requirements for lake infrastructure (where known), action plans in the event of non-conformities arising, and performance indicators.

vii. Provide an assessment of the anticipated maintenance costs for the lake (and any associated infrastructure).

viii. Provide a water balance assessment of the lake, including an analysis of water level variation and residence time (and identification of any additional sources of water, if required).

ix. For any top-up water identified as being necessary according to the water balance assessment, identify potential sources of water, their likely quality and reliability, and any proposed treatment prior to top-up water entering the lake.

x. Detail flood levels applicable to the lake for a range of flood events by referencing a flood report which includes an appropriate flood model. The flooding report shall be generally consistent with the *Flinders Precinct 1: Flood Impact Assessment*, revision 4, dated 21 April 2017, prepared by BMT WBM.

xi. Detail measures proposed to maximise public safety and minimise risk in both normal and flood conditions

xii. Present the results of a Dam Failure Impact Assessment that has been undertaken in accordance with relevant Queensland and Australian guidelines and provide a description of the design of the dams to be constructed at the downstream end of each lake.

xiii. Reference a Stormwater Management Report detailing measures to be implemented to augment the protection of lake water quality by the treatment of runoff from developed areas entering the lake. The report shall be generally consistent with the *Flinders Precinct 1: Stormwater Quality Management Plan*, revision 3, dated 21 April, prepared by BMT WBM.

Note: It is expected that the approval of any future Infrastructure Master Plan in accordance with this condition will:

a) Confirm that maintenance costs estimated in response to item (vii) above will be generally similar to the costs of maintaining embellished open space but recognising the significant economic and community benefits offered by the lake; and

b) Include requirements for the handover of the lake. It is anticipated that such requirements will involve:

    i. completion of an agreed maintenance period commencing on the completion of all stormwater infrastructure in the lake catchment;

    ii. demonstrating that annual maintenance costs are similar to those identified in the IMP; and

    iii. demonstrating that the nominated lake water quality criteria has been achieved for two (2) consecutive years.

7 References

Barry, M.E., McAlister, A.B., Weber, T.R., Abal, E. and Scott, N. (2004) Impacts of Stormwater Runoff from Roads in South East Queensland. In: *WSUD 2004: Cities as Catchments; International Conference on Water Sensitive Urban Design, Proceedings of*. Barton ACT

BMT WBM (2017a) the *Flinders Precinct 1: Concept Lake Management Plan.* Prepared for Pacific International Development Corporation.

BMT WBM (2017b) *Flinders Precinct 1: Stormwater Quality Management Plan.* Prepared for Pacific International Development Corporation.

Department of Infrastructure, Local Government and Planning (2017) *State Planning Policy*, July 2017, Brisbane.

Fletcher, T. Duncan, H., Poelsma, P. and Lloyd, S. (2004) *Stormwater flow and quality, and the effectiveness of non-proprietary stormwater treatment measures – a review and gap analysis*. Technical report 04/8.

Mackay City Council (2008) E*ngineering Design Guidelines: constructed lakes – planning policy No. 15.15.* Mackay, Queensland.

Water By Design 2013, *Waterbody Management Guideline*. Healthy Waterways, Brisbane.

Appendix A Further Issues Letter from EDQ

Queensland Government

Department of Infrastructure, Local Government and Planning

Our ref: DEV2017/844

29 May 2017

Pacific International Development Corporation Pty Ltd
ATF The PIDC Trust
C/- Mr Gavin Johnson
Mortons – Urban Solutions
PO Box 2484
SOUTHPORT QLD 4215

Dear Gavin

FURTHER ISSUES FOR PDA DEVELOPMENT APPLICATION FOR A PDA DEVELOPMENT PERMIT FOR A MATERIAL CHANGE OF USE – WHOLE OF SITE (COMMERCIAL; INDUSTRIAL; RESIDENTIAL; RETAIL; RURAL; SERVICE, COMMUNITY AND OTHER; SPORT, RECREATION AND ENTERTAINMENT) WITH CONTEXT PLAN AT DAIRY, UNDULLAH AND WYATT ROADS, UNDULLAH DESCRIBED AS LOT 3 ON S311896, LOT 200 ON SP133189 AND LOT 1 ON RP97710

After undertaking a preliminary assessment of the Priority Development Area (PDA) development application, the Minister for Economic Development Queensland (MEDQ) has identified the following further issues:

Water sources for lake filling and topping up

1. Please provide confirmation from the appropriate authority or entity demonstrating the reliability of a water supply source for the initial filling and subsequent top up of the lake.

   It is our understanding that Seqwater is planning to bring forward the construction of the Water Treatment Plant at the Cedar Grove weir and this may impact on the availability of water from Lake Wyaralong for the initial filling and subsequent top up of the lake.

Water quality management

2. Undertake a preliminary analysis to determine the likely lake water quality obtained from the inflow streams and any management measures necessary to maintain the required water quality objectives. It is accepted that detailed analysis is not required at this time, however the preliminary water quality analysis, combined with scenario testing of outcomes, will be a way to provide sufficient confidence in the likely outcomes.

Economic Development Queensland
GPO Box 2202
Brisbane Queensland 4001 Australia
Website www.edq.qld.gov.au
ABN 76 590 288 697

3. Please confirm the preferred management measures for lake water quality i.e. is this by recirculation through upstream water ways; is it by the use of a water treatment plant; or is it both or some other measures. If a water treatment plant is preferred its operating parameters and likely process should be defined.

Dispersive soil

4. Please address the impacts of the dispersive soils on the lake water quality along with the effectiveness of upstream water quality management measures.

5. Section 7.1 of the Lake Development Dispersive Soil Management Plan: Addendum for Lake Development (Planning) - Prepared by Wholistic Environment Version 7, dated 16 February 2017 submitted with the application states:

   "preferred design for the lake is for steep banks below water level to minimise the growth of aquatic plants along the lake edge."

   Furthermore this report states:

   "Based upon assessment of the material recovered for the relevant geotechnical investigations, and discussions with the authors, some innovative methods will be warranted to stabilise the banks of the lakes against erosion whilst simultaneously achieving this design."

   If steep banks are proposed, please confirm the methods to be used to stabilise the banks of the lake against erosion (dispersion) whilst simultaneously achieving this design.

6. Please provide details on how the embankment design can accommodate the soil dispersive constraints outlined in the report, and provide public safety.

Lake Maintenance and Operations

7. Please provide further detail with respect to the costs of the maintenance and operations of the lake. This should include considerations of the costs of:
   - Aquatic weed harvesting;
   - Invasive pests: fish, snails;
   - Riparian edge maintenance;
   - Lake edge treatments;
   - Water quality monitoring;
   - Recirculation pumping;
   - Water Treatment Plant;
   - Upstream waterway maintenance;
   - Destratification;
   - Main embankment / Dam;
   - Fish kill response;
   - Top up water from Lake Wyaralong; and
   - Proposed structures ie jetties, pontoons, boat ramps etc.

Water Licence under the *Water Act 2000*

8. The proposed lake is to be located on an existing watercourse and may impact on the downstream flow regime and potentially private water allocations and natural ecosystems. Can you please confirm whether the proposed lake will require the granting of a Water Licence from DNRM under the *Water Act 2000*.

Ecology

9. Please provide further analysis of the suitability of the proposed 50m wide biodiversity corridor associated with Undullah and Woollaman Creeks to facilitate the safe movement of native species. The analysis should:
   - include a description of those species the corridor is intended to support and individual requirements for their safe movement
   - address the ability of the corridor to facilitate movement for species at the regional scale given its location within the location of a planned biodiversity corridor indicated on the Greater Flagstone Development Scheme.

10. Show the extent of the Undullah and Woollaman Creeks biodiversity corridor on the Flinders Context Plan separate from the proposed adjacent land uses and include details of allowed uses within the biodiversity corridor.

Should you have any queries in relation to this matter, please do not hesitate to contact me on 3452 7422.

Yours sincerely

Brandon Bouda
Manager

Appendix B Water Quality Results

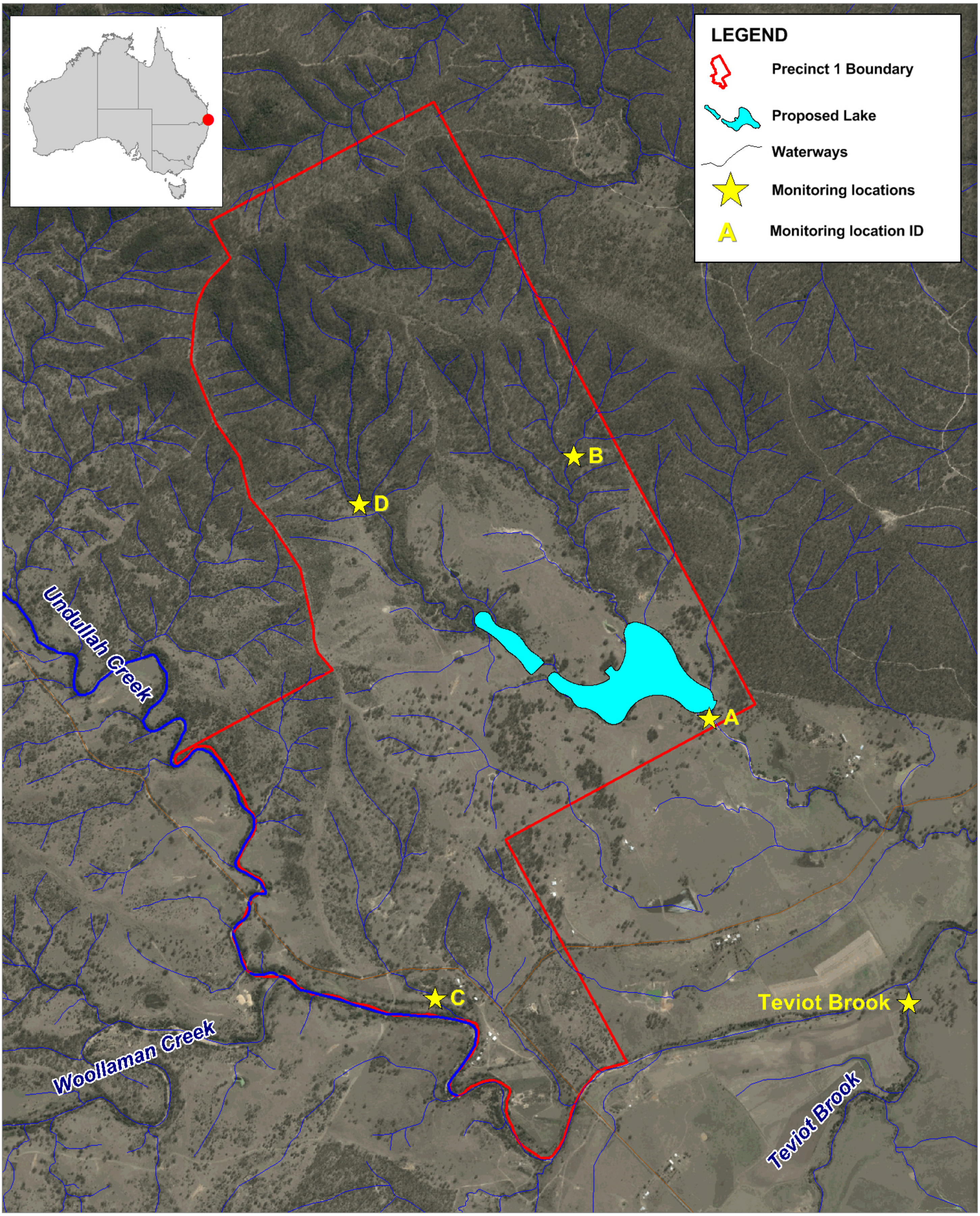
This section presents water quality monitoring results that relate to the quality of inflows to the proposed lakes. Results are presented for the following four sites:

Site A, B and D – these sites are located within the lake catchment and are sampled through rising stage samplers and grab samples.

Teviot Brook – this site provides water quality results from Wyaralong Dam discharges that will be used as additional 'top up' water for the lake.

The location of the four sites is presented in Figure B-1.

The water quality monitoring results are summarised Table B-1 to Table B-4.



Title:

Location of Water Quality Monitoring Sites

Figure: **B-1**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B21415_I_JLB Flinders Project NC\DRG\UW_056_170623_WQMonitoring Locations.wor

Table B-1 Water Quality Grab Sample Results, Teviot Brook

Parameter	Results		
	21/03/17	22/03/17	17/05/17
TSS (mg/L)	30	22	8
TOTAL PHOSPHORUS (mg/L)	0.13	0.029	0.057
TN (mg/L)	1.7	0.86	0.89
PO3	0.04	0.008	0.026
Total dissolved phosphorus	-	-	0.029
NOx	0.03	<0.005	0.29
NH3	0.069	0.021	0.032
Total dissolved nitrogen	-	-	0.86

Table B-2 Water Quality Grab Sample Results, Site A

Parameter	Results				
	22/02/16	20/06/16	03/01/17	16/01/17*	03/04/17
TSS (mg/L)	3500	58	24	44	41
TOTAL PHOSPHORUS (mg/L)	0.14	0.03	0.086	0.098	0.063
TN (mg/L)	1.5	0.96	1.3	1.6	1.5
PO3	0.011	0.021	0.017	0.015	-
NOx	0.18	0.14	0.04	0.04	-
NH3	0.017	0.038	0.051	0.021	-

*Rising Stage Sampler Result

Table B-3 Water Quality Rising Stage Sampler Results, Site C

Parameter	Results					
	06/06/16	20/06/16	19/12/16	03/01/17	16/01/17	03/04/17*
TSS (mg/L)	72	420	500	20	66	73
TOTAL PHOSPHORUS (mg/L)	0.11	0.32	0.32	0.071	0.11	<0.05
TN (mg/L)	1.7	1.9	2.0	1.5	1.6	1.0

*Grab sample collected during Ex-Tropical Cyclone Debbie

Table B-4 Water Quality Rising Stage Sampler Results, Site D

Parameter	Results			
	19/12/16	03/01/17	16/01/17	03/04/17*
TSS (mg/L)	280	54	19	16
TOTAL PHOSPHORUS (mg/L)	0.26	0.091	0.1	0.052
TN (mg/L)	1.3	1.2	1.6	1.0

*Grab sample collected during Ex-Tropical Cyclone Debbie

Appendix C Mass Balance Water Quality Results

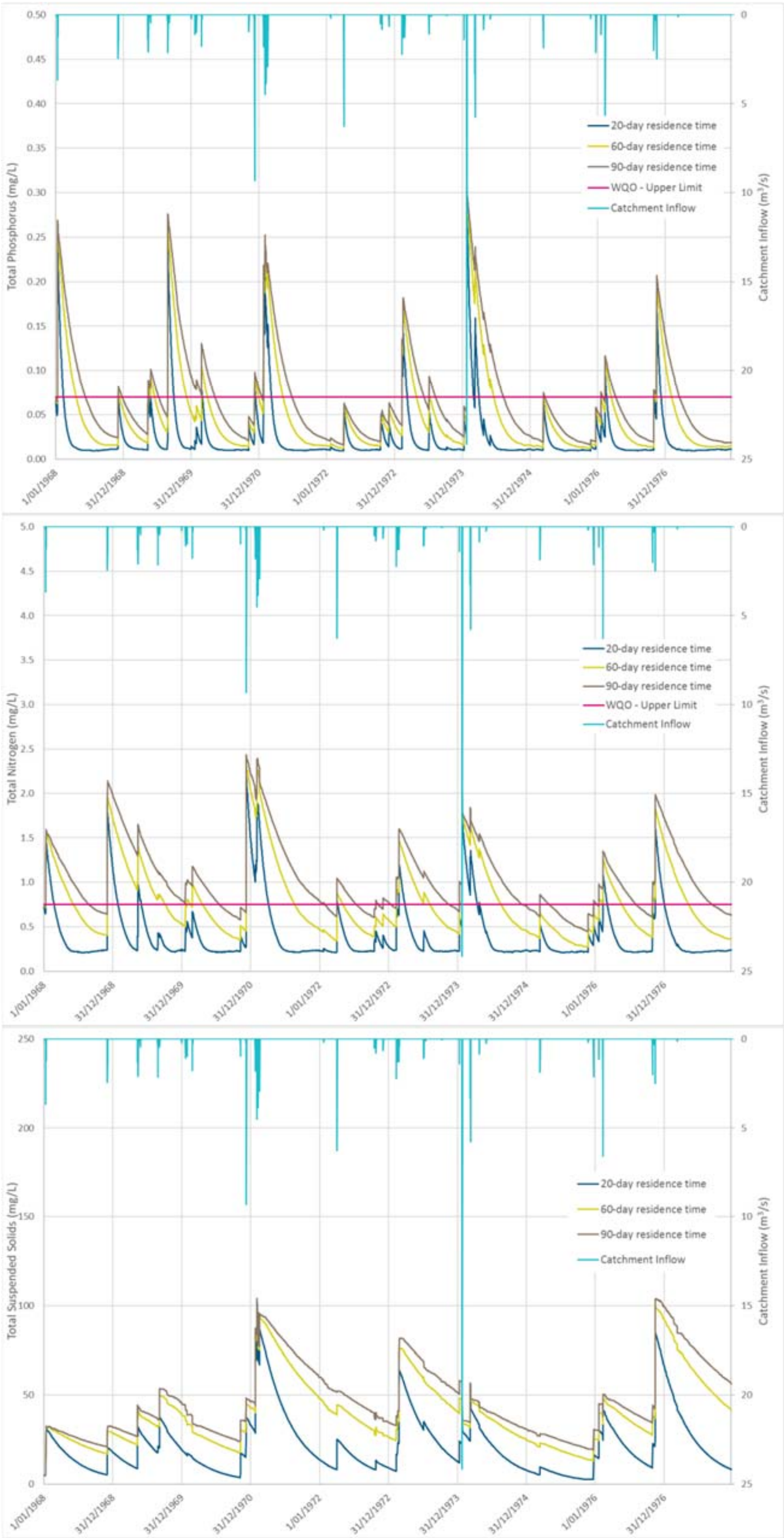


Figure C-1 Predicted water quality variation in lake (Total Phosphorus, Total Nitrogen and Total Suspended Solids), pre-developed catchment

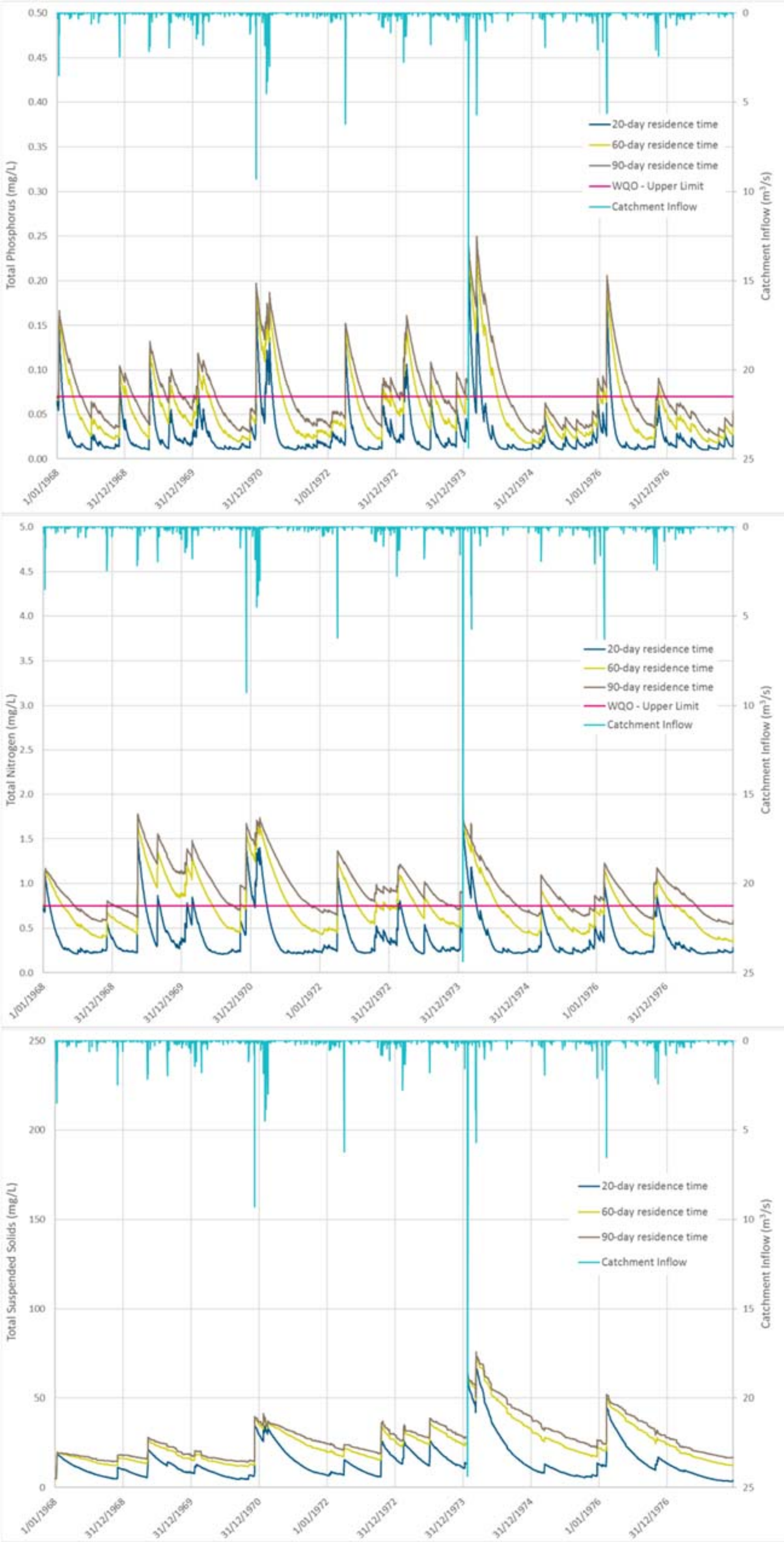


Figure C-2 Predicted water quality variation in lake (Total Phosphorus, Total Nitrogen and Total Suspended Solids), 50% developed catchment

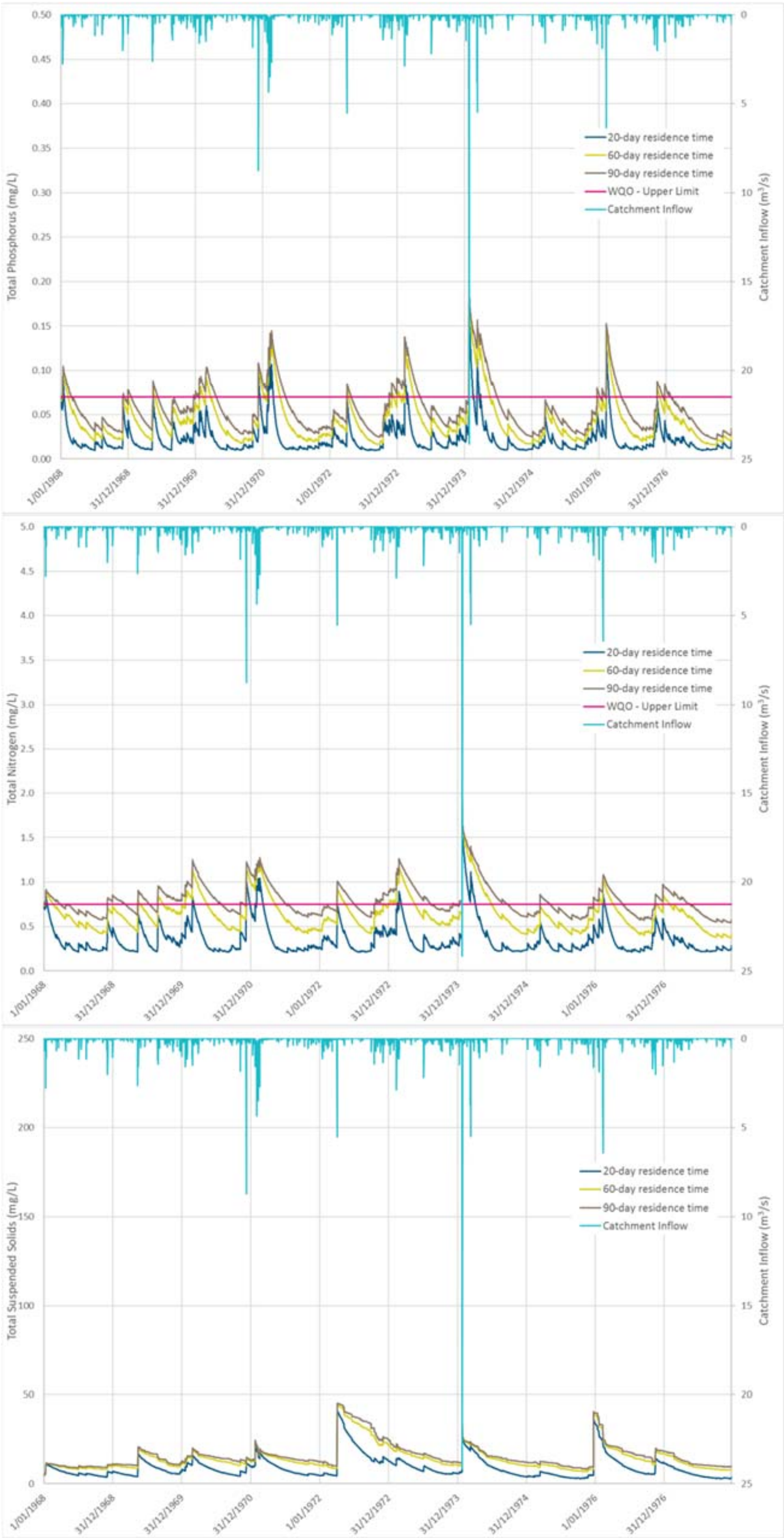


Figure C-3 Predicted water quality variation in lake (Total Phosphorus, Total Nitrogen and Total Suspended Solids), fully developed catchment

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