“Where will our knowledge take you?”

Water Quality Report for Lakes Freeman and Apex, Gatton

May 2018

LOCKYER VALLEY REGIONAL COUNCIL

Document Control Sheet

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Document	R.B22609.001.01.docx	**Client**	Lockyer Valley Regional Council
Title	Water Quality Report for Lakes Freeman and Apex, Gatton	**Client Contact**	Belinda Whelband, Martin Bennett and Richard Collins
Project Manager	Paul Dubowski	**Client Reference**	LVRC-17-10
Authors	Paul Dubowski, Adyn de Groot and Brad Dalrymple	**Synopsis**	This document provides a Water Quality Report for Lakes Freeman and Apex, Gatton for Lockyer Valley Regional Council.

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
1	1 May 2018	Brad Dalrymple		Paul Dubowski	
0	3 August 2017	Brad Dalrymple		Paul Dubowski	

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
Lockyer Valley Regional Council	PDF	PDF									
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Cover Photos: Main Image: Lake Freeman; Top Right: Lake Apex; Bottom Right: Project Workshop

Executive Summary

Lockyer Valley Regional Council (LVRC) engaged BMT to prepare a report on the current water quality in Lakes Freeman and Apex, Gatton (the lakes). The project included establishing the likely cause of poor water quality in the lakes and making recommendations for remediation. Given that the changes in water quality are influenced strongly by receiving waters, the project study area extends to the total catchment of the lakes. Both the lakes and their catchment are shown in Figure 1 below.

The methodology included a range of tasks including:

- An onsite collaborative planning workshop with the community and Council including Councillor Jim McDonald.
- Desktop assessment of background information.
- A field-based lake condition assessment including:
  - Physical and chemical water and soil quality profiling
  - Lake depth/bathymetry assessment
  - Accumulated sediment sampling
  - Aquatic and semi-aquatic macrophyte survey
  - A snapshot fish survey.

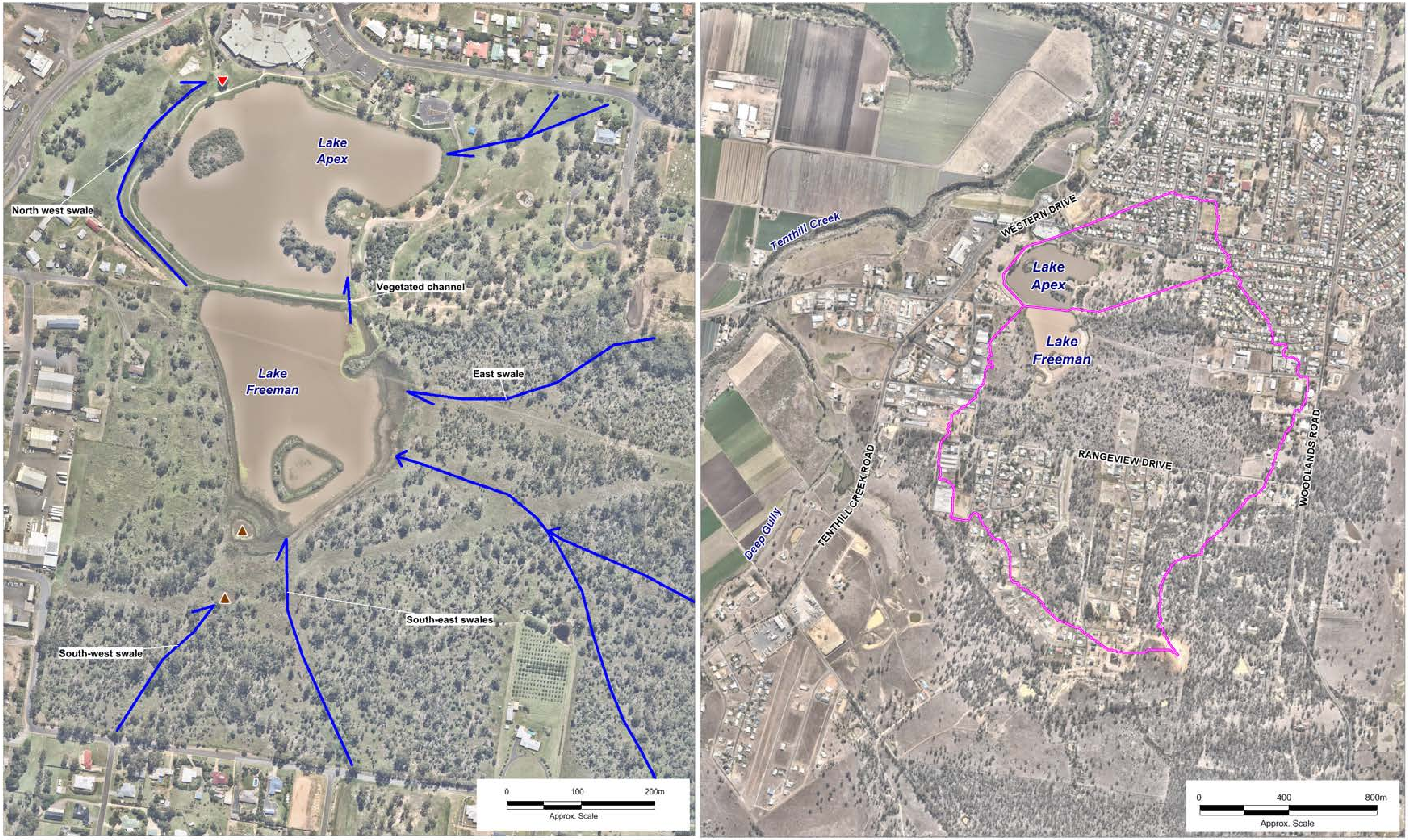
The outcomes of the workshop were used to prepare a vision for the remediation of the lakes as follows:

Lakes Freeman and Apex are remediated back to their pre-impact water quality and ecological condition with additional investment placed in improving community custodianship. The approach to remediation and its outcomes are sustainable and based on a total catchment management approach.

This is a long-term aspirational vision which although achievable, would require significant investment over a long duration including through the recommendations outlined below. Quantifying whether the pre-impact water quality and ecological condition has been achieved is not inherent in the vision statement, especially as baseline conditions are not known or recorded.

Instead, it is expected that water quality and ecological condition will be more reflective of the historic photographs of the lake presented in this report. This should include an extensive increase in macrophyte coverage over the lakes, an increase in bird species diversity and a visually perceptible reduction in turbidity accounting for seasonal variation and weather.

These are simple, qualitative measures of change without strict quantitative targets. They can be supported by quantitative measures such as macrophyte coverage, turbidity measurements and bird counts although it is not the intent of this report to attribute such prescriptive measures to the vision. This is especially the case as there are numerous external factors (e.g. weather and bird population influences beyond the LVRC boundary) which are beyond the control of Council and the local community. A qualitative approach is therefore recommended.



LEGEND

- Catchment
- Concentrated Flow Path
- Sediment Basin
- Outlet Weir

Aerial Imagery by nearmap.com

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Lakes Freeman and Apex and their catchment

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Water Quality

Further to the completion of aforementioned tasks, it was determined that the primary cause for high turbidity in the lakes is likely to have been from a combination of factors including:

- Sediment inputs including from:
  - Construction and building works in the catchment. This is considered to have been the primary source of sediment inputs.
  - Unvegetated areas of open space around the lakes (Lake Apex Park and the Gatton Cemetery), especially into Lake Apex. This is considered to have been the secondary source of sediment inputs.
- The high dispersivity and low settling rate of local soils.
- Wind-induced resuspension of sediments. This has been exacerbated by a loss of macrophytes, shallow depth of the lakes and lower water levels associated with the sediment accumulation.

These sediment inputs have also changed the hydrology of the lakes by increasing the bed level of the lakes which means they store less water. By having less water storage volume, the lakes are expected to dry out more frequently and the duration of dry periods is expected to have been prolonged.

The combined effects of the increased sediment and turbidity levels and severity of drying during drought, has been the extensive dieback of macrophytes across the lakes and a decline in biodiversity, most noticeably a decrease in bird species diversity. The more common sedentary birds have however benefited which has increased their abundance.

Nutrients in the lakes are also very high and remain elevated through the resuspension of nutrients from benthic sediments into the water column. This has also been exacerbated by a loss of macrophytes and change in hydrology. The dieback of macrophytes has further increased nutrients in the lakes including by:

- Limiting nutrient treatment previously provided by the plants and the biofilms which live on the plants.
- Release of nutrients into the water column through the decomposition of the plants.

Other nutrients sources may include:

- Stormwater runoff including both dissolved nutrients and those bound to sediment particles.
- Mowing mulch either blown or washed into the lakes.
- The increase in sedentary bird populations.

The loss of macrophytes, high nutrients loads and limited flushing with fresh water from the catchment means there is now a very high risk of algal blooms. It is considered that algal blooms are currently being supressed by the high turbidity which limits the light necessary for algal growth. Managing both the high turbidity and high nutrients concurrently is therefore essential to improving water quality and amenity.

Recommendations

Further to the establishment of the likely causes of poor water quality in the lakes, potential management actions were assessed and a series of twelve (12) recommendations were made for the remediation of the lakes. The actions have subsequently been prioritised according to their costs and timeframes having due regard for the values that they deliver (water quality, ecology and social). The recommended actions including their estimated costs, indicative timeframes, durations and priorities are summarised in Table 1 below.

While indicative timeframes and durations are provided, these will be highly dependent on Council's available budget and resources.

The approach recommended primarily includes minimising further sediment runoff from the catchment and improving water quality, ecology and amenity through extensive revegetation works. Although the revegetation works are estimated to be the single most expensive action (approximately $1.8 million), this is significantly cheaper than alternative options assessed.

Nevertheless, it is expected that the delivery of the actions is feasible but will require the development of a funding strategy by Council. Various methods for the delivery of these actions, such as grants, have been identified to assist in their implementation.

Table 1 Summary of Recommended Management Actions and Priorities

ID	Recommended Action	Cost Range	Cost Estimate	Indicative Timeframes and Durations	Priority
Catchment management solutions					
1	An Erosion and Sediment Control (ESC) and Water Sensitive Urban Design (WSUD) enforcement campaign	Low - could result in a net benefit	Subject to enforcement effort	Should commence immediately and continue until the catchment is fully built out	High
2	An ESC education campaign	Low	Subject to education effort	Should commence immediately and continue until the catchment is fully built out	High
3	Stabilising eroding soils on Council land	Moderate	$115,000	Should be undertaken in the 2017-2018 financial year. This will take 1-2 months to complete	High
5	Planning Scheme and approval controls	Low	Included in existing planning roles	Can be included in the next round of Planning Scheme amendments. Timeframe subject to planning review timeframes. Also subject to existing development approvals	High
6	Improving community custodianship	Low	Subject to effort	Should be undertaken 2018-2020 years and will take a few months to complete	High
Pre-treatment management solutions					
7	Constructing a sediment basin immediately upstream of Lake Freeman	Low	$210,000	Should be undertaken in 2019. Should take approximately 4 months for design and construction	Moderate
Lake management actions					
12	Revegetation of macrophytes and riparian vegetation	High	$1.2 million	Should commence in the 2018-2019 financial year. Will take approximately 5 years to complete in stages plus time for plant establishment	High
15	Importation of rocks and logs	Low	<$3000	Subject to availability	Low
16	Delineate riparian zone and turfed area using a concrete edge	Low	$19,400	Should be undertaken in the 2017-2018 financial year. Should take about three weeks to complete	Moderate
18	Development of new maintenance arrangements	Low	$10,000-$15,000	Should be undertaken in the 2017-2018 financial year. Should take less than a month to complete	High
19	Follow up targeted fish survey in Lake Apex	Low	~$3500	1 day for survey and 2-3 days reporting.	High

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1 Introduction

1.1 Background

Lockyer Valley Regional Council (LVRC) has engaged BMT to prepare a report on the current water quality in Lakes Freeman and Apex, Gatton (the lakes). The project was initiated due to concerns raised by the community that the quality of water in the lakes was deteriorating and that this was resulting in a '*loss of birdlife and wildlife in and around the Lakes*' (LVRC 2017).

1.2 Project Aims

The aim of this report has also been determined by LVRC and is outlined in its *Request for quotation* (LVRC 2017). This document states that Council:

> Requires a report assessing the water quality of Lake Apex and Lake Freeman. The study needs to determine the likely cause of the lack of clarity[1] and to suggest possible methods, where suitable, for remediation.

The aim of the report therefore includes not only the assessment of current water quality, but also the investigation of likely causes for the deterioration in lake water quality and the assessment of remediation options.

Further, it is understood that the aim of this report also includes the recommendation of remediation methods which would provide the best water quality outcomes having due regard for practical limitations. Limitations may include for example, Council's fiscal constraints and the time constraints of community groups which may assist with remediation i.e. recommendation must be practically achievable.

Given the background to the project described above, the aim of improving water quality in the lakes is primarily to encourage the bird and other wildlife species which have been discouraged from the lakes due to a decline in water quality, to return to the lakes. The recommended mitigation measures therefore need to ensure that:

- Water quality and biodiversity outcomes can be achieved.
- Any changes to water quality, bathymetry or hydrology limit exposed benthic habitats (drying), thermal stratification, 'dead zones' and algal blooms (a decrease in turbidity could for example increase algal growth).
- Any changes to bathymetry or hydrology need to be integrated with landscape design to ensure native plants can withstand wetting and drying conditions.
- Delivery of measures can be practically achieved within Council's expected budget.
- Initial investment does not increase long term maintenance costs for Council beyond Council's expected capacity.

1.3 Project Study Area

The study area primarily includes Lake Freeman and Lake Apex located in Gatton, Queensland. A total catchment approach has been taken in this report so the study area also extends to whole catchment of the lakes. Both the lakes and their catchment are shown in Figure 2-1. A more detailed description of the catchment is provided in Section 2 below.

[1] Where referring to 'water clarity', Council was clear that this was a broad term used deliberately to describe possible changes in water quality associated with turbidity but also potentially due to algal growth associated with increase in nutrients which are often bound to sediment particles (R Collins 2017, pers. comm., 13 March).

2 Site and Catchment Description

2.1 Preamble

This section provides an overview of the location of the lakes, including a description of existing catchment land uses, topography and drainage within the catchment of the lakes.

2.2 Site Location

As noted in Section 1.3 above, the lakes are located in Gatton, Queensland. The lakes form part of the broader 'Lake Apex Park' also colloquially known as the 'Lake Apex and Freeman Wildlife Sanctuary and Parkland', which is a recreation and conservation public open space parkland located approximately 1.4 km from the central business district of Gatton.

2.3 Existing Catchment Land Use

The catchment of the lakes is dominated by urban development. The catchment south of Rangeview Drive is mostly park residential style development with conventional residential in the north east of the catchment. The land immediately south of the lakes is also zoned for urban development but currently features regrowth vegetation.

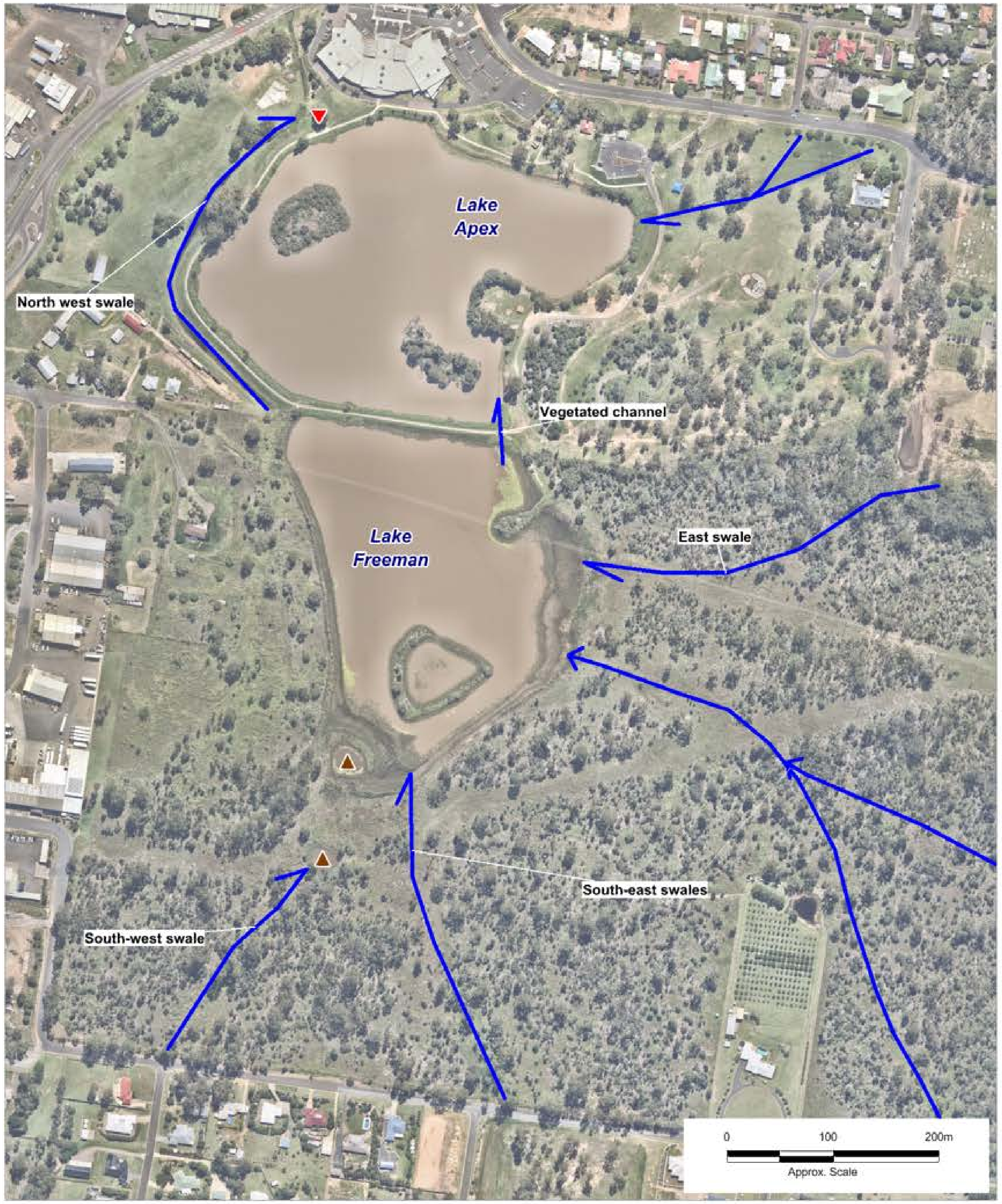
There is a small industrial precinct located in the eastern part of the catchment along Woodlands Road. The only other land uses of the catchment include Lake Apex Park in the north west of the catchment and Gatton Cemetery located centrally in the catchment. An aerial photograph is provided in Figure 2-1 which shows the various land uses.

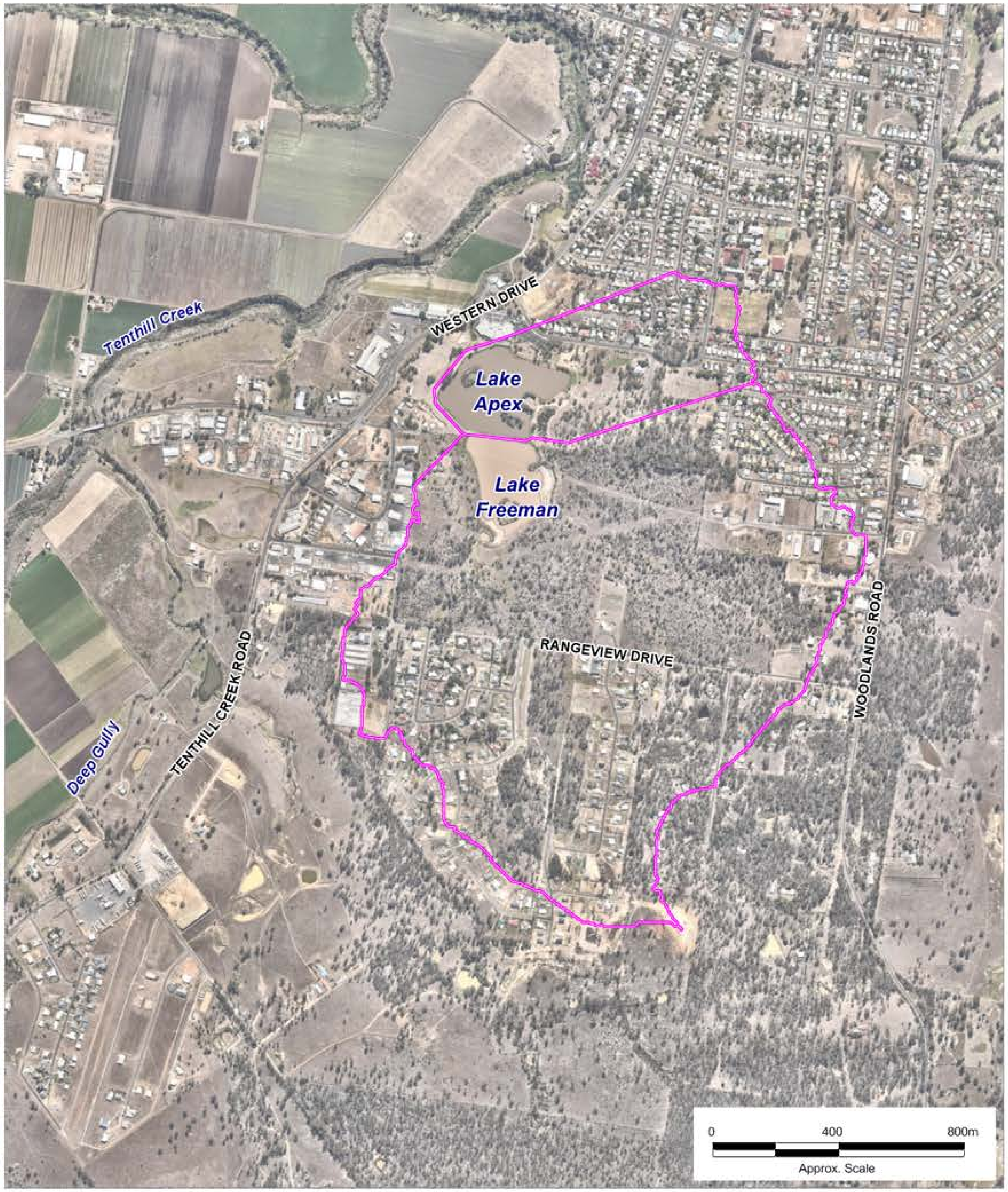
2.4 Topography and Drainage

The site features gently undulating terrain from approximately 110 m Australian High Datum (AHD) around the lakes, up to approximately 160m AHD in the highest parts of the catchment located south of the lakes. A digital elevation model (DEM) showing the topography of the catchment is shown in Figure 2-2.

The lakes drain towards Tenthill Creek approximately 635 m north of the lakes which drains into the Lockyer Creek approximately 1.3 km north of the lakes (geodesic distances). The lakes form part of the Locker Creek drainage sub-basin which itself forms part of the broader Brisbane River drainage basin. The ultimate receiving environment for water which flows out of the lakes is Moreton Bay.

The lakes were constructed in 1975, prior to which, the land featured a semi-ephemeral wetland known as Cleary's Swamp. The lakes are therefore artificial assets which have become naturalised over time. At the time of construction, the surrounding land use was primarily grazing. A further description of the history of Cleary's Swamp and the lakes is provided in Section 3 below.





LEGEND

- Catchment
- Concentrated Flow Path
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Aerial Imagery by nearmap.com

Title:

Lakes Freeman and Apex and their catchment

Figure: 2-1

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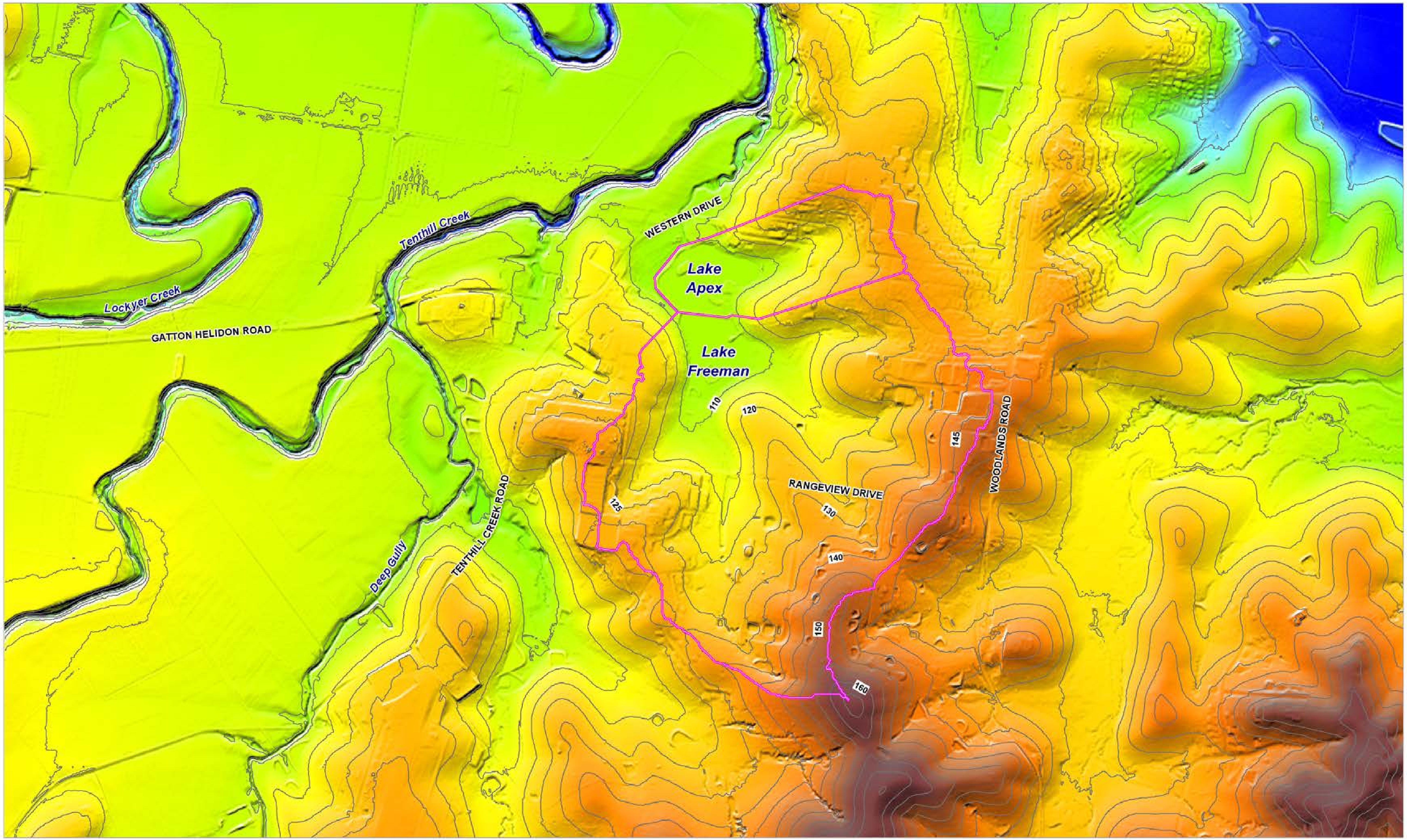

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Catchment — Contours

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Elevation (mAHD)

Title:

Digital Elevation Model of the lakes' catchment

Figure: 2-2

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3 Condition Assessment Methodology

3.1 Preamble

This section of the report provides a summary of the methodology undertaken in assessing the causes of poor water quality in the lakes and in preparing this report.

3.2 Stage 1 Preliminary Investigations

3.2.1 Stage 1A: Project Initiation Meeting and Onsite Collaborative Planning Workshop

On Tuesday 30 June 2017, the project was formally commenced with a project initiation meeting and an onsite collaborative planning workshop. The project initiation meeting was held between Council and key members of the consulting team and its purpose was primarily to discuss administrative aspects of the project. Immediately following the meeting, the onsite collaborative planning workshop was held.

The workshop was attended by Councillor Jim McDonald, Council's representative Martin Bennett, representatives of the Friends of Lake Apex (FOLA) community group including Jocelyn Wilson, Alan Wearing and Julie Reid, teachers (including Theresa Tapara, Rebecca Horsey and Rebecca Qualifcheski) and students from the Faith Lutheran College, and key members of the consulting team (Brad Dalrymple and Paul Dubowski). Some of the attendees from Council and FOLA are also members of the Lake Apex Community Advisory Committee (LACAC). Councillor Jim McDonald was able to represent broader community interests during the workshop.

The workshop objectives were to:

- Capitalise upon the knowledge and experience of all those in attendance
- Develop a common understanding of the lakes and causes of water quality issues
- Set an agreed vision for the lakes
- Identify and discuss possible solutions
- If possible, develop consensus on preliminary solutions.

This workshop was broken down into two components including a joint inspection of the lakes followed by the workshop held at the Lockyer Valley Visitor Information Centre. During the workshop, BMT presented some of the preliminary condition assessment data collected in the preceding week as described below in Sections 3.3-3.4 below.

3.2.2 Stage 1B: Site and Catchment Assessment

Immediately prior to the project initiation meeting BMT undertook an inspection of the lakes and their catchment including:

- The lakes, inlet ponds and any associated flow control structures.
- Overland flow paths including swales, channels, drainage reserves etc.
- Land uses across the catchment including current building and development sites.
- Any important topographic or geologic features.
- Extent of vegetation cover, cleared land and exposed soils.

In accordance with Council's Request for Quote, the inspection was undertaken with a particular emphasis on sediment entrainment through overland flow paths and stormwater infrastructure including detention basins. This inspection was undertaken to supplement an earlier inspection of the same features noted in the above points by BMT in March 2017.

3.3 Stage 2: Desktop Assessment

3.3.1 Stage 2A: Data Review

This step included interrogation of all available data by the project team to begin identifying and prioritising issues. As part of this task, we were able to assess the following:

- The contributing catchment and overland flow paths including swales, channels, drainage reserves/easements etc.
- Contributing land uses including extent of current building and development
- Geology and soil types
- Vegetation cover and extent of exposed soils
- Available lake design sketches
- Location and suitability of hydraulic controls
- Flora and fauna records (local, state and federal) and their conservation significance.

Other data supplied by Council and FOLA was also assessed. The various data sources analysed are described in the subsections below. Results from this analysis are presented in Section 4.3 below.

3.3.1.1 Historic Data Sources

A range of data sources were accessed to provide historic aerial photography including:

- State Government historic records from the QImagery database
- Nearmap
- Google Earth including Qld Globe.

This task also included review of historic photos provided by workshop attendees. The purpose of this analysis was to develop a better understanding of how the lakes and their catchment have changed over time. In particular, aerial photos can often be used to identify changes in macrophyte abundance and changes in water quality including algal blooms and changes in turbidity.

Newspaper articles and historic photos provided were also reviewed.

3.3.1.2 Water Quality

The *Environmental protection (water) policy 2009 Lockyer Creek environmental values and water quality objectives* (DEHP 2010) was assessed to identify water quality objectives in the region. This policy provides objectives considered by the State as being necessary to protect aquatic ecosystem environmental values for freshwater lakes in the Lockyer Creek catchment. These are long-term, aspirational objectives and should not necessarily be interpreted as objectives for short term water quality restoration works. Nevertheless, the objectives are used for comparison against currently water quality.

Data on water quality was limited to a single data source and there are no other known water quality results available. The *Lockyer wetlands directory* (Gould and Grant 2003) provides results from a snapshot survey of water quality in the lakes undertaken in 2001.

3.3.1.3 Geology and Soils

A range of data was analysed to provide the dominant geologic and soils conditions of the lakes and their catchment including:

- *Australian stratigraphic units database* (Geosciences Australia 2017)
- Soils mapping produced by the State government (Department of Science, Information Technology, Innovation and the Arts 2007).

3.3.1.4 Extent of Exposed Soils

A desktop assessment using recent, high resolution aerial photography (Nearmap, dated 10 April 2017) was undertaken to identify areas of exposed soils within the catchment which are likely eroding and increasing turbidity in the lakes. The areas were confirmed on site during the inspection described above in Sections 3.2.2 above.

3.3.1.5 Flora and Fauna

Prior to undertaking the field survey of the lakes, a search of online data sources was undertaken to identify species likely to inhabit the lakes, especially those recognised as being endangered, vulnerable or near threatened (EVNT species). This included:

- A search of the Wildnet database which is based on confirmed specimen records (dating from 1980).
- Commonwealth Government Protected Matters Search Tool (PMST) modelled species distribution.
- A search of the *Biodiversity recovery plan for Gatton and Laidley Shires* (Lockyer Catchment Association 2004).

A species list for the lakes was also prepared based on records from the Wildnet and PMST databases.

Both databases produce reports based on a central coordinate(s), including all species known or expected to occur within a defined proximity. Of these reports, WildNet includes all species while the PMST provides only those listed under schedules to the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), including threatened and migratory species.

While a species may be triggered using the reports for these databases, further screening has been undertaken in order to distinguish between species likely or known to occur and those that are reported only due to the defined proximity. This screening consists of the following:

- Flora species have been screened based on the results of a site survey and assessment of habitat suitability (refer to 4.4.4 below for the results of this survey).
- Fauna species have been screened by habitat requirements, noting that the focus of the assessment was species that occur within or are supported by the lakes.

The relevant habitat types of the site (identified during a site survey) consist of:

- Lacustrine habitat (i.e. the lakes)
- Macrophyte zone (shallow areas supporting aquatic vegetation)
- Steep-sided banks subject to periodic flooding
- Riparian fringe.

Other habitat in the area is not considered relevant as the assessment is focused upon species supported by the lakes.

Lastly, the bird species were cross referenced against the *Lake Apex bird guide* (Friends of Lake Apex Inc. 2015) which provides a list of bird species confirmed to have occurred on site.

3.3.1.6 Location and Suitability of Hydraulic Controls

A desktop assessment using recent, high resolution aerial photography (Nearmap, dated 10 April 2017) was undertaken to identify potential hydraulic controls which regulate water levels in the lakes. These hydraulic controls were confirmed on site during the inspection described in Section 3.2.2 above.

3.3.2 Stage 2B: Water Balance Modelling

A water balance model of the lakes was developed to provide an understanding of the water level variation, residence time (or lake 'turnover'), and environmental flows required to maintain downstream ecology. All the known water inputs and outputs were considered including inputs from direct rainfall and stormwater and outputs due to seepage and evaporation. The analysis included assessment of three scenarios including:

(1) Existing catchment conditions.

(2) Ultimate catchment conditions with the catchment fully developed in accordance with the zoning provided in the *Gatton Shire planning scheme* (Lockyer Valley Regional Council 2007).

(3) Ultimate catchment conditions with the catchment fully developed in accordance with the zoning provided in the *Gatton Shire planning scheme* (Lockyer Valley Regional Council 2007) and potential harvesting of water from the lakes for irrigation of a portion of Apex Park (8.8 ha) i.e. 179m^3/day.

A more detailed description of the model parametrisation used in developing this water balance model has been provided in Appendix A.

Results were compared to recommended guideline values for lakes to determine the potential risk of algal blooms if turbidity is reduced.

3.4 Stage 3: Lake Condition Assessment

A field-based lake condition assessment was undertaken to support and validate the desktop analysis. There were five (5) tasks included in this assessment including:

- Stage 3A: Physical and chemical water and soil quality profiling
- Stage 3B: Lake depth/bathymetry assessment
- Stage 3C: Accumulated sediment sampling
- Stage 3D: Aquatic and semi-aquatic macrophyte survey
- Stage 3E: Snapshot fish survey.

These tasks were designed to ensure that the work met Council's requirements as outlined in the Request for Quote.

All five (5) tasks are described in the following sub-sections.

3.4.1 Stage 3A: Physical and Chemical Water and Soil Quality Profiling

All water and sediment quality sampling was undertaken in accordance with the *Monitoring and Sampling Manual Version 2* (DERM 2009). The following subsections provide a more detailed description of the water and sediment quality analyses undertaken.

3.4.1.1 Water Quality Profiling

In-situ water quality monitoring can assist in identifying water quality issues and processes e.g. thermal stratification, turnover, high nutrient loads. It may also help identify causes for management such as prolific weed growth or algal bloom risks. Testing the accumulated soils is also important to understand potential latent build-up of nutrients and potential for these to become resuspended.

This task involved taking physical water quality measurements with a pre-calibrated water quality instrument at the water surface, and continually throughout the full water depth of the water column to the bottom of the lakes at each sampling location. A range of physio-chemical water quality indicators was analysed including:

- Temperature
- Conductivity
- Salinity
- Dissolved oxygen (DO)
- DO concentration
- pH
- Turbidity.

Water quality grab samples were also taken at two (2) locations in each of the two lakes i.e. a total of four sites. The location of these sampling locations is shown in Figure 3-1. The water quality samples were taken to a laboratory accredited by the National Association of Testing Authorities (NATA) for analysis of the following chemical parameters:

- Total suspended solids (TSS)
- Total nitrogen (TN)
- Total Kjeldahl nitrogen (TKN)
- Ammonia (NH_3)
- Nitrogen oxide (NOx)
- Organic nitrogen (ON)
- Total phosphorus (TP)
- Phosphate (PO_4).

These samples were also analysed for cyanobacteria species including Potential Toxin Producing Cyanobacteria (PTPC) (toxic blue green algae). Samples from Sites 2 and 4 were further analysed for cyanobacteria ‘biovolume’ or ‘biomass’. Compared to simply analysing for species, biomass is a more accurate method of linking algal populations to environmental factors and to determine potential toxicity.

Use of biovolume measurement for monitoring blue-green algae is useful as some potentially toxic blue-green algae produce liver or nerve toxins. Additionally, all blue-green algae produce endotoxins (a toxin located within the cell of the bacteria which is released when the cell is damaged) in direct proportion to their cell size. As some blue-green algae are very small, biovolumes are the best estimate of the risk of these toxins causing water quality issues.

3.4.1.2 Sediment Quality Profiling

To better understand the accumulation of nutrients associated with lake sediments, sediment samples were also taken in each lake using a Veen Veen Grab. These samples were taken at Sites 1 and 3 shown on Figure 3-1.

As with the water quality grab samples, the sediment samples were taken to a NATA accredited laboratory for analysis. Sediment quality samples were analysed for a range of chemical parameters including:

- Total nitrogen (TN)
- Total Kjeldahl nitrogen (TKN)
- Ammonia (NH_3)
- Nitrogen oxide (NOx)
- Total phosphorus (TP)
- Phosphate (PO_4).

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● Sampling Location

Title:

Sampling Locations

Figure: 3-1

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3.4.2 Stage 3B: Bathymetric assessments

3.4.2.1 Lake Depth and Bathymetry

Assessment of the lake depth and bathymetry allows for the comparison of the current lake profile against accumulated sediment data (refer to Section 3.4.3). This enables the assessment of build-up of sediment depth over time and the spatial extent of sediment accumulation. This information can then be used to inform management decisions particularly related to the need and extent of any sediment removal. It is also useful in understanding which parts of the lakes are likely to experience thermal stratification (discusses in Section 4.4.1.1).

The depth of the lake was measured by traversing the lakes in a small vessel in a grid pattern and measuring depth using a combination of methods including:

- Marking the waterline with a hand-held GPS
- A single-beam multi-frequency echo sounder mounted to the survey vessel
- A multi-beam multi-frequency echo sounder mounted to the survey vessel.

This combined method provided sufficient data to create a very simple Digital Elevation Model (DEM). The single-beam echo sounder provided accurate depths below keel, while the multi-beam echo sounder provided a swath of data up to 12 m either side of the vessel. However, the multi-beam data was not corrected for vessel motion artefacts and was used sparingly around the channel areas of the eastern margin of the lakes to better define the channel areas. Over broad flat areas, the multi-beam data was anomalous and discarded in preference to interpolated single-beam data.

The water levels in the lakes were referenced to a nominal reference level taken from an existing permanent survey mark (PSM 66735) located directly to the west of Lake Apex along Western Drive. Heights were derived using laser levelling and cross checked between within and between lakes. The height of this mark also enabled the water level and lake bed to be referenced to Australian Height Datum (AHD).

3.4.2.2 Benthic Surface and Benthic Hardness

Although not included in the project proposal, further scans of the lakes were undertaken to provide images of the benthic surface and benthic hardness. These scans were undertaken using a side-scan sonar also attached to the survey vessel.

Side-scan sonar imagery is useful in providing an understanding of the differences in material and texture type of the lake bed. It is a commonly used tool to detect debris in lakes such as dumped car bodies, discarded whitegoods, shopping trolleys, barrels and other large items of rubbish. Being able to detect such items is useful in informing lake restoration methods.

As the analysis also assists in analysing the texture type of the lake bed, the hardness was analysed for recently deposited sediments which have not yet had time to become compacted.

The hardness map developed provides a relative measure of hardness, based on peak signal return from the first echo of the 200 kHz single-beam return. This represents the relative hardness of the uppermost layer of sediment. Seven classes were arbitrarily chosen and each of the classes are unitless grades of relative hardness. It should be noted that the sediment had relatively similar penetration depths (x-y) and the hardness map may slightly over-represent actual differences in hardness.

3.4.3 Stage 3C: Accumulated Sediment Depth Measurement

Determining the depth of accumulated sediment within the lakes is important to inform potential vegetation management and sediment removal requirements. Such depth measurements could for example inform methods and associated costs of sediment removal and handling/deposition should removal of accumulated sediment be considered a worthwhile management option.

Measuring sediment accumulation in the lakes was undertaken by manually driving a rod into the sediments at numerous locations across the lake from a survey vessel. The sediment depth was recorded at each point and later calculated to an AHD level which was taken from the survey mark as described above (see Section 3.4.2).

Results from this analysis are presented in Section 4.4.3 below.

3.4.4 Stage 3D: Riparian and Aquatic Flora Survey

A survey of the aquatic and semi-aquatic macrophyte species and other riparian vegetation was undertaken by a botanist with extensive experience in plant identification. Such surveys are important task in lake rehabilitation planning as they inform potential management responses, particularly if recommendations include revegetation.

An assessment of the existing flora provides an indication of what species can adapt to the locally specific climate, hydrology and water quality and help identify whether any weed species require specific management responses. They also provide a good indication of the existing habitat values. Based on this survey, a species list and basic habitat map were prepared.

3.4.5 Stage 3E: Snapshot Fish Survey

A one-day snap-shot survey of fish was undertaken to determine the composition and relative abundance of fish species within the lakes. This assessment improves ecological understanding of the lakes and helps to determine whether exotic species may require management (e.g. carp and tilapia are known to increase turbidity).

A range of sampling techniques was used to ensure that the methodology did not bias against any species or size class. This included for example dip netting, fyke netting, box trapping and backpack electro-fishing (non-harmful to fish). The fish survey was undertaken in accordance with the necessary scientific and ethics permits for this type of survey work.

Other fauna species were not surveyed given:

- Project budget limitations.
- Amphibian surveys would likely have been limited by the season in which the survey work was undertaken i.e. the survey was undertaken in winter when the results of amphibian surveys are typically less successful.
- Birds are already well surveyed by FOLA, as documented in *the Lake Apex bird guide* (FOLA 2015).

4 Condition Assessment Results and Discussion

4.1 Preamble

This section provides the results of the various investigations described in Section 3 above and where appropriate, provides some discussion on how the results affect the condition of the lakes. The various issues identified are then summarised in a table which also provides appropriate performance indicators, a condition rating score, priority rating and management/maintenance responses for each issue.

4.2 Stage 1 Preliminary Investigations

4.2.1 Stage 1A: Onsite Collaborative Planning Workshop

A brief summary of the key points of discussion for each of the two components of the workshop are summarised below while a more detailed summary is provided in Appendix A. This information is anecdotal only and is not quantified in any way.

There were three key points of discussion including the following:

- The history and changing ecological values of the lakes.
  - Based on the discussions during the workshop, it is understood that the lakes were previously characterised by much 'cleaner' water (less turbid). Additionally, it is understood that the lakes featured dense macrophytes across most of the surface area of the lakes (especially Lake Freeman) and that this vegetation provided a more favourable habitat for a broader diversity of bird species compared to the current situation.
- Water quality issues.
  - the main water quality issue identified during the workshop was a significant increase in turbidity and sediment deposition in the lakes since circa 2009.
- Particular areas of concern and possible solutions previously considered by workshop attendees.
  - The lakes are considered by the workshop attendees as part of a wetland complex which is connected both hydraulically and ecologically and which cannot be considered as pair of separate waterbodies.
  - Solutions previously considered included:
    - Enforcement action and education for ongoing erosion and sediment control issues.
    - Replanting to address decline in macrophyte cover across the lakes and islands.
    - Stabilisation and returfing disturbed soils in the catchment.
    - Revegetation, flocculation, floating wetlands and dredging to address accumulated sediment across the bed of the lakes.
    - Stabilisation of the inlet swale located in the north-east corner of Lake Apex Park.
    - Comprehensive education campaign to limit ongoing feeding of wildlife

Many of the solutions considered noted above are considered worthwhile and analysis of these and other options is provided in Section 5 below.

4.2.1.1 Collaborative Planning Workshop Key Discussion Points

The workshop focused on the three questions including:

(1) Where are we now? – Characterising the condition of the lakes and their catchment.

(2) Where do we want to be? – Setting a common vision for the lakes.

(3) How are we going to get there? - Assessing solutions to address the causes of poor water quality in the lakes.

A more detailed description of these discussions is provided in Appendix A.

Vision for the Restoration of Lakes Freeman and Apex

Utilising the outcomes of the above discussions and recognising the existing vision for the broader Lake Apex Park, the following vision for Lakes Freeman and Apex was developed:

Lakes Freeman and Apex are remediated back to their pre-impact water quality and ecological condition with additional investment placed in improving community custodianship. The approach to remediation and its outcomes are sustainable and based on a total catchment management approach.

While the pre-impact condition cannot be readily quantified, the photos provided in Figure 4-1 adjacent provide a que for both the water quality and ecological condition mentioned by the vision.

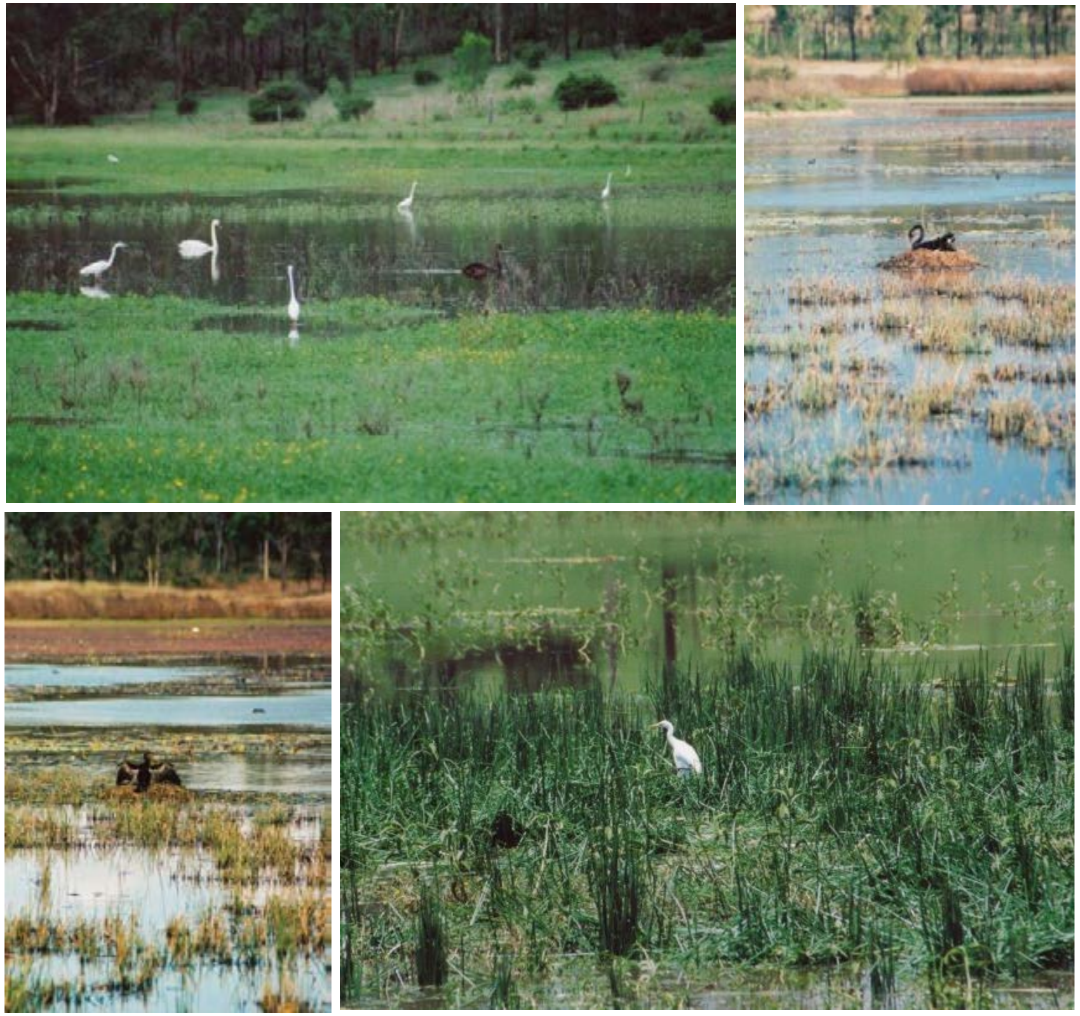


Figure 4-1 Photos from 2003-2005 which provide a visual que for improved water quality and ecological condition sought by the vision (courtesy Julie Reid)

4.2.2 Stage 1B: Site and Catchment Assessment

A visual inspection was undertaken of the lakes, the surrounding parkland and the contributing catchment. Based on the visual inspection, a summary of the key issues identified during the inspection are summarised in the points below.

The lakes

- High levels of turbidity were evident in both lakes.
- The riparian fringe of both lakes was in relatively poor condition and in many locations, was dominated by weed species or bare soils.
- Erosion of the riparian fringe was evident on the two islands in Lake Apex.
- There was a significant population of Australian white ibis (*Threskiornis molucca*) and ducks (various species but mostly Pacific black ducks (*Anas superciliosa*)) observed in Lake Apex especially on the western and eastern islands. They were by far the most abundant bird species observed. While the presence of these birds in itself is not an issue, their abundance may become an issue in an ecologically degraded environment which cannot process the nutrient and bacterial loads in the lakes. The lakes in their current state are unlikely to be able to process the current loads and elevated nutrient and bacterial loads could be expected. Water quality monitoring results are discussed further in Section 4.4.1.1.
- The channel between the two lakes was heavily overgrown with exotic grasses. It may also have been inundated by deposited sediment but due to the dense weed cover this was difficult to confirm. In any case, the current state of the channel is likely to limit the flow of water from Lake Freeman into Lake Apex.

Parkland and immediately adjacent undeveloped land

- Two basins are located immediately upstream of Lake Freeman on Council land (Lot 100 RP846013). These basins would assist with settling sediments from stormwater runoff from the catchment. The volume of the basins is however, too small to have a meaningful beneficial effect on water quality in the lakes and therefore the basins are unlikely to function as effective sediment basins.
- It is likely that these basins have never been cleaned out, a process which is complicated by the fact that there is no formal maintenance access into the basins. Without regularly clean out of sediments, the storage volume is decreased which means less sediment can settle out and resuspension of sediment results in increased turbidity.
- There are two vegetated channels which flow into Lake Freeman including one from the south-west and one from the south-east (refer to Figure 2-1). These vegetated channels provide pre-treatment of stormwater pollutants from the catchment prior to discharge to the lakes. They are however, located on private land (Lot 2 CP860760) which is zoned for urban development and may be developed in the future, meaning those channels could also be developed. Development of those channels would remove the pre-treatment water quality function they currently provide. Development of those allotments would also likely result in a decline in water quality of the lakes as the water quality standards in the *State planning policy* (DSDIP 2017) only require reduction in stormwater pollution loads rather than the avoidance of increased stormwater quality pollutant loads or 'sustainable' stormwater quality pollutant loads.
- The topography around the basins appears to flow from the south-east vegetated channels directly into Lake Freeman bypassing any treatment through the existing basins. This means that approximately 65 ha of the upstream catchment flows directly into the Lake Freeman. In comparison, the catchment which flows into the south-west channel is approximately 20 ha.

- There are a number of areas within Lake Apex Park which feature exposed soils. These areas likely contribute to the increased sediment and turbidity of Lake Apex. There are also other exposed soils on private land across the catchment although as Council has greater control over the public land, this report focuses on that land. It should be noted that the historic clearing of the catchment and sodic soils across the catchment increase sediment runoff to the lakes.
- There is a stormwater channel located in the north-east corner of Lake Apex Park which flows directly into Lake Apex. This channel is currently a degraded grass channel. In its current form, the channel could be a sediment source although given flows spread over turf (especially when the capacity of the channel is exceeded), it could also provide some limited treatment of stormwater prior to discharge to Lake Apex. A well vegetated channel would provide significantly better treatment.

The catchment of the lakes

- Although the lack of appropriate stormwater runoff controls, particularly poor erosion and sediment control at upstream developments is a historic issue, the matter remains unresolved. Specifically, the following issues were identified during the inspection of the catchment:
    - Poor erosion and sediment control (ESC) practices on land managed by the upstream developers. Although there are some existing stormwater treatment measures for the construction phase of development, they did not appear to be appropriate to ensure that the development was meeting the water quality objectives stated in State regulation. Based on discussions with Council, it is understood that sediment runoff was exacerbated when a severe storm occurred following clearing which was undertaken for infrastructure and utility construction which exposed underlying sodic soils.
    - Poor stormwater quality best management practices on land managed by the upstream developers. Although there are some existing stormwater quality management measures for the operational phase of development, they did not appear to be appropriate to ensure that the water quality objectives stated in State regulation current at the time of approval would be met.
    - Poor erosion and sediment control practices on numerous individual building sites.

  The flow of sediment from upstream developments and building sites has decreased following completion of construction and stabilisation of building sites. Nevertheless, runoff from these areas flows into the lakes and construction and building sites are still expected to be contributing excessive sediment laden runoff to the lakes.
- Some road verges along Rangeview Drive particularly near where the road turns north, were devoid of vegetation and in places eroding. These areas require stabilisation.

4.3 Stage 2: Desktop Assessment

4.3.1 Stage 2A: Data review

4.3.1.1 Historic Data Sources

As noted in Section 3.3.1.1 above, this assessment included a review of historic photos from workshop attendees, historic aerial photos provided in Appendix C, historic newspaper articles provided in Appendix D and photographs Figure 4-1

The historic aerial photos were used to develop a timeline of visible changes to the lakes and catchment. Using the timeline, the following observations can be made:

- Aerial photo records commenced in 1933 at which time, the lakes were still a naturally formed waterbody known as ‘Cleary's Swamp’. The catchment of Cleary's Swamp was at this time undeveloped although was partially cleared and grazed. The extent of vegetation in Cleary's Swamp also appears to have been affected by clearing prior to this date.
- By 1951, the two existing sediment basins upstream of Lake Freeman are already evident, most likely farm dams. Drainage paths appear eroded there are numerous areas of exposed soil.
- The condition of Cleary's Swamp and its catchment remained relatively unchanged in photo records up to and including 1974. The photos suggest however, that while Cleary's Swamp may have had some minor permanent sections, water levels fluctuated in response to rainfall. Sometimes it appeared quite dry while other times (for example following the 1974 flooding) the swamp greatly expanded in area (refer to photo from 3 February 1974).
- The first aerial photo which shows Lake Freeman and Lake Apex full constructed was 1 June 1976. At this time some residential development had commenced in the north-east corner of the catchment although the catchment was still predominantly open forest and paddock and likely used for grazing. Both the eastern and western islands are evident in Lake Apex. The northern sediment basin now appears to form part of Lake Freeman and was mostly submerged. The first water quality issues may have arisen following construction of the lakes as the lakes are clearly different colours in this photo.
- Further to the above point, there were two photographs sourced from FOLA which show the construction of the lakes (refer to Figure 4-2). One of the photos shows part of what was likely to have been Cleary's Swamp before it was constructed into the lakes. The water appears quite turbid although it is unclear whether this was the natural condition of Cleary's Swamp or due to the earthworks being undertaken.
- On 14 October 1979, high levels of turbidity were evident in Lake Freeman but not in Lake Apex. This was likely associated with clearing of land in the southern part of the catchment and suggestive of the effect that the highly clay-based nature of the catchment soils can have on the lakes.
- On 13 May 1982, Lake Freeman had cleared somewhat although Lake Apex was now highly turbid. The increased turbidity in Lake Apex may have been associated with turbid water from Lake Freeman draining into Lake Apex. Additionally, soils in what was now Lake Apex Park and nearby residential development had been disturbed and this could have contributed to the turbidity in Lake Apex.

Figure 4-2 Photos showing Lake Apex construction at Cleary's Swamp 1975. (Courtesy of Jim Galletly via FOLA)

- By 1 June 1988, both lakes had cleared up and the water quality appeared quite good. The catchment appeared stable with limited disturbed soils apart from the industrial estate east of Lake Freeman which had been cleared. This is also the first time that extensive macrophyte cover appeared across Lake Freeman.
- On 8 October 1994, the lakes appeared have to very low water levels which is consistent with the photos shown in Figure 4-2This is the first incidence in the photo records of such low water levels. The water in Lake Freeman appears turbid and the macrophyte cover also appears to have been significantly affected.
- On 2 August 1997, water levels were again high and the macrophytes appeared to have returned suggesting that the lakes used to be quite resilient to drying and that natural regeneration post-drought was typical. There also appeared to be some algal blooms in both lakes. This was the first incidence in the photo records that algal blooms were recorded. Also evident is the ring of vegetation in the south of Lake Freeman and additional island in Lake Apex.
- The photos from 2001 indicate macrophyte decline although the reason for this decline is not known. It may also be that the macrophytes were simply less visible or submerged as the photos in Figure 4-1 show extensive macrophyte coverage during 2003-2005. Water levels are very high and algal blooms are present. Both lakes appear relatively turbid.
- On 27 July 2003 the second drought during the period of the photo records appears to have affected the lakes which is also consistent with the photos shown in Figure 4-1.
- The next photo available is from 8 June 2006 and this shows the commencement of further residential development to the south although increased turbidity in the lakes is not clearly evident. While both lakes exhibit some level of turbidity, it is not overly high and Lake Apex in particular appears quite clear. At ground level, the water would likely have looked more blue than brown particularly in Lake Apex.

- The subsequent photo dated both 11 August 2009 and 30 April 2010 (by QImagery), shows the expansion developments and a notable increase turbidity which continued through to the most current photo dated 10 April 2017.
- A number of additional observations can be made based on the photos taken between these dates including that:
  - While Lake Freeman showed high levels of turbidity from the 11 August 2009 and 30 April 2010 aerial photo onwards, Lake Apex remained less affected by turbidity until the 26 May 2013 aerial photo. This suggests that there may have been inadequate flows to push the highly turbid water into Lake Apex. Some settling of sediment in Lake Freeman may also have occurred.
  - From 26 May 2013 onwards, Lake Apex is also affected by high turbidity and by 10 April 2017 appears to display similar, if not higher, levels of turbidity compared to Lake Freeman. Results from water quality monitoring presented in Section 4.4.1.1 below support this observation. This period also coincided with flooding in 2013 and 2017.
  - The 16 March 2014 aerial photo appears to show an algal bloom occurring round the lake edges. The reason why this bloom is not more widespread is probably because there the high turbidity is limiting algal growth across the lakes. Any management which seeks to minimise turbidity must therefore also address nutrients which support algal growth.
- Based on the review of all the historic aerial photographs, it is clear the lakes have never been perfectly clear but have often become significantly more turbid in response to works across the catchment, droughts and flooding. The relationship between the soils in the catchment, rainfall, earthworks which expose these soils to erosion and high turbidity is therefore clear based on the review of historic aerial photography.
- Equally, there are periods where turbidity decreases in both lakes suggesting that the type of sediment in the catchment (discharged to the lake via surface runoff) will eventually settle given the right conditions, although this may take a number of years to occur. This is however, only a hypothesis at this stage as there is no precedent to the very high sediment loads which have occurred in the lakes over the past decade to compare against.
- Lake Freeman has almost always had higher turbidity compared to Lake Apex. Lake Freeman is therefore acting like a sediment basin for Lake Apex.

The last item of historic data reviewed was the newspaper articles provided in Appendix D. The first article provided in Figure D-1 is dated from December 1975 and describes the construction and opening of the lakes. It is relevant to this assessment as it states that original volume of the lakes was '*150,000,000 litres*'. Further discussion on how lake volume may have changed over time is provided in Section 4.4.2.1 below.

Further it states that the lakes were '*stocked successfully by Apexians with jewfish*'. The jewfish referenced were most likely the eel-tailed catfish (*Tandanus tandanus*) which have been colloquially been called 'jewfish' in the past. No eel-tailed catfish or any other species called a 'jewfish' were however identified during the fish survey.

4.3.1.2 Water Quality

Site specific water quality objectives are not available for the lakes as there is insufficient data upon which to base such objectives. In the absence of site-specific objectives, objectives for the Lockyer Creek catchment are referenced in Table 4-1 below.

These are long term, aspirational water quality objectives (WQOs) considered by the State government as being necessary to support and protect different environmental values identified for waters within the Lockyer Creek catchment (DERM 2010). Given the lakes are artificial and located within a catchment which has dispersive soils, they are not directly transferrable to the lakes but are referenced here simply as they are the only objectives available for waterways in the catchment.

Table 4-1 EPP Water quality objectives for freshwater lakes in the Lockyer Creek catchment

Parameter	Objectives[2]
Turbidity	<6 NTU
Suspended solids	<6 mg/L
Chlorophyll a	<5 µg/L
Total nitrogen	<500 µg/L
Oxidised N	<60 µg/L
Ammonia N	<20 µg/L
Organic N	<420 µg/L
Total phosphorus	<50 µg/L
Filterable reactive phosphorus (FRP)	<20 µg/L
Dissolved oxygen	(20th—>80th percentile) % saturation 85% –
pH	6.5 – 8.0

The *Lockyer wetlands directory* (Gould and Grant 2003) provides results from a single snapshot survey of water quality in the lakes. The directory noted that water quality was taken at the 'eastern end of footbridge' at 1:15 pm to 2:30 pm on 3 July 2001. The water quality results from this directory are provided in Table 4-2. Results which exceed the objectives provided in Table 4-2 are highlighted in yellow.

Table 4-2 Water quality results from survey undertaken 3 July 2001

Parameter	Value
Water temperature	20.7°C
Air temperature	22.1°C
Electrical conductivity	250 µS/cm
Turbidity	45 FAU[3]
pH	7.9
Dissolved oxygen	70% sat. (6 mg/L at 2:05 pm)
Nitrate	1.0 mg/L
Phosphate	0.25 mg/L
Cyanobacteria	Suspected cyanobacteria (blue-green algae) visible on water surface

As can be seen from these results, in 2001 turbidity was much higher than the WQOs presented in Table 4-1. The results from the 2001 survey, although only a snapshot, may provide a more realistic turbidity objective for these lakes, at least in the short term.

[2] Source: (DERM 2010)
[3] One FAU is equivalent to one Nephelometric Turbidity Unit (NTU)

Nutrients were also elevated in 2001 and there was a visible presence of cyanobacteria. Comparison of these results against the water quality results from the testing undertaken as part of this project is provided in Section 4.4.1.1 below.

4.3.1.3 Geology and Soils

The catchment is located within the Clarence-Moreton geologic basin. The geology of the catchment is characterised by Gatton Sandstone of the Bundamba Group which is described in the Australian Stratigraphic Units Database (2017) as:

> Thin- to thick-bedded, coarse- to medium-grained, feldspathic to lithic feldspathic sandstone with clay matrix; subordinate intervals of granule, pebble and minor cobble polymictic conglomerate, with abundant ferruginised fossil wood logs and fragments.

Alluvial soils mapping produced by the State government (2007) was assessed and is presented in Figure 4-6 Soils of the Lockyer Valley alluvial plainsbelow. There are three (3) distinct alluvial soils types recognised within the catchment by this mapping as outlined below. Interpretation of soil classifications are based on the Australian soil classification system (CSIRO, 2017) and the Queensland Government soils descriptions (Queensland Government 2017). The three alluvial soils identified in the mapping are as follows:

(1) Soils in the north-west corner of Lake Apex are described as:

- A black vertosol which is dark self-mulching, cracking medium to heavy clay with dark, brown or grey calcareous subsoil to 1.5m deep or over medium to heavy clay palaeosol.

(2) Soils over most of Lake Apex and Lake Freeman are described as:

- An aquic vertosol which has a humic mottled surface horizon over mottled dark or grey medium to heavy clay with grey calcareous subsoil to1.5m deep.

These vertosol soils are clay soils which exhibit strong cracking when dry. They have high agricultural potential including due to their very high-soil fertility and large water-holding capacity but they require significant amounts of rain before water is available to plants. Gypsum and/or lime can be used to improve their structure although this is probably not be necessary for any revegetation within the lakes given they are typically wet. The heavy plastic clays can be difficult to cultivate however, especially when they are wet which may have implications for revegetation works within the lakes.

(3) Soils over the southern part of Lake Freeman and the drainage corridors leading into the lakes are described as:

- A grey or brown sodosol which is a hardsetting texture contrast soil with grey brown or brown sandy loam to sandy clay loam surface soil with variable A2 horizon development to 0.15 to 0.45 m over grey brown or yellow brown alkaline clay subsoil to 0.6 m. Layering common below 0.6 m.

Sodosols are known for their high sodicity leading to high erodibility, poor structure and low permeability. The presence of these soils helps to explain the high turbidity in the lakes. Although sodic, these soils are not highly acidic (pH > 5.5) which is supported by the water quality results provided in Section 4.4.1.1below. They also typically have low agricultural potential meaning they have low soil fertility and are often associated with soil salinity.

4.3.1.4 Extent of Exposed Soils

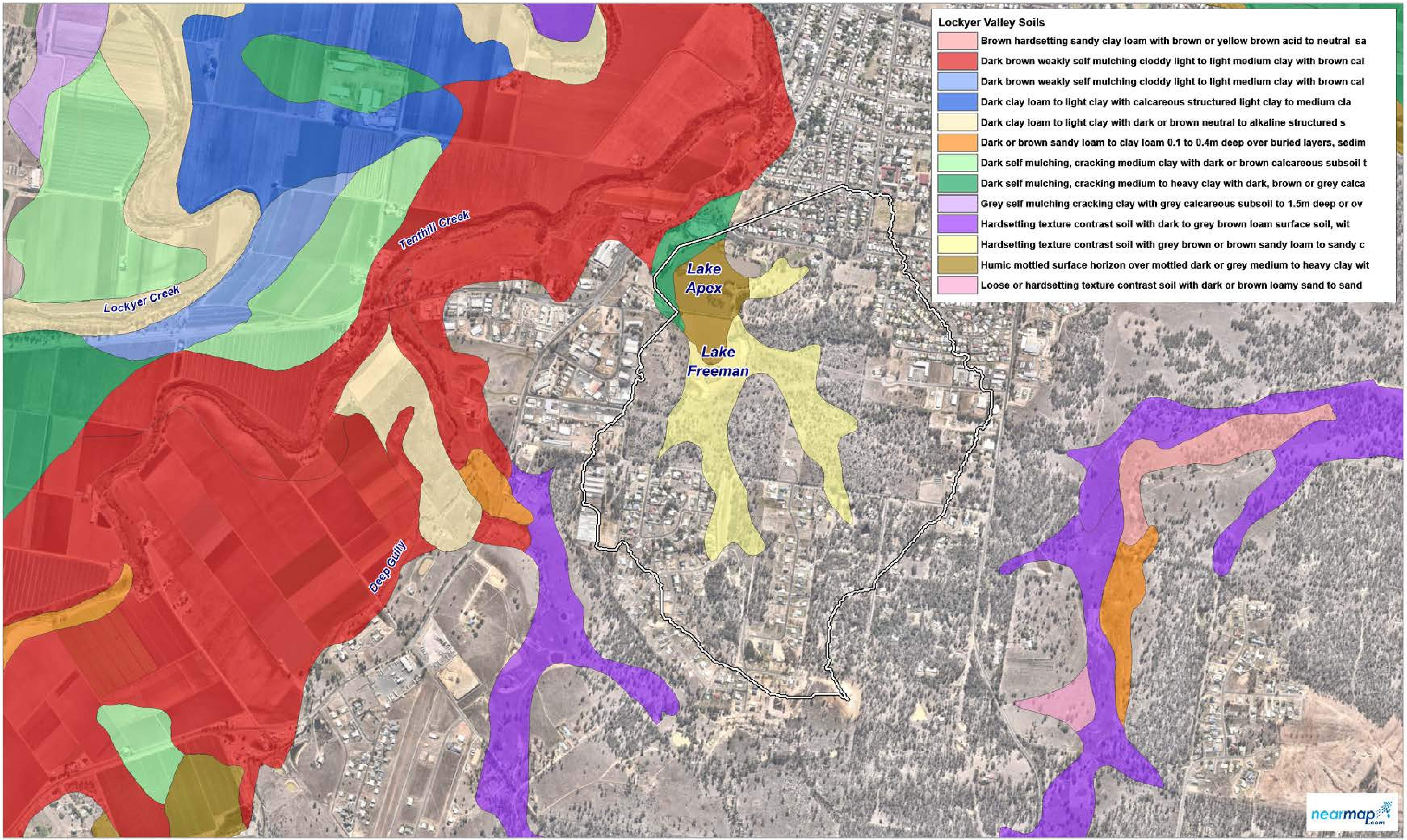
Given the relationship between the soil of the catchment and the high turbidity of the lakes, the extent of exposed sols on Council land within the catchment of the lakes was assessed and is presented in Figure 4-7. As can be seen in this figure, exposed soils exist within Lake Apex Park, Gatton Cemetery and Rangeview Road which need to be stabilised. Most of these areas have had topsoils washed away so will need cultivation and topsoiling prior to replanting. Examples of such areas are shown in Figure 4-5.

As described in Section 4.2.2 above, there are also exposed soils on upstream development land and on private building sites which will need to be controlled. The intent of this section is however to develop strategies to address exposed soils on Council land. Managing exposed soils on private land is addressed through separate management strategies discussed further in Section 5 below.

Figure 4-3 Examples of eroded topsoils at Lake Apex Park

Figure 4-4 Example of Eroded topsoils at Gatton Cemetery

Figure 4-5 Example of Eroded topsoils at Rangeview Road



LEGEND

Catchment

No Window

Title:

Soils of the Lockyer Valley alluvial plains

Figure: **4-6**

Rev: **A**

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.

N 0 400 800m Approx. Scale

BMT www.bmt.org

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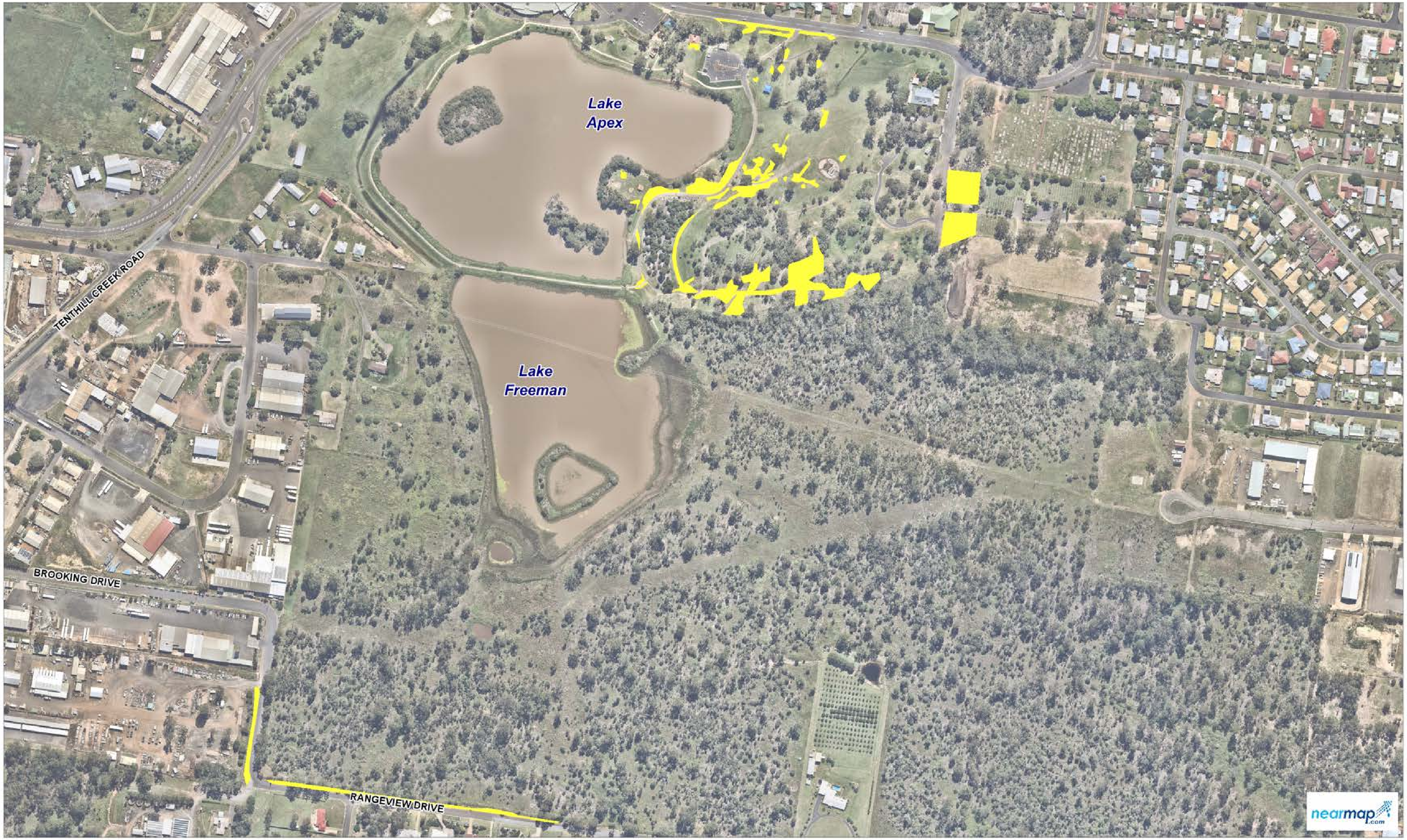

LEGEND

Exposed Soils

Title:

Exposed soils across Council owned land

Figure: 4-7

Rev: A

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.

N

0 100 200m

Approx. Scale

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www.bmt.org

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4.3.1.5 Flora and Fauna

The Wildnet database search revealed the following EVNT species in the locality:

- *Eucalyptus taurina*
- *Melaleuca irbyana*
- *Grevillea quadricauda*.

None of these species were however, identified in the aquatic and riparian survey, the results of which are provided in Section 4.4.4 below.

The search of the *Biodiversity recovery plan for Gatton and Laidley Shires* (Lockyer Catchment Association 2004), revealed that the following regionally significant wetland taxa were potentially occurring in the locality:

- *Brasenia schreberi, Watershield*
- *Carex lophocarpa*
- *Cyperus gunnii subsp. novae-hollandiae*, Flecked flatsedge
- *Cyperus squarrosus*, Bearded flatsedge
- *Damasonium minus*, Starfruit
- *Eryngium vesiculosum*, Prostrate blue devil
- *Potamogeton pectinatus*, Sago pondweed.

As per the EVNT species identified in the Wildnet database, none of these species were identified in the aquatic and riparian survey the results of which are provided in Section 4.4.4 below.

All species identified by the Wildnet and PMST databases and biodiversity recovery plan have been listed together with their status under federal and state legislation, including the EPBC Act, *Nature Conservation Act 1992* (Qld) (NC Act) and *Biosecurity Act 2014* (Qld). Status under these acts include:

(1) Federal:

- (a) Threatened: critically endangered (CE), endangered (EN), vulnerable (Vu)
- (b) Migratory (Mi)
- (c) Marine (Ma)

(2) State (native):

- (a) Threatened: endangered (E), vulnerable (V), near threatened (NT)
- (b) Special least concern (SLC)
- (c) Least concern (LC)

(3) State (invasive):

- (a) Restricted matter: category 1-7 (Re 1-7)
- (b) Prohibited matter (Pr).

The final flora and fauna species lists are provided in Appendix E.

4.3.1.6 Location and Suitability of Hydraulic Controls

The various hydraulic controls identified are presented in Figure 2-1 and include:

- The vegetated channel which joins the two lakes located at the eastern end of the lakes beneath the footpath as shown in Figure 4-8.
- The outlet weir and associated culverts in the north-west corner of Lake Apex as shown in Figure 4-9.
- The various swales which lead into the lakes and the two basins located upstream of Lake Freeman control water levels in the lakes.

An analysis of water levels and was undertaken and is described in Section 4.3.2 below.

Figure 4-8 Footbridge and the vegetated channel which joins the two lakes

Figure 4-9 Outlet weir and culverts in the north-west corner of Lake Apex

4.3.2 Stage 2B: Water Balance Modelling

As outlined in Section 3.2.2, a water balance model of the lakes has been developed to provide an understanding of anticipated water levels in response to inputs from stormwater and outputs due to evaporation and potential irrigation. Using a 117-year period of historic climate data, the model has provided results for the existing condition, ultimate condition (fully developed catchment) and the ultimate condition. The model was also expanded to testing the effect of harvesting from the lakes for irrigation of Lake Apex Park as this was an item discussed with the community at the project workshop.

The results of the model have been converted into easily interpretable graphs which are provided in Appendix A. These graphs include:

- Predicted water level variations (refer to Figure B-3 to Figure B-8). Based on the results presented in these graphs, the following observations can be made about the water balance in the lakes:
  - As the catchment becomes more developed, a greater volume of water will flow into the lakes as result of the increased in imperviousness across the catchment. This will result in less frequent periods of drying and a decrease in the duration of dry periods so there will be overall greater volume of water in the lakes.
  - If water was harvested from the lakes for irrigation of Lake Apex Park, both the frequency and duration of drying is expected to be worse than the current scenario, even with a fully developed catchment.
- The predicted probability of water level exceedance, identifying how probable various water levels would be exceeded (refer to Figure B-9 to Figure B-14). Based on the results presented in these graphs, the following observations can be made about the water balance in the lakes:
  - The probability that there will be adequate water in the lakes to support ecological processes increases the more developed the catchment becomes over time.
  - If water was harvested from the lakes for irrigation of Lake Apex Park, this probability decreases.
- The predicted probability of exceedances of lake residence (‘turnover’ time), with comparison made to a maximum 20-day residence time target (Mackay City Council[4] 2008) (refer to Figure B-15 to Figure B-20). Based on the results presented in these graphs, the following observations can be made about the water balance in the lakes:
  - Lake Apex and Lake Freeman exceed the maximum 20-day residence time target for approximately 80% and 70% of the time respectively under the current scenario. This suggests that the lakes are at a high risk of algal blooms occurring.
  - The duration in which water remains in the lakes decreases the more developed the catchment becomes, down to approximately 50% of the time for both lakes under the ultimate scenario. This decrease minimises the risks of algal blooms occurring as more fresh water flows into the lakes and flushes them out.

[4] Although this is a Mackay based guideline, the targets are considered ‘best practice’ in Queensland and the model accounts for variation in climatic conditions between Mackay and Gatton.

- If water was harvested from the lakes for irrigation of Lake Apex Park, the remaining water in the lakes would remain in the lakes for longer, increasing the probability that the lake residence would be exceeded and increasing the risk of algal blooms occurring.

Based on the modelling results presented in Appendix A and the discussion provided above, the lakes are at high risk of algal blooms including due to the lack of water available to regularly flush them out. It is therefore essential that any strategy designed to minimise turbidity also either minimise the residence time (for example by increasing flows) and/or minimise nutrient loads in the lakes in order to minimise the risk of algal blooms. There are however, no known viable options for increasing flows to these lakes[5] so managing nutrients will be critical to minimising the risk of algal blooms.

The modelling results also suggest that the harvesting of water from the lakes for any purpose, such as irrigation of Lake Apex Park, would increase the risk of algal blooms occurring. As such, harvesting and irrigation are not recommended for these lakes.

[5] It is understood that groundwater was previously used to top up the lakes but the practice was discontinued due to high salinity of local groundwater.

4.4 Stage 3: Lake Condition Assessment

4.4.1 Stage 3A: Physical and Chemical Water and Soil Quality Profiling

4.4.1.1 Water Quality Profiling

Physical water quality monitoring results

The results from the pre-calibrated water quality instrument monitoring results are presented in Table 4-3. Given that measurements were taken through the full depth of the water column at each location from the surface to the bed of the lakes, the results presented are depth-averaged. Results which exceed the objectives provided in Table 4-3 are highlighted in yellow.

Table 4-3 Depth-averaged water quality monitoring results (16 June 2017)

Lake	Site	Temp* (°C)	Conductivity (µS/cm)	Salinity* (ppt)	DO* (mg/L)	DO (%Sat.)	pH*	Turbidity (NTU)
Objective						80-100		6
Apex	1	15.4	273	0.13	7.22	72	7.22	347
	2	15.5	274	0.13	7.84	79	7.34	344
Freeman	3	15.9	206	0.10	8.25	83	7.36	96
	4	16.2	207	0.10	7.94	81	7.60	141

* Denotes no WQO available

Results from both the 2001 and 2017 sampling events were snapshot surveys only which would be highly influenced by preceding weather conditions. More frequent testing is essential to understand water quality patterns in the lakes. The observations made below are therefore also limited. Based on the available results, the following observation have been made about water quality in the lakes:

- Turbidity, as expected, was well above the objectives provided in Table 4-1. As discussed in Section 4.3.1.3 above, the soils in the catchment are sodic and highly erosive so the lakes could be expected to naturally have a higher turbidity than the WQO. Nevertheless, the results are significantly higher than 2001 monitoring results presented in Table 4-2 above, which suggests that turbidity levels have increased well beyond natural background levels.

  Interestingly, the results indicate much higher turbidity in Lake Apex compared to turbidity in Lake Freeman suggesting that some of the suspended solids from Lake Freeman have either settled out or have been washed into Lake Apex. This is a promising result as it highlights potential for further decreases in turbidity if the sources are appropriately controlled and management of current levels is undertaken i.e. the suspended particles are expected to either settle further or be washed out with appropriate management.

- Temperature was relatively consistent throughout the lake profiles and there was no evidence of temperature-induced thermal stratification. Given the timing of monitoring (in winter), this result could be expected. Nevertheless, the shallow profile of the lakes means that the likelihood of thermal stratification is limited.

- The conductivity and salinity are appropriate for freshwater lakes and although soils in catchment are sodic, as described in Section 4.3.1.3 above, there is no concern about salinity in the lakes. The results are also comparable to the 2001 monitoring results presented in Table 4-2 above, suggesting that there has not been a measurable increase in salinity over the past 16 years.

- DO in both lakes was slightly below the WQO provided in Table 4-1above. Although not a major concern at this stage, measures such as revegetation should ideally be undertaken to improve DO levels given that DO is essential to all the fish and many of the aquatic macroinvertebrate species which form the basis of the food chain in the lakes.
- pH was within the range identified Table 4-1 above and comparable to the 2001 monitoring results presented in Table 4-2 above. No management of pH is therefore necessary.

Chemical water quality monitoring results

The TSS and nutrient results from the laboratory testing of water quality samples are presented in Table 4-1. Results which exceed the objectives provided in Table 4-4 are highlighted in yellow.

Table 4-4 Chemical water quality monitoring results (16 June 2017)

Lake	Site	TSS (mg/L)	TKN* (mg/L)	NH_3 (mg/L)	NOx* (mg/L)	ON (mg/L)	TN (mg/L)	TP (mg/L)	PO_4* (mg/L)
Objective		6		0.02		0.42	0.5	0.05	
Apex	1	17	2.10	0.1	0.34	2.000	2.40	0.78	0.10
	2	8	2.20	0.12	0.35	2.080	2.60	0.81	0.10
Freeman	3	9	1.60	0.05	0.05	1.550	1.60	0.33	0.10
	4	<5	1.50	0.05	0.04	1.450	1.50	0.32	0.10

* Denotes no WQO available

Based on these results, the following observation can be made about water quality in the lakes:

- TSS is higher than the WQO at all but Site 4 in Lake Freeman. The volume of suspended solids can be low but turbidity can remain high if there are many fine particles suspended which could explain these results.
- TP and TN are exceptionally high as are the ammonia and organic nitrogen results. Results for TKN, NOx and PO_4 are not highlighted in Table 4-4 as there are no objectives against which to compare but results for these nutrients are also high compared to other artificial lakes in SEQ. In general, nutrients are very high in the lakes which presents a major risk of algal blooms. As noted previously, it is essential to manage these nutrients as well as turbidity otherwise severe algal blooms can be expected.
- The resuspension of nutrients previously trapped in benthic sediments has occurred with the dieback of macrophytes. This dieback has further increased nutrient concentrations in the lakes including by:
  - Limiting nutrient treatment previously provided by the plants and the biofilms which live on the plants.
  - Release of nutrients into the water column through the decomposition of the plants.
- Other nutrients sources may include:
  - Stormwater runoff including both dissolved nutrients and those bound to sediment particles.
  - Mowing mulch either blown or washed into the lakes.
  - The increase in sedentary bird populations.

Although a bacterial analysis was not undertaken, (apart from cyanobacteria discussed below) it is likely that bacteria levels have also increased and are now at very high levels.

Cyanobacteria water quality monitoring results

The cyanobacteria results from the laboratory testing of water quality samples are presented in Table 4-5 and Figure 4-10 below.

Table 4-5 Cyanobacteria monitoring results (16 June 2017)

Cyanobacteria Type	Unit	Site Location			
		Site 1	*Site 2*	*Site 3*	*Site 4*
Aphanocapsa spp. < 2µm	cells/mL	[BDL]*	[BDL]*	[BDL]*	1500
Cyanocatena spp.	cells/mL	[BDL]*	[BDL]*	1520	1300
Cyanogranis libera	cells/mL	[BDL]*	[BDL]*	325	200
Merismopedia spp.	cells/mL	[BDL]*	[BDL]*	[BDL]*	400
Unidentified Chroococcales	cells/mL	[BDL]*	[BDL]*	2150	600
Total Chroococcales	cells/mL	[BDL]*	[BDL]*	4000	4000
Total Cyanophytes	cells/mL	[BDL]*	[BDL]*	4000	4000

* [BDL] denotes 'below detectable limit'

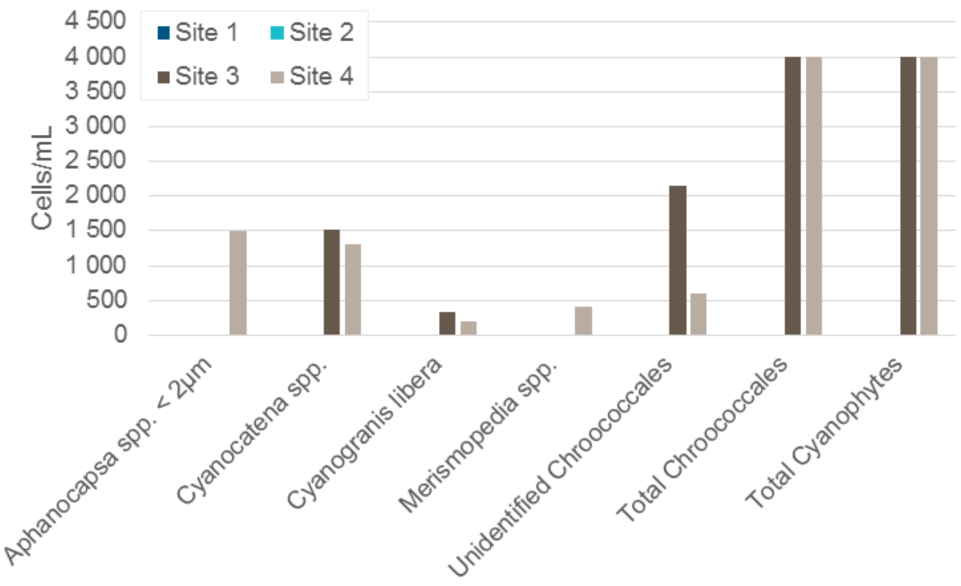


Figure 4-10 Graphed cyanobacteria monitoring results (16 June 2017)

Based on these results, the following observation can be made about water quality in the lakes:

- Low cyanobacteria levels were detected in Lake Freeman.
- No cyanobacteria were detected at either of the two sites in Lake Apex. This does not necessarily mean that cyanobacteria is not in Lake Apex however, simply that it was not detected at the two monitoring locations. It is not uncommon for two waterbodies to have different algal populations even if they are connected and populations can vary even within the same waterbody. Lake Apex also has higher turbidity compared to Lake Freeman which would reduce the likelihood of cyanobacteria compared to Lake Freeman.
- None of the species detected were species recognised as potential toxin producing.

The results from the biovolume analysis are provided in Table 4-6 below.

Table 4-6 Cyanobacteria biovolume analysis results (16 June 2017)

Species	Site			
	1	2	3	4
Aphanocapsa spp. < 2µm	ND	ND	ND	0.001
Unidentified Chroococcales	ND	ND	0.001	ND
TOTAL BIOVOLUME	-	-	**0.001**	**0.001**

* [ND] denotes 'non- detected'

The biovolume results are very low due to the morphological characteristics of the cyanobacteria detected in the sample i.e. mostly very small cyanobacteria approximately 1µm in diameter.

Despite these results, the risk of algal blooms forming in the lakes is still considered quite high as the nutrients levels are very high and the hydraulic retention time is very high (as explained in Section 4.3.2 above). Cyanobacteria growth and blooms are also regulated by light, turbidity, temperature, grazing pressure and type of substrate. Light is currently limited by high turbidity however, as turbidity declines over time (naturally and through management actions) light will become more available in the water column, as has happened in Lake Freeman, and the risk of algal blooms will increase. Temperature will increase over summer and new temperature highs can be expected in the lake as the depth has decreased with sediment accumulation.

Given these multiple factors working together to increase the risk of algal blooms, the management of algal blooms risks is critical to the amenity and ecology of the lakes. If major blooms do occur, controlling them is very difficult and would require substantial investment in excess of prevention measures.

4.4.1.2 Sediment Quality Profiling

Table 4-7 Chemical water quality monitoring results (16 June 2017)

Lake	Site	Moisture Content	TKN (mg/L)	NH_3 (mg/L)	NOx (mg/L)	TN (mg/L)	TP (mg/L)	PO_4 (mg/L)
Apex	1	78.6	3680	135	4.8	3685	1130	0.20
Freeman	3	69	2560	58.4	1.5	2562	532	<0.1

Based on these results, the following observation can be made about sediment quality in the lakes:

- Exceptionally high nutrient levels were recorded in the sediment of both lakes. The resuspension of sediments by wind and fauna in the lakes would remobilise not only the sediment but also the nutrients back into the water column. These results support the water quality results presented in Section 4.4.1.2 above.

4.4.2 Stage 3B: Bathymetric Assessments

4.4.2.1 Lake Depth and Bathymetry

The results of the bathymetry survey including the bathymetry, water depth, benthic surface and benthic hardness are presented in Figure 4-11, Figure 4-12, Figure 4-13 and Figure 4-14 respectively. It is noted that it is not possible to undertake the hardness survey in very shallow water so the survey does not include the very edges of the lakes and was not possible to complete over much of Lake Freeman. Based on the results presented in these figures, the following observation can be made about bathymetry of the lakes:

- Both lakes are quite shallow with Lake Apex being 1.75m at its deepest point and Lake Freeman being 0.7m deep at its deepest point at the time of the survey.
- Deep areas within the lakes are limited meaning that during periods of drying, there are limited refugia in which aquatic species can retreat to. Temperatures would also be high and unsuitable for many fauna species. This also increases the likelihood of algal blooms. The moats which were dug by Council during the 2003 drought can be seen on Figure 4-11 and Figure 4-13 in particular, although the depth of these moats may have been reduced by the accumulating sediment.
- The benthic surface shown in Figure 4-13 reveals that there does not appear to be any major features which are noteworthy apart for the extensive small holes across the benthic surface. It is unclear what caused these holes but was likely either the turtles or a fish species not detected in the fish survey, noting that the survey was mostly around the edges of the lakes where such holes are limited. It is acknowledged that one of the comments in the *Lake Apex management plan* (Place Design Group 2011) suggested the presence of Queensland lungfish (*Neoceratodus forsteri*) in the lakes however, this is considered unlikely as they would have been detected during the 1994 and 2003 droughts when the lakes dried up.

The lack of features on the benthic surface also limits suitable habitat for many aquatic species which typically inhabit lakes and wetlands. The placement of logs and rocks in the lakes would improve habitat values.

Fortunately, no large items of dumped rubbish (cars, white goods, shopping trolleys, barrels etc.) were detected in the benthic surface survey.

- The benthic hardness survey presented in Figure 4-14 provides an indicator of recent sediment deposition as it is an indicator of the degree of consolidation or compaction of sediments. More consolidated or ‘harder’ sediments would likely have been compacted over a longer duration and vice versa. Most of Lake Freeman features sediments with a low level of hardness suggesting widespread, recent (during the past decade) sediment deposition. The eastern edge in particular shows the most recent depositions.

  Lake Apex features less of the low hardness sediments but the eastern side of the lake does feature unconsolidated sediments especially in the north-east corner of the lake. This would suggest that the primary source of new sediment into Lake Apex is from Lake Apex Park, Gatton Cemetery and surrounding open space which flows directly into Lake Apex. This further supports the need to urgently stabilise these areas as previously discussed in Section 4.3.1.3 above.

  The construction of the carpark in Lake Apex Park would also have contributed to this sediment load however this now sealed.

4.4.3 Stage 3C: Accumulated Sediment Depth Measurement

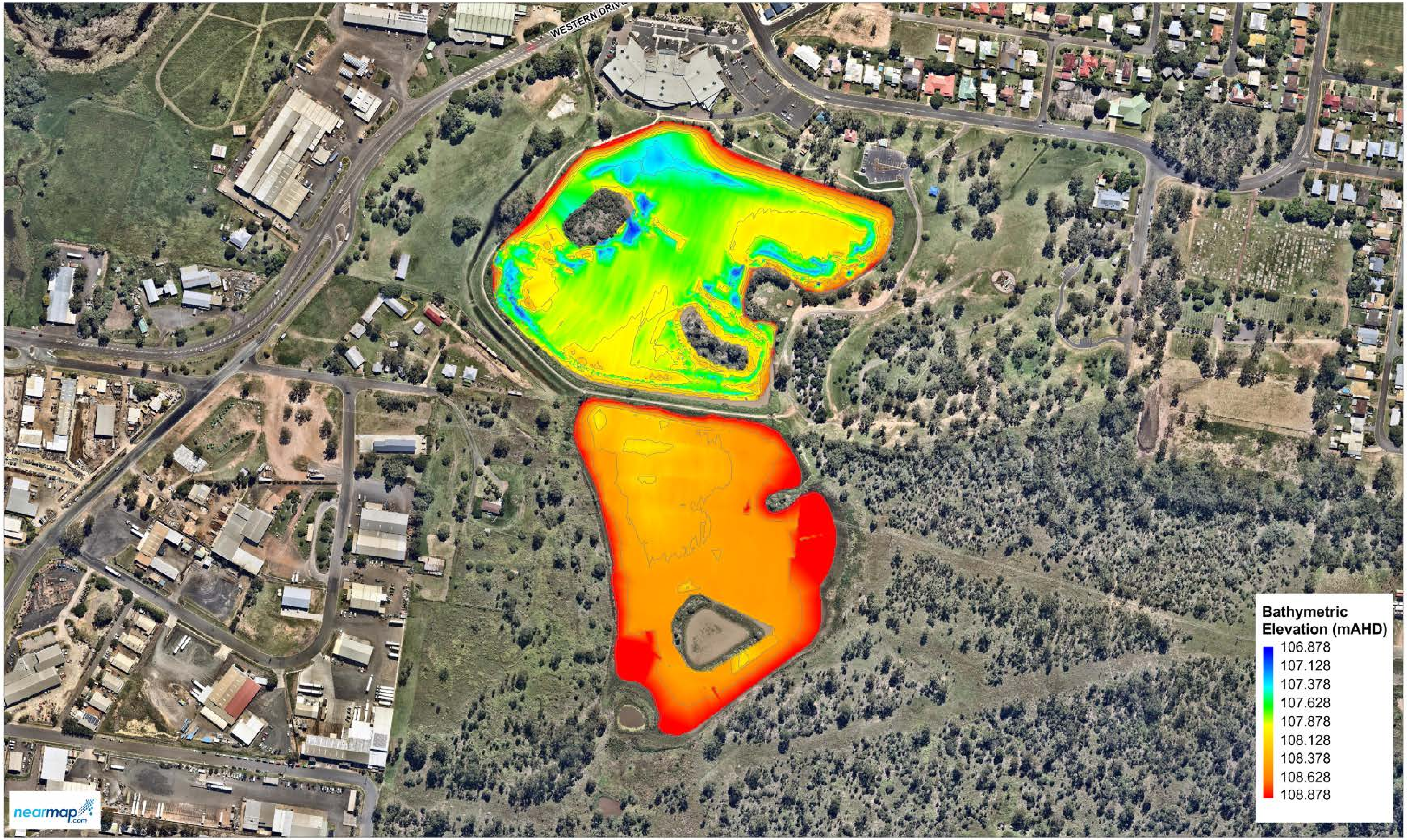
The accumulated sediment depth measurements results are presented in Figure 4-15. These results indicate that at least up to a metre of sediment has accumulated in both of the lakes since they were constructed. It is possible that the actual depth could be greater and the initial sediments have compacted too much to be detected but in any case, it is clear from the results that an extensive volume of sediment is now present in the lakes.

As noted in Appendix D, the original lake volume was quoted as being ‘150,000,000 litres’ (150 Megalitres). However, based on the survey results, the volume has now been reduced to 34,146,000 litres (34.15 Megalitres).

As noted in Section 4.4.2.1 above, the effects of this sedimentation are expected to include:

- Reduced total volume of water storage meaning more frequent and prolonged periods of drying.
- Higher water temperatures which are unsuitable for many fauna species.
- Increased risk of algal blooms.
- Reduced habitat diversity including less refugia in which aquatic species can retreat to during periods of drying.

The cumulative effect of this sedimentation is an overall decline in ecosystem health. This in turn reduces the amenity of the lakes and decreases the value which many members of the community place in the asset.



Title:

Surveyed bathymetry of the lakes

(as surveyed 14 June 2017)

N

0 100 200m

Approx. Scale

Figure:

4-11

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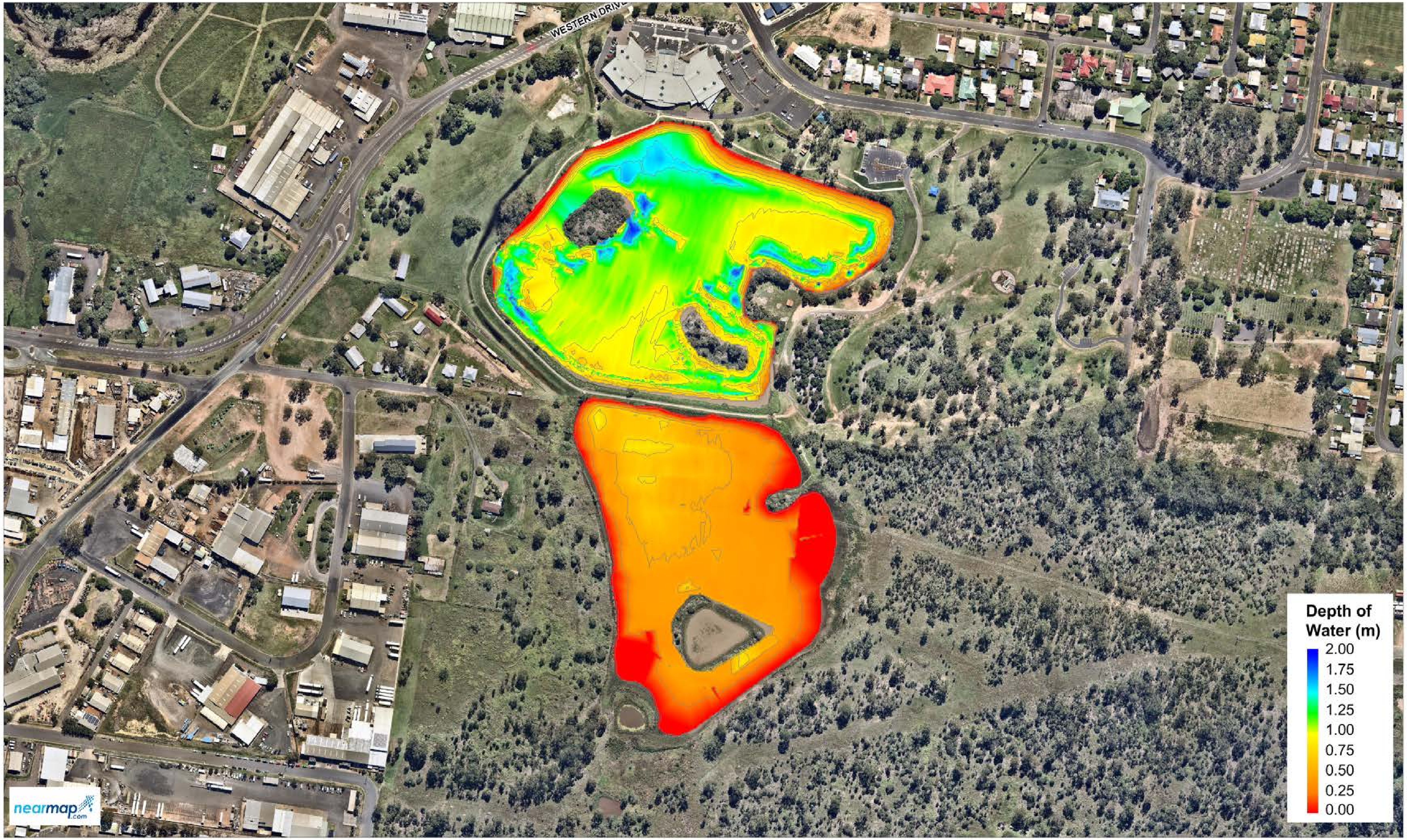

Title:
Surveyed water depth in the lakes
(as surveyed 14 June 2017)

Figure: **4-12**

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LEGEND

Benthic surface

Title:

Benthic surface survey results (as surveyed 14 June 2017)

Figure: **4-13**

Rev: **B**

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LEGEND

Relative Hardness

Hard — **Soft**

Title:

Benthic hardness survey results (as surveyed 14 June 2017)

Figure: **4-14**

Rev: **B**

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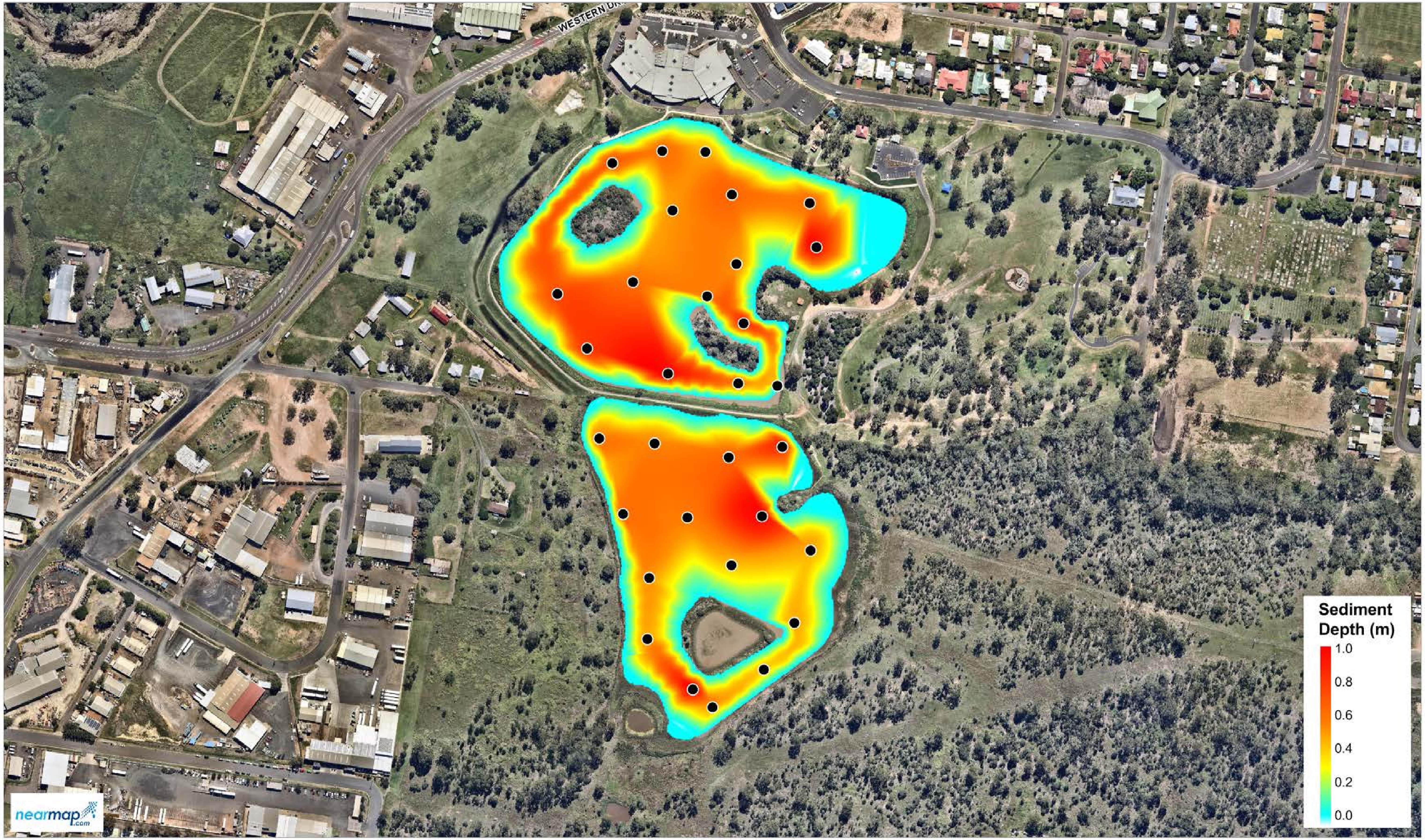

LEGEND

● Field data location (sediment depth)

Title:

Accumulated sediment depth in the lakes (as surveyed 14 June 2017)

Figure: **4-15**

Rev: **B**

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4.4.4 Stage 3D: Riparian and Aquatic Flora Survey

As described in Section 3.4.4 above, a survey of the lakes was undertaken to identify aquatic and semi-aquatic vegetation as well as riparian vegetation on the banks of the lakes. The relevant habitat types of the lakes identified during the survey included:

- Lacustrine habitat (i.e. the lakes)
- Macrophyte zone (shallow areas supporting aquatic vegetation)
- Steep-sided banks subject to periodic flooding
- Riparian fringe.

A plan showing these various habitat zones has been prepared and is provided in Figure 4-17. A species list was also developed based on these habitats and is provided in Appendix F. The list includes both native and exotic species including species recognised as weeds.

Based on the survey, the following observation can be made about the riparian and aquatic flora of the lakes:

- The most striking aspect of the flora is the lack of aquatic macrophytes across the lakes. This is in stark contrast to the extensive macrophyte cover which once covered the lakes as shown in the photos provided in Figure 4-1 above. This demonstrates that there has been a major decline in the ecological health of the lakes since the photos provided in Figure 4-1 above.

  This change is expected to have had significant implications for water quality resulting in significant increases in nutrient concentrations and turbidity.

  Similarly, this change is expected to have had significant implications for the ecology of the lakes with a loss of habitat resulting in major declines in species abundance and diversity including macroinvertebrates, fish, amphibians (especially frogs), and birds.

It is not surprising therefore, that the fish survey results presented in Section 4.5 below identified only common fish species tolerant of low habitat values/poor water quality and that during the workshop, FOLA members described a decline in bird species diversity. These survey results including comparison with historic photos certainly support those observations.

It should be noted that the cyclic decline and recovery of macrophyte habitats would appear to be a ‘natural’ process of these lakes, in response to changing hydrologic conditions. The current decline has however, persisted for approximately a decade and the macrophytes are showing no signs of recovery. It is expected therefore, that the condition of the lakes has progressed past a tipping point where natural regeneration is no longer expected. This has likely been caused by the various issues described previously particularly the sedimentation (which smothers vegetation and the soil seed bank preventing regrowth and increases drying) and increased turbidity (which limits light availability for plants). Assisted revegetation will therefore be necessary.

Given the lack of macrophyte cover across the lakes, most of the area across the lakes could not be mapped as a particular habitat zone in Figure 4-17. While open water still has an important habitat role, the extent of shallow open water which should be vegetated could not be considered a particular vegetated habitat zone.

- Another major finding of the riparian and aquatic flora survey is that while many native species exist in the lakes, there is a heavy presence of weeds across the lakes. Para grass is particularly prevalent dominating most of the Lake Apex riparian zone and a large part of Lake Freeman as well.
- The remainder of the lakes are dominated by *Ludwigia, Persicaria* and *Eclipta* species. *Ludwigia peploides* (water primrose) is considered a weed as well. These are common species and overall provide limited habitat diversity with sedges and rushes, which once dominated the lakes, now being noticeably limited.
- While numerous weed species were identified, a copse of *Phyla canescens* (Lippia / Condamine couch) was located on the south-eastern banks of Lake Apex and is a cause for concern. The location of this copse is shown on Figure 4-17. Although this is not a prohibited or restricted invasive plant under the *Biosecurity Act 2014*, it is a serious environmental weed which poses a threat to aquatic habitats as it forms dense carpets and prevents growth of other riparian vegetation. This can result in decreases in bank stability, subsequent erosion of banks and degradation of waterbody health and water quality. It is extremely difficult to control and is spread by floodwater, seed dispersal, vehicles, machinery, birds and livestock. The careful eradication of Lippia is required to impacts upon the lakes and prevent its further spread.
- Macrophytes along the lake edge are likely being affected by maintenance activities including mowing/brush cutting and potentially also spraying of weeds. In many locations, there is poor delineation between the riparian habitat and turf (see for example Figure 4-16). This makes it unclear where to stop mowing. Creating a well-defined mowing edge is a simple action which can be undertaken to protect the riparian habitat from accidental mowing.

Figure 4-16 Example of poor delineation between riparian habitat and turf around lake edge

LEGEND

- Eucalypt/Acacia regrowth
- Lantana / Sally Wattle / Wild Tobacco
- Nymphoides
- Phyla canescens (Lippia / Condamine couch) copse
- Shallow macropyhte zone dominal Persicaria / Eclipta
- Steep banks of Para Grass / Persi
- Steep planted embankments

Title:

Broad riparian and aqualtic habitat types identified in the lakes (as surveyed 14 June 2017)

Figure: **4-17**

Rev: **B**

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Approx. Scale

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4.4.5 Stage 3E: Snapshot Fish Survey

The snapshot fish survey resulted in the identification of eight (8) fish species and one turtle. The species identified included the following:

- Native fish:
  - Boney bream (*Nematalosa erebi*)
  - Glass fish (*Ambassis agassizii*)
  - Spangled perch (*Leiopotherapon unicolor*)
  - Australian smelt (*Retropinna semoni*)
  - Western carp gudgeon (*Hypseleotris klunzingeri*)
  - Fire tail gudgeon (*Hypseleotris galii*).
- Exotic fish:
  - Mosquitofish (*Gambusia holbrooki*)
  - Goldfish (*Carassius auratus*).
- Amphibians:
  - Kreffts river turtle (*Emydura macquarii krefftii*).

The native fish species identified are all common species which are tolerant of poor water quality and habitat. It is feasible that a greater diversity of native fish once existed in the lakes and that these have become extinct in the lakes due to the declines in water quality and habitat although, as there has never been any other known fish survey of the lakes previously, this cannot be confirmed. The hydrologic conditions, especially the lake drying would also have had an effect on fish species over time.

Based on the results of the fish survey, the exotic fish captured may not be considered to a be a major concern given the persistence of the native fish captured and no obvious relationship between poor water quality and the fish identified. Only a single goldfish was captured and although this was a sizable individual (30 cm in length), the fact that more goldfish were not captured would suggest that a sustainable population does not exist in the lakes.

It is however feasible that foraging by the goldfish could be the cause of the holes described in the benthic surface analysis presented in Section 4.4.2 above, and that a much larger population exists in the lakes than is suggested by the snapshot fish survey. If that is the case, the goldfish could be contributing to increased turbidity and grazing damage to macrophytes. The effects of this habitat and water quality degradation as well as direct predation could be further decreasing native fish populations. As such, a target survey aimed at the deep water zones is justified.

Figure 4-18 Photos of the 30cm goldfish and one of the Kreft's River Turtles caught during the lake survey

4.5 Condition Assessment Summary

A summary of the various issues identified in this section has been prepared and is provided in Appendix G. This appendix also provides appropriate performance indicators, a condition rating score, priority rating and management/maintenance responses for each issue.

The table in Appendix G was then used to inform the management actions discussed in Section 5 below and to inform the recommendations provided in Section 6 below.

5 Potential Management Actions and Recommendations

5.1 Preamble

This section discusses the various management actions which could be implemented to address the issues identified in Section 4 and summarised in Appendix G. Also provided here is an indication of associated cost range (low (<$100,000), moderate ($100,000-$500,000) or high ($500,000+)), estimated costs (where feasible) and timeframes. Further, this section clarifies which actions are actually recommended.

5.2 Water Quality and Hydrologic Management

5.2.1 Catchment Management Actions

Management options at the catchment scale include the following:

1. **An ESC and WSUD enforcement campaign** aimed at developers and builders. This option includes both the enforcement of current best practice standards (as defined by the *State planning policy* (DSDIP 2017) on developments and the issuing of fines for poor onsite practices. This option is considered to be feasible as there is good regulatory mechanisms already in place for both aspects of this action and they are already a regulatory responsibility of local governments (pursuant to the *Planning Act 2016*). Enforcement at the development application stage should already be undertaken by existing Council development assessment engineers and issuing of stormwater pollution fines should already be undertaken by existing Council compliance officers. The cost is therefore likely to be very low and can actually result in a net benefit i.e. revenue from fines can be used to pay the enforcement officer's time and training. The timing of such enforcement should continue until the catchment is fully built out. Given the feasibility and low cost of this action as well as the water quality benefits it would provide, this option is recommended.

2. **An ESC education campaign** aimed at developers and builders. This option is considered feasible as there is a wealth of freely available information through the DEHP and Healthy Land and Water which can be used in such a campaign. It will, need to be led by an officer who is knowledgeable in best practice ESC or be subcontracted to someone with specialised skills in this field. The overall costs are still considered to be low. The education program should continue until the catchment is fully built out. Given the feasibility and low cost of this action as well as the water quality benefits it would provide, this option is recommended.

3. **Stabilising eroding soils on Council land**. This action includes stabilising the exposed and eroding soils identified on Figure 4-7. Given that the topsoil has eroded over most of these areas, it will be necessary to cultivate the existing subgrade, replace the topsoil and either turf or plant/mulch the exposed areas. The area along Rangeview Road may require engineering input given it is drainage swale. An indicative plan showing the areas proposed to be turfed or planted/mulched is provided in Figure 5-1.

   These works are straightforward and could be undertaken within 1-2 months with establishment time being a little longer for planted areas. The capital cost is also low and estimated to be approximately $115,000 based on the extents shown in Figure 5-1. Maintenance costs would be additional however would not require anything more substantial than mowing. Given the feasibility and low cost of this action as well as the water quality benefits it would provide, this option is recommended.

LEGEND

- Proposed returfing area
- Proposed revegetation area

** To note - prior cultivation of soils and topsoiling is required before turfing or planting/mulching*

Title:

Indicative areas proposed to be either returfed or planted

Figure: 5-1

Rev: A

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4. **Land purchase**. As noted in Section 4.2.2 above, Lot 2 CP860760 could be developed in the future under Council's current planning scheme. One option is for Council to purchase this land for parkland which would protect it from future development.

   The current cost of this land is not known although during the workshop, it was suggested by FOLA members that it was for sale in 2010 for $3 million dollars and therefore the cost is considered high in the context of this project. It was also suggested by Council (Mark Bennett) that Council had previously given consideration towards purchasing the land at that time but was in the process of reducing the extent of land it manages rather than increasing land under its control.

   Unless a cost benefit analysis is undertaken, prioritising such a purchase is not possible and no recommendation can be made about its purchase at this point in time.

5. **Planning Scheme and approval controls**. Another option to minimise the impacts that future development will have on the lakes are Planning Scheme and approval controls. This includes two key aspects including:

   i. Revising the current Planning Scheme to require an open space setback to the lakes and protection (and rehabilitation) of the two swales which flow into Lake Freeman from the south. The current *State development assessment provisions* (DSDIP 2017) for example, limits vegetation clearing within 50 m of a 'natural wetland'. While the lakes have been modified, they were historically a natural wetland and the distance of at least 50 m (measured from the top of the batter shown in Figure 5-3 below) would be appropriate to minimise impacts upon the lakes.

      The distance should also consider flooding levels which may result in a wider corridor around lakes. Flooding is not however, the only factor determining the buffer distance so if flooding is less than 50 m, a buffer of at least 50 m should remain. A buffer of at least 15 m to the two swales which flow into Lake Freeman (plus any flooding) is appropriate.

   ii. Revising the current Planning Scheme to require that any stormwater runoff from the development achieve '*no net worsening in stormwater quality concentrations in the lakes*' and that this is '*to be demonstrated through receiving water quality monitoring and modelling*'. This objective is likely to be more stringent than current pollutant load reduction targets but is a common standard enforced by regulatory agencies wherever there is a sensitive downstream receiving waterway such as these lakes. It is not considered onerous as it meets both the reasonable and relevant tests for development approval conditions. Furthermore, the current State legislation allows for more stringent objectives than those set by the *State planning policy* (DSDIP 2017).

These provisions would obviously need to be enforced by Council through development and reflected in development permit conditions. They are only applicable however to allotments without existing development approvals.

The cost of implementing this action is very low and the timeframe is also relatively short i.e. the amendments can be included in the next round of Planning Scheme amendments. The cost to the developer of implementing a treatment strategy which meets such standards is also not considered excessive given that numerous developers across the State have implemented such actions i.e. it is standard practice wherever sensitive downstream receiving environments exist. Given the feasibility and low cost of this action as well as the water quality benefits it would provide, this option is recommended pending existing development approvals.

6. **Improving community custodianship**. Improving water quality and habitat will improve amenity which is expected to improve the value placed on the lakes by the community. However, interactive education techniques targeted at different age groups is also required to increase education and develop greater custodianship over the lakes. Partnerships with community groups and local schools would improve the quality of such education strategies and directly engage key groups in process. It is expected that interactive education techniques would include signage with quick response (QR) codes and activities around the lakes.

   New signage should also make the community aware of the value of riparian zones for water quality and ecology and minimise perceptions that snakes and other wildlife which have probably inhabited land around the lake for decades (without any known issues) create unacceptable risk for the community.

   The timeframe for consulting with stakeholders to determine the best techniques and content and implementing the actions would take no more than a few months. Capital costs are expected to be low although this would require a substantial investment of staff time.

   Given the feasibility of this action as well as the community benefits it would provide, this option is recommended.

5.2.2 Pre-treatment Management Actions

Management options for the pre-treatment of flows into the lakes include the following:

7. **Constructing a sediment basin** to provide adequate pre-treatment of sediments. Even if all the best practice actions are implemented across the catchment, sediment will still flow into the lakes. This option therefore includes constructing a new sediment basin to provide adequate pre-treatment of sediments and is considered a very important management response.

   The expansion of either of the two existing basins was considered however discounted as they are significantly undersized and the northern basin is generally underwater during high water levels in Lake Freeman. Also, neither basin accepts flows from the south-eastern flow paths. A new basin is therefore considered the best action however, this would need to be confirmed during subsequent design stages.

   As part of this project, an analysis was undertaken to conceptually a sediment basin designed to capture both coarse and fine sediment particles. The analysis suggests that the volume of the basin should be approximately 2050m^3 (based on sediment basin sizing methods outlined in the *Wetland Technical Design Guidelines* (Water by Design 2017)). This equates to an area of approximately 3600m^2 as shown indicatively on Figure 5-2 below.

   The shape of this indicative basin aims to maintain the basin within Council's property, accept flows from both flow paths and avoid the exiting northern basin although needs to be refined during detailed design. Whether constructing the basin within the power easement would be acceptable would need to be conformed prior to subsequent design stages and the design adapted as necessary. The subsequent design stages would also need to allow for appropriate maintenance access into the bed of the basin.

   The timeframe for the design and construction of this basin is estimated to be approximately 4 months. The cost of constructing was also assessed as part of this project and is estimated to be approximately $210,000 (construction cost only). This is considered to be a moderate cost in the context of this project.

   Given the feasibility as well as the water quality benefits it would provide, this option is recommended.

   The local ground levels may require reconfiguration to ensure both swales flow into the sediment basin. The batters of the sediment basin should be planted with native species rather than turfed although some turfing is likely to be required for the maintenance access path.

8. **Constructing the dry creek bed in north-east corner of Lake Apex Park**. As noted in Appendix A, a design for this has completed (Bligh Tanner and Yurrah in 2014) and is ready for construction. The timeframe for construction is likely to be approximately one month. The 2014 cost estimate supplied by Bligh Tanner estimated works to have cost $115,257 in 2014 dollars. Advice from Council's Belinda Whelband was that the actual cost is expected by Council to be closer to $200,000. The cost is therefore considered to be moderate.

   Given that the swale and its catchment is not a high sediment source compared to other inflows to Lake Apex, this action is not a high priority and would only be recommended if other priorities were not undertaken. At this point, other more important actions are recommended so the action is not currently recommended.

LEGEND

Cadastre

Sediment Forebay

Title:

Indicative and location of recommended sediment basin

Figure: 5-2

Rev: A

N

0 50 100m

Approx. Scale

BMT WBM

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Filepath: I:\B22609.i.pd.Lakes_Freeman_&_Apex\DRG\UW_012_170719_ProposedSedimentForebayLocation.wor

5.2.3 Lake Management Actions

Management options within the lakes include the following:

9. **Removal of accumulated sediment**. This option includes the removal of sediment through options such as dredging, or through excavation of sediment when the lakes are dry (i.e. by either draining the lakes or during a drought). The volume of sediment which has accumulated in the lakes since their construction is one of the most strongly determining factors affecting hydrology, water quality, ecology and amenity of the lakes making removal highly desirable.

   The duration of sediment removal works would likely be approximately two (2) months although subsequent revegetation works would be required as well (refer to Action 12 below). The feasibility of removing the sediment utilising excavation of a dry lake is estimated to be to approximately $1.5 million although the actual cost is likely to be higher due to disposal costs. Although this is a conservative estimate, it is nevertheless considered to be a high cost in the context of this project. If removal of wet sediment was required, this cost would likely increase to over $3.5 million. This action would also have significant impacts on the ecology of the lakes including the potential loss of all existing aquatic life in the lakes.

   So while the removal of sediment is highly desirable, the financial and ecological costs of this action may be too great when there are other methods which could provide improved water quality and ecological benefits at similar financial cost (see for example Action 12). This option cannot therefore be recommended. Although unlikely, there is a chance Council could undertake the works utilising its own resources at a much cheaper rate than the commercial rates used in the estimation of the cost. If this was feasible, it could change the recommendation and should therefore be considered further by Council. Potential ecological impacts would still need to be managed however.

10. **Treatment of water using a packaged water treatment plant**. Packaged water treatment plants are a very effective method for managing water quality in newly constructed lakes typically in new urban developments. The construction of such a plant for Lakes Freeman and Apex would result in the rapid improvement of water quality including significantly reduced turbidity and nutrient levels. The water quality would likely return to pre-impact conditions (or better) probably within the first year of operation. Such a plant would therefore be highly desirable.

    The construction of such a plant would take approximately one month. The capital cost of a plant for this site was estimated as part of this project. The capital cost of a water treatment plant for these lakes was estimated to be $3.2 million and operational costs would also be quite high. So while the construction of a water quality treatment plant is highly desirable, the financial cost of this action is expected to prevent its implementation i.e. the cost is expected to be beyond the fiscal constraints of LVRC. This option cannot be recommended therefore from a practical perspective.

11. **Treatment of water using floating wetlands**. Floating wetlands are strongly promoted by manufacturers of such products as the solution to various water quality problems. The scientific data on their successes is however limited. The biggest constraint with these wetlands is that in order to function as intended, they require water to pass through the root zone of the floating plants meaning that a specifically designed lake or wetland is required which directs water through this very shallow and narrow zone.

    This may be feasible for newly constructed lakes or wetlands but is generally not feasible for existing systems such as Lakes Freeman and Apex even though both lakes are quite shallow. To provide any meaningful benefit, the majority of the lakes would likely need to be covered by such wetlands which would be cost prohibitive.

Such an approach would also likely conflict with ecological objectives for the lakes and could actually result in higher nutrient loads into the lakes as greater numbers of sedentary birds species take up residence on the floating islands. Their effect on native fish and amphibian species has not been widely studied and therefore a precautionary approach would suggest not adopting this option regardless of costs and timeframes.

12. **Revegetation of macrophytes and riparian vegetation**. This action includes revegetation of the lakes with both macrophytes and other riparian vegetation including groundcovers, shrubs and trees and associated weeding.

Revegetation of the lakes would have multiple benefits including reduction in nutrients, reduction in turbidity, lower water temperatures, improved species diversity and abundance, greatly improved habitat values and greatly improved amenity. This action is therefore a highly desirable management action.

The timeframes for such works is unknown as there are many variables which will control the success or failure of revegetation works especially the weather (and flows into the lake) which is a non-quantifiable variable. Other variables which may affect revegetation works include soils types, plant maturity upon planting, season of planting, water level control, foraging by birds and maintenance during the establishment period.

The total capital cost of revegetation (including 1 year establishment) was assessed as part of this project and is estimated to be approximately $1.2 million. Although this is considered to be a high cost in the context of this project, it can potentially be reduced significantly through a testing different options (such as natural regeneration between planted patches) as discussed in the dot points on the following pages. Staging the project over a number of years would be required with works commencing in Lake Freeman first to limit the downstream spread of weeds into newly planted areas.

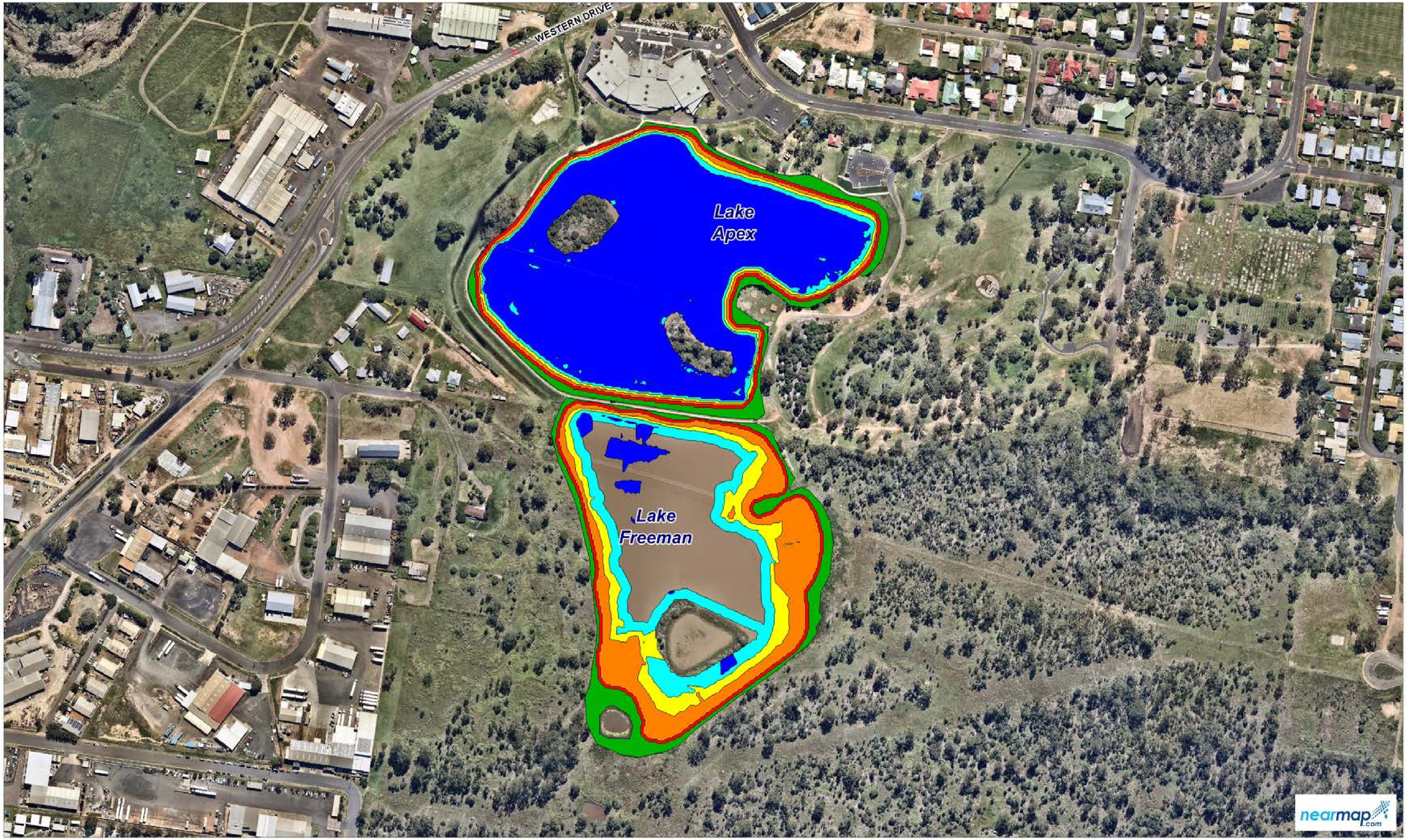
Given the feasibility of this action as well as the significant multiple benefits it would provide, this option is recommended to be implemented over a number of years and co-funded utilising a range of mechanisms (discussed further in Section 6.3 below). The extent of revegetation works is shown in Figure 5-3 according to the various bathymetric zones for planting. The bathymetric zones are summarised in Table 5-1 below.

It should be noted that the entire submerged marsh zone in Lake Freeman is not proposed to be planted. Instead, it is recommended that a 10 metre wide band of the submerged marsh zone be planted. Given that plants historically established across Lake Freeman without any assistance, this would allow the plants to naturally expand over lake given the right environmental conditions (especially water levels and rainfall). To plant the entire submerged marsh zone in Lake Freeman would add another $500,000 to this action which is not considered achievable.

Table 5-1 Depth and RL level of bathymetric zones in lakes

Bathymetric Zone	Depth (m)	RL Level (mAHD)
Ephemeral marsh	*0.2 (above NWL[6])* – 0	109.078 – 108.878
Shallow marsh	0 – 0.2	108.878 – 108.678
Deep marsh	0.2 – 0.4	108.678 – 108.478
Submerged marsh	0.4 – 0.7	108.478 – 108.178
Pool (no reveg. proposed)	0.7 – *lowest invert level*	108.178 – *lowest invert*

[6] NWL – Normal Water Level



LEGEND

Waterbody Zones

- Terrestrial Batter
- Ephemeral Marsh
- Shallow Marsh
- Deep Marsh
- Submerged Marsh
- Pool

Title:

Approximate location and extent of bathymetric zones for proposed revegetation works

Figure: **5-3**

Rev: **A**

N

0 100 200m

Approx. Scale

BMT

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An indicative plant species list for the recommended revegetation works has been provided in Appendix H. A number of other important points are made with respect to the revegetation works:

- The current bathymetry does not provide ideal conditions for the long-term sustainability of macrophytes within the lakes. While some earthworks could be undertaken to shape the bathymetry of the lakes to make them more conducive to a healthy system, this would add cost to this action. An alternate option may therefore be to specify species which are more resistant to drying and adjusting the indicative plant species list provided in Appendix H during detailed design for revegetation works.
- The staged approach to planting is recommended for a number of reasons including to assist in managing the many variables discussed above. For example, it may be worthwhile preparing landscape plans for the entire revegetation works but revegetating some test areas first. This approach would inform decisions such as what plants are likely to succeed long term, the success of natural regeneration between planted patches, whether or not bird exclusion is necessary during the establishment phase, and allow testing of any water level controls.
- The staged approach to planting could be misinterpreted as a means to spread out the works over a prolonged period of time. This is not the intent of staging the works which should be completed within five (5) years from commencement of planting. This will obviously require a funding strategy to be developed by Council. As noted above, some advice on funding is provided in Section 6.3 below.
- The planting cost has been estimated at the lower end (4 plants per square metre) of recommended planting density (4-12 plants per square metre)[7], in order to reduce the cost. This planting density applies to all planting zones. The staged approach allows for testing methods which may reduce the cost rather than the planting density. For example, planting in patches and allowing natural regeneration between patches should be tested to see if costs can be reduced further. The density should not be decreased any further but should be increased if methods and funding allow.
- Water level control is essential for establishing plants in lakes however would be difficult for these lakes as there is no outlet pipe. Water could however, be pumped from Lake Freeman to Lake Apex (and temporarily blocking the connecting swale) to allow planting of Lake Freeman Another method to maximise the success of plants would be to plant with more mature stock. For example, ordering plants well in advance would provide for much more robust plants able to better withstand adverse conditions during establishment. The longer the lead time, the taller the plants can be grown, making a significant difference when planting. This would obviously require an extended contract with the contractor and/or nursery.
- Tree planting on the edges of the lakes would provide for multiple benefits including shading and improved microclimate around the lakes for visitors, reduced water temperatures and shading out weed species which reduces weeding costs. Trees should therefore feature heavily in the landscape design with due consideration of maintaining sight lines for safety.

[7] As recommended in the 'Technical Design Guidelines for Water Sensitive Urban Design' (Healthy Waterways Partnership, 2006).

- Melaleuca trees are exceptionally good at stripping nutrients from water which is why they are commonly used in wastewater wetlands. Creating melaleuca zones within each of the lakes would greatly assist in reducing nutrient levels and minimising risks of algal blooms. They could also be planted to minimise the wind-induced stirring of the benthic sediments further minimising turbidity. This can be achieved by planting dense stands of melaleucas in the direction of south-east summer breezes and south-west winter breezes.
- Turbidity does not necessarily need to be reduced prior to planting depending on the depth of planting. Plants for example should be planted so that they ideally maintain one third of their stems above water level and not more than half of their stems are submerged. This will allow adequate gaseous exchange and photosynthesis. This is something that would need to be trailed as part of the staged planting strategy.

13. **Flocculation of lakes to reduce turbidity**. Flocculation is chemical reaction which results in suspended particles of clay forming small clumps and settling out. It is typically initiated through the addition of a clarifying agent such as aluminium, iron, calcium or magnesium or combination thereof. It is very useful therefore in reducing turbidity very rapidly.

    The issue with reducing turbidity in the lakes quickly is that due to the exceptionally high nutrients in the water and sediments, severe algal blooms would be expected to follow soon after the application of the flocculating agent. While the timeframes for application of a flocculating agent would be very quick and costs relatively low, this action carries too great a risk of algal blooms and therefore cannot be recommended at this stage. There are also concerns about toxicity although this varies widely depending on products used, receiving conditions and species.

    It may however, be worthwhile reconsidering this option in the future as the revegetation works progress. For example, if a healthy community of macrophytes is established but turbidity remains high, flocculation could be re-assessed at that point. Similarly, if during the initial planting stage it is found that turbidity is too high to successfully establish plants, the gradual and repeated application of low doses of a flocculating agent could be tested to find an optimal level of turbidity which allows plant establishment but does not allow widespread algal blooms (assuming such a level exists).

14. **External top up of lakes**. This action was identified to minimise risks of algal blooms by reducing residence times. Although the lakes lack adequate freshwater inflows, there are limited opportunities for external top up. Based on advice from the community during the workshop, it is understood that groundwater was historically pumped into the lakes but this practice was ceased due to concerns about the high salinity of the groundwater.

    Pumping of water from Tenthill Creek was also considered but this creek does not appear to sustain adequate baseflow to supply the lakes during drought conditions when the water would be needed. Such a scheme is also therefore considered unfeasible.

    As there are no known viable options for external top up of water, there is no practical option which can be recommended. Instead, managing the risk of algal blooms may best be achieved by reducing nutrients and increasing shading which can both be achieved through revegetation (see Action 12 above).

15. **Importation of rocks and logs**. This action was identified to increase the aquatic habitat diversity of the lakes. It is expected that logs and rocks could be sourced from nearby developers and placed within the lakes as they become available. Another potential source would be Council's green waste disposal facilities. The only cost therefore, is for a vehicle to transport them to site and another vehicle to put them in place. The overall cost is very low in the context of this project.

    It is recommended that such features be placed in clumps to aid in their stability and that most of the features be placed in locations where they would typically be underwater. Given the very low cost and benefits to aquatic habitat this action would provide, it is recommended.

16. **Delineate riparian zone and turfed area edge**. This action was identified to delineate between the riparian zone and turfed areas so as to minimise accidental mowing of the riparian vegetation. The areas where such a concrete edge is necessary is shown on Figure 5-4 and included the northern, eastern and southern edges of Lake Apex and the northern edge of Lake Freeman. These areas were selected as other parts of lakes edge habitat are not affected by mowing. The concrete edge should be placed 1 m from existing footpaths where they exist.

    The timeframe for constructing the edge is expected to be three (3) weeks. The cost was estimated as part of this project at approximately $19,400. This is considered to be a low cost in the context of this project. Given the need to protect investment in planting of the riparian zone, the low cost of the action and the associated benefits this action has on riparian habitat and water quality, this action is recommended.

17. **Stabilise eroding islands**. This action was identified as the islands in Lake Apex are becoming eroded following the loss of stabilising vegetation and the erosion is contributing to the turbidity in the lakes. This action therefore includes the earthworks required to stabilise the batters and revegetation of those batters.

    Both the timeframe and cost of this action would be dependent on the design but the cost is expected to be high. With regard to timeframe, the cost of earthworks would increase significantly if attempted while the lakes were full so waiting until the next drought to undertake this action would be more feasible from a cost perspective.

    Although this is a desirable action, it is expected that the costs would make the action prohibitive. In terms of water quality and habitat values there are other actions which would provide greater return for investment. As such, this action cannot be recommended. Revegetation of these areas could however be undertaken as part of Action 12 (see above) which would aid in stabilisation.

LEGEND

Edging location

Title:

Approximate extent of recommended planting/mowing edge

Figure: 5-4

Rev: A

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.

N

0 100 200m

Approx. Scale

BMT WBM

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18. **Development of new maintenance arrangements**. This action was identified as historic maintenance practices may have contributed to some of the issues in the lake and would not account for the new conditions to be created by the recommended actions outlined in this report. The action includes the development of a new maintenance plan which accounts for the issues and actions outlined in this report including for the maintenance of aquatic macrophytes and the riparian zone. Delineation between the riparian edge and turfed areas as outlined in Action 16 above would also assist in delineating the separation of maintenance responsibilities between Council teams. The plan should:

- Be based on Integrated Pest Management (IPM) techniques and minimise the use of chemical sprays recognising that even those pesticides/herbicides labelled as safe for use around aquatic ecosystems have been shown to have deleterious effects on aquatic fauna.
- Include a specific strategy aimed at the careful eradication of *Phyla canescens* (Lippia / Condamine couch) on the south-eastern banks of Lake Apex.
- Require the collection and removal of grass clipping from Lake Apex Park to minimise nutrient inputs.

The development of the plan is expected to take less than a month and the cost is expected to be approximately $10,000 if undertaken by Council, or approximately $15,000 if undertaken by a specialist consultant. The cost is therefore considered to be low in the context of this report. Given the relationship between lake maintenance and habitat, ecology, water quality, amenity and the need to protect investment in revegetation works, the low cost of the action, this action is recommended.

Implementation of the plan would require additional cost to be invested subject to the content of the plan.

19. **Follow up targeted fish survey in Lake Apex**. This action was identified due to the identification of goldfish in the lakes and excavated holes throughout the deeper zones of the lakes. Specifically, the concern is that there could feasibly be a much larger population of goldfish or other species such as carp or tilapia which may be causing these holes leading to an increase in turbidity.

Undertaking a targeted follow up fish survey would confirm if there are any pest fish species in the lakes which are contributing to increased turbidity. If such species are identified, a further action would be recommended to control these species. Associated benefits could include for example:

- an expected reduction in turbidity
- a decrease in predation of native fish and competition with native fish for resources
- a decrease in foraging of macrophytes.

This action includes a one day follow up fish survey specifically aimed at the deeper zones of the lakes to confirm whether such a species exists in the lakes and whether further pest control actions are required. The cost of the survey is expected to be approximately $3500.

Given the potential impact of pest species on both water quality and the ecology of the lakes, and the feasibility and low cost of the action, it is recommended for implementation.

Costs associated with pest fish species control would be dependent on a range of factors such as what species are present, their level of expected impact upon native fish, their distribution and their abundance.

20. **Construction of a Lake Freeman outlet** that will allow turbid water to bypass Lake Apex. This option relates to creating a bypass from Lake Freeman to the north-western swale shown on Figure 2-1.

Regardless of costs and timeframes, this would minimise flows into Lake Apex which already has insufficient water flows (as discussed in Section 4.3.2 above). Minimising flows further would reduce the volume of water in Lake Apex leading to more frequent and prolonged drying in the lake. It would also further increase the residence time leading to greater risks of algal blooms. As such, this action cannot be recommended.

21. **Water aeration and recirculation**. Aeration is a strategy used in lakes to minimise the risk of thermal stratification i.e. the layering of warm surface water over cold bottom waters, primarily to minimise the release of sediment-bound nutrients from the bed of lakes under anoxic conditions (which can lead to algal blooms). It also helps with increasing dissolved oxygen levels and is therefore a good strategy for improving water quality conditions for fish and species which depend upon them.

While recirculation is also used to limit thermal stratification, its benefits are greatest where the lake water is recirculated through some kind of water quality treatment system, such as a wetland. This further assists in reducing sediment and nutrient loads and minimises risks associated with cyanobacteria or algal blooms.

As noted in Section 4.4.1.1, the shallow profile of the lakes means that the likelihood of thermal stratification is limited and therefore aeration or recirculation to manage stratification is not justified. There is also no viable treatment system through which to recirculate water in order to provide any meaningful water quality benefit and the cost of constructing one would make it unviable. Given the volume of the lakes, recirculation though the north-east swale/dry creek bed would provide no discernible water quality benefit.

Aeration could certainly be designed to improve dissolved oxygen level although improved dissolved oxygen would occur naturally through extensive macrophyte planting.

This option cannot be recommended therefore on practicality grounds.

6 Prioritisation of Recommended Management Actions and Funding

6.1 Preamble

This section provides an indication of priorities for the recommended actions and provides discussion on funding mechanisms.

6.2 Prioritisation of Recommended Management Actions

A summary of recommended management actions and priorities is provided in Table 6-1 below. With regard to the prioritisation allocated to each action, the following comments are worth nothing:

- All of the catchment management actions are estimated to have either low or costs or are on the low side of moderate and are expected to have short timeframes. These could therefore be considered 'low-hanging fruit' and have therefore been allocated high priorities.
  - The exception to this is the purchase of land around the lakes which is high cost in the context of this project. Without a proper cost-benefit analysis which considers other environmentally valuable land within the LVRC boundary, no recommendation can be made with regard to this action.
  - The two pre-treatment management actions both require constructing treatment devices which aid in water quality treatment. Both actions have similar costs and timeframes. Only the construction of a sediment basin is however, considered to provide meaningful water quality benefits at this point in time and is therefore recommended.
- With regard to the lake management actions:
  - Revegetation of macrophytes and riparian vegetation (Action 12) is the most expensive recommended action by a large margin but is also significantly cheaper than alternatives of constructing a treatment plan or floating wetlands (refer to Action 10 and Action 11 above).

    Along with minimising further pollutant inputs, this is considered to the most important action as it would provide the greatest benefits including water quality, ecology and amenity.

    It is expected that the cost of this action can be reduced through careful planning, testing what works on site through a staged planting approach, providing adequate pre-treatment (Actions 1, 2, 3, 5 and 7) and a diversification of delivery methods/funding as explained in Section 6.3 below.
  - Delineation between the riparian zone and turfed area using a concrete edge (Action 16) is considered a moderate priority as it will assist with further deterioration of riparian habitat.
  - Actions 18 and 19 also have low costs and short timeframes and could therefore be considered 'low-hanging fruit'. As such, these actions have also been allocated high priorities.

While indicative timeframes and durations are provided, some of these will be highly dependent on Council's available budget. Some suggestions for a funding strategy are provided in 6.3 below.

Table 6-1 Summary of Recommended Management Actions and Priorities

ID	Recommended Action	Cost Range	Cost Estimate	Indicative Timeframes and Durations	Priority
Catchment management solutions					
1	An Erosion and Sediment Control (ESC) and Water Sensitive Urban Design (WSUD) enforcement campaign	Low - could result in a net benefit	Subject to enforcement effort	Should commence immediately and continue until the catchment is fully built out	High
2	An ESC education campaign	Low	Subject to education effort	Should commence immediately and continue until the catchment is fully built out	High
3	Stabilising eroding soils on Council land	Moderate	$115,000	Should be undertaken in the 2017-2018 financial year. This will take 1-2 months to complete	High
5	Planning Scheme and approval controls	Low	Included in existing planning roles	Can be included in the next round of Planning Scheme amendments. Timeframe subject to planning review timeframes. Also subject to existing development approvals	High
6	Improving community custodianship	Low	Subject to effort	Should be undertaken 2018-2020 years and will take a few months to complete	High
Pre-treatment management solutions					
7	Constructing a sediment basin immediately upstream of Lake Freeman	Low	$210,000	Should be undertaken in 2019. Should take approximately 4 months for design and construction	Moderate
Lake management actions					
12	Revegetation of macrophytes and riparian vegetation	High	$1.2 million	Should commence in the 2018-2019 financial year. Will take approximately 5 years to complete in stages plus time for plant establishment	High
15	Importation of rocks and logs	Low	<$3000	Subject to availability	Low
16	Delineate riparian zone and turfed area using a concrete edge	Low	$19,400	Should be undertaken in the 2017-2018 financial year. Should take about three weeks to complete	Moderate
18	Development of new maintenance arrangements	Low	$10,000-$15,000	Should be undertaken in the 2017-2018 financial year. Should take less than a month to complete	High
19	Follow up targeted fish survey in Lake Apex	Low	~$3500	1 day for survey and 2-3 days reporting.	High

6.3 Funding

A funding strategy would need to be developed by Council for the recommended actions but is expected to include a range of funding sources including for example:

- Utilising Council's existing environment levy.
- Allocating specific funding under the annual budget.
- Utilising funding from the enforcement action campaign (see Action 1).
- Utilising in-kind support from the community, community groups and schools for revegetation works including holding tree planting community days.
- A tree funding scheme aimed as businesses within the community.
- Applying for grants. This may include for example grants under the National Landcare Program and Threatened Species Recovery Fund, Community Sustainability Action grants and 20 Million Trees Program grants.
- Engaging the Green Army.
- Stormwater quality offsets (this would require a separate strategy).
- Holding crowdfunding events and/or creating an online crowdfunding page.

Examples of grants currently available include the two provided below. Council was advised of these grants before the issue of the draft version of this report to assist in preparing submissions ahead of the closing dates.

7 Conclusion

This report has been prepared by BMT to assess the condition of Lakes Freeman and Apex, Gatton and provide recommendations for the remediation of the lakes. The report has found that nutrients are very high in both lakes and the lakes are at significant risk of algal blooms, which are currently being limited by the other main cause of concern with regard to water quality – the very high turbidity levels. While sediment has been washing into the lakes since their construction, the catchment has been relatively stable up until the past decade when residential development and building works commenced in the catchment. Flow of pollutants into the lakes has been exacerbated by periods of drought (which reduce vegetation cover) and floods (which increase flows).

With erosive soils in the catchment, the development and building works are expected to have been the primary sources of sediment loads into the lakes since their construction. Exposed soils around the lakes have been another major contributor, especially to Lake Apex.

There have been multiple effects of these increased sediments loads on the lakes including:

- An increase in turbidity in the lakes and associated decrease in the ability for macrophytes to access sunlight.
- Lower water holding capacity meaning more frequent and prolonged drying during droughts and an associated decline in macrophyte coverage.
- Smothering of macrophytes and their soil seedbank limiting natural regeneration.

These combined effects have subsequently contributed to extensive dieback of macrophytes and resulted in a decline in the biodiversity of the lakes.

While it must be acknowledged that the lakes are artificial, such a decline is nevertheless meaningful given the numerous rare bird species which have historically inhabited the lakes. In response, this report recommends a series of actions aimed at remediating the lakes back to their pre-impact water quality and ecological condition with additional investment placed in improving community custodianship.

The approach to remediation aims for a sustainable lake environment and has been based on total catchment management principles. This reflects the vision developed for the remediation of the lakes.

There are eleven recommendations outlined in this report which include:

- Catchment management actions
- Pre-treatment management actions
- Lake management actions.

The actions account for potential limitations including Council's fiscal and temporal limitations and aim to further empower the community to provide in-kind support for some of the recommended actions.

The actions have subsequently been prioritised according to their costs and timeframes having due regard for the values that they deliver (water quality, ecology and social). It is expected that the delivery of the actions will require the development of funding strategy by Council but various methods for the delivery of these actions, such as grants, have been identified.

8 References

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Appendix A Key Discussion Points During Onsite Collaborative Planning Workshop and Joint Inspection of Lake

A summary of the key points of discussion for each of the two components of the workshop are summarised below. This information is anecdotal only and is not quantified in any way.

A.1 Joint Inspection of Lakes Key Discussion Points

During the inspection, there were three key points of discussion including the following:

- The history and changing ecological values of the lakes
- Water quality issues
- Particular areas of concern and possible solutions considered previously.

Each of these is discussed in further detail below.

- **The history and changing ecological values of the lakes** – the discussion focused primarily upon:
  - What the lakes looked like prior to 2009 which is approximately when the current water quality issues commenced.
  - The ecological values of the lakes in the preceding years.

  Based on the discussions during the workshop, it is understood that the lakes were previously characterised by much ‘cleaner’ water (less turbid). Additionally, it is understood that the lakes featured dense macrophytes across most of the surface area of the lakes (especially Lake Freeman) and that this vegetation provided a more favourable habitat for a broader diversity of bird species compared to the current scenario. The photos presented at the workshop by FOLA members supported these descriptions (see for example Figure 4-1).

  Since the change in water quality and subsequent decline in macrophyte abundance and diversity, a decline in the diversity of bird species was noted by FOLA members. While the knowledge of how the changes to water quality affected other fauna species was limited, an overall decline in ecosystem health was expected.

  Discussion about the history of the lakes also highlighted that during periods of prolonged drought, the lakes dried out (although there may have been some limited standing water remaining) including for example, in September 1994 and February 2003. Photos showing the condition of lakes during these periods were later provided by Jocelyn Wilson of FOLA and are shown in Figure A-1 below.

  Mrs Wilson also advised that Robert Wilson (also of FOLA) recalled that during the 1994 drought, ‘*that volunteers collected about 300 turtles and relocated them to Lake Galletly at UQ Gatton*’ and that many of these were later returned.

Similarly, Martin Bennett from LVRC recalled that he and other volunteers waded through the drying mud and physically removed turtles at risk of desiccation and transported ‘ute-loads’ to Tenthill Creek. During this period, Council also dug out two ‘moats’ within Lake Apex to provide a refuge for aquatic species in subsequent droughts.

.

Figure A-1 Photos showing lake drying during prolonged drought (courtesy Julie Reid)

- **Water quality issues** – the main water quality issue identified during the workshop was a significant increase in turbidity and sediment deposition in the lakes since circa 2009. There were a series of likely sediment sources identified by the workshop attendees including:
  - Ongoing sediment runoff associated with poor erosion and sediment control practices at upstream developments.
  - Ongoing sediment runoff associated with poor erosion and sediment control practices on individual building sites located within the catchment.
  - Ongoing sediment runoff from disturbed soils in Lake Apex Park located between the Lake Apex and Dennis Minson Drive and Gatton Cemetery. While many of these areas remain exposed, some have now been covered over including by the new car park located near the toilet block on Lake Apex Drive. Erosion during the construction of the car park was also identified as a historic problem. Council recently installed bollards to limit vehicular traffic in the park which will minimise disturbance to the soils however, the remaining exposed areas throughout the park were identified as a source that requires control.
  - Sediment runoff associated with poor erosion and sediment control during the construction of the Cultural Centre in 2008/2009. Given the centre is now fully constructed and landscaping works are fully established, this area is no longer an active site of erosion.

  The other key concerns with respect to water quality which were identified included:
  - Increase in nutrient build up associated with:
    - The stormwater runoff particularly that from local developments.
    - A decline in nutrient treatment which was previously provided by the dense aquatic and semi-aquatic macrophytes which have significantly declined since circa 2009.
    - A change in bird species noting that less of the migratory species were identified by FOLA members but larger populations of more sedentary species are now more typical potentially resulting in higher nutrient loads from bird droppings.
  - A potential decline in microbial water quality also associated with the decline in aquatic and semi-aquatic macrophytes and increase in the populations of more sedentary bird species.
- **Particular areas of concern and possible solutions previously considered by workshop attendees** – The lakes are considered by the workshop attendees as part of a wetland complex which is connected both hydraulically and ecologically and which cannot be considered as pair of separate waterbodies. As such, concerns on one lake apply equally to concerns in the other lake. There were however, a number of areas within the lakes and their catchment which were specifically mentioned as areas of concern including:
  - Ongoing erosion and sediment control issues which need to be managed both at the development scale and the individual building scale. Previous solutions considered include both enforcement action and education.
  - The open water and riparian habitats which have declined across the lakes since circa 2009. Previous solutions considered include replanting.
  - Disturbed soils in Lake Apex Park. Previous solutions considered include stabilisation and returfing.

- ○ Managing the accumulated sediment across the bed of the lakes. Previous solutions considered include revegetation, flocculation, floating wetlands and dredging.
- ○ The inlet swale located in the north-east corner of Lake Apex Park. This swale is relatively stable and unlikely to be a significant source of sediment. Previous solutions considered include stabilising this inlet into a dry creek. A design for this has previously been commissioned by Council and was completed by Bligh Tanner and Yurrah in 2014.
- ○ The edges of the islands within the lakes. Due to the decline in the riparian vegetation, the islands are now severely eroding. Previous solutions considered include replanting.
- ○ The ongoing feeding of wildlife which occurs despite signage installed by Council. Previous solutions considered include a more comprehensive education campaign.

Many of the solutions considered noted above are considered worthwhile and analysis of these and other options is provided in Section 5 below.

A.2 Collaborative Planning Workshop Key Discussion Points

The workshop focused on the three questions as discussed below:

(4) **Where are we now? – Characterising the condition of the lakes and their catchment**. This included:

- Presentation of historic information to describe broadly the changes in the lake and catchment since aerial photo records began in 1933.
- Presentation of some of the preliminary findings from the condition assessment undertaken by BMT.

(5) **Where do we want to be? – Setting a common vision for the lakes.** This included:

- Discussion about various options for managing water quality and what might work locally. The various options discussed during the workshop are presented in detail in Section 5 below.
- Establishing a vision and objectives for improved water quality in the lakes. A number of themes were identified which lead to the development of the water quality vision as follows:
  - ○ **Theme 1:** There was a desire to return water quality, particularly turbidity, back to the condition it was in prior to the significant sediment inputs commenced circa 2009. Importantly, the group recognised that aiming for some higher aspirational objective may not be practically achievable in the short term.

    While historic water quality data was not available at the time of the workshop, both the historic aerial photos (see Appendix C) and the photos taken by FOLA members (see Figure 4-1) provide a visual que for desirable turbidity. Water quality monitoring results from 2001 (refer to Section 4.3.1 above) also provide an indicator of more desirable turbidity levels.

- **Themes 2:** The improved water quality outcomes were considered a means to achieve a greater aim i.e. to improve the biodiversity values and ecological functioning of the lakes. Specifically, this included bringing back the aquatic and semi-aquatic vegetation which is expected to attract the less common bird species back to the lakes and improve the overall ecological functioning of the lakes. Again, this theme centred around restoration of the lakes to pre-impact conditions rather than restoration to some higher 'ideal' level. The extent of aquatic and semi-aquatic vegetation shown in the photos provided in Figure 4-1 above also provides a que for the desirable ecological condition represented by the abundance of macrophytes and bird species in these photos.
- **Theme 3:** The conservation and recreational values of the lakes are currently at an acceptable balance and that there is no driver for increasing social use of the lakes for primary contact (such as swimming) or secondary contact (such as canoeing)[8]. There is however, a desire to improve the community's custodianship over the lakes by improving the water quality, visual appeal of the lakes and through greater education.
- **Theme 4:** The vision needed to be sustainable. The workshop participants wanted any investment in the restoration of the lakes to have long-lasting effects in order to provide ongoing return for the investment. This means that 'half-measures' such as undertaking only some or part of the recommended strategies outlined in this report would not be consistent with the vision. Sustainability was also taken to mean that the ongoing causes for declining water quality needed to be stopped as a matter of priority. As one workshop participant noted 'I would like the lakes to still be there in 50 years'. If the current rate of sedimentation continues or worsens, the lakes could feasibly fill to unsustainable levels[9] with sediment in that time.
- **Theme 5:** The vision needed to recognise that what happens in the catchment of the lakes determines the condition within the lakes. In this case, a total catchment approach needs to be taken to achieve the vision for the lakes.

These themes are considered to complement the vision for the broader Lake Apex Park developed as part of the *Lake Apex management plan* (Place Design Group 2011) which states:

> *Lake Apex Park - A Place to Discover*
>
> *An oasis within the Region, Lake Apex Park provides refuge for residents, visitors and wildlife. It is a place to meet, a place to celebrate, a place to play and recreate, a place to unwind and relax, a place to discover.*

This vision does not however provide adequate direction for the restoration of the lakes and as such, the vision for the restoration of the lakes is provided below in accordance with the above themes.

[8] This would be limited by microbial water quality in any case as explained further in Section 4.3.2 below.
[9] Meaning that the lakes would dry out due to a lack of water storage volume too frequently to support aquatic flora and associated fauna.

Vision for the Restoration of Lakes Freeman and Apex

Utilising the five themes discussed above and recognising the existing vision for the broader Lake Apex Park, the restoration vision for Lakes Freeman and Apex is as follows:

Lakes Freeman and Apex are remediated back to their pre-impact water quality and ecological condition with additional investment placed in improving community custodianship. The approach to remediation and its outcomes are sustainable and based on a total catchment management approach.

While the pre-impact condition cannot be readily quantified, the photos provided in Figure 4-1 provide a que for both the water quality and ecological condition mentioned by the vision and the turbidity monitoring results from 2001 (refer to Section 4.3.1) also provide an indicator of more desirable turbidity levels.

(6) **How are we going to get there? - Assessing solutions to address the causes of poor water quality in the lakes.** This included:

Identification and discussion about preferred strategies and actions. The different strategies discussed during the workshop are presented in Section 5 along with potential additional other options.

Appendix B Water Balance Modelling

As outlined in Section 3.2.2 a water balance model of the lakes was developed, to provide an understanding of water inputs and outputs (including inputs from stormwater and outputs due to seepage and evaporation), water level variation, and residence (or lake 'turnover') times – with comparisons to recommended guideline values for lakes.

This appendix details the parameterisation of the models. Specifically, Table B-1 provides a summary of the water balance model while Table B-2 provides a summary of the catchment model that has been utilised to calculate flows from the catchment upstream of the lakes.

This appendix also provides the graphs which have been produced from the results of the model designed to aid in interpretation of the model results. Specifically, these graphs include:

- Predicted water level variations (refer to Figure B-3 to Figure B-8).
- The predicted probability of water level exceedance, identifying how probably various water levels would be exceeded (refer to Figure B-9 to Figure B-14).
- The predicted probability of exceedances of lake residence ('turnover' time), with comparison made to a maximum 20-day residence time target (Mackay City Council[10] 2008) (refer to Figure B-15 to Figure B-20).

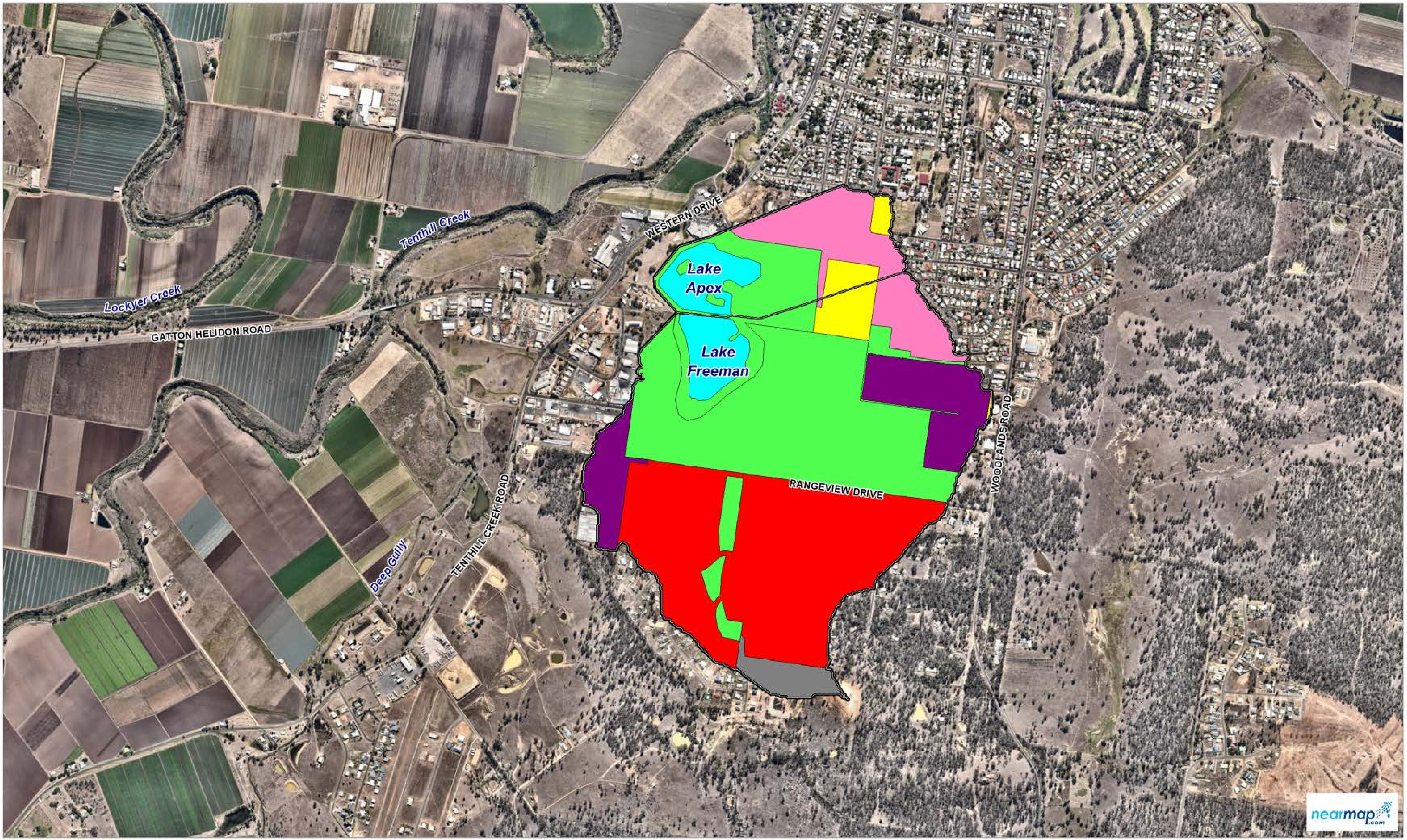
[10] Although this is a Mackay based guideline, the targets are considered 'best practice' in Queensland and the model accounts for variation in climatic conditions between Mackay and Gatton.

Table B-1 Summary of water balance model for Lakes Freeman and Apex

Parameter	Comments
Waterbodies	Lake Freeman and Lake Apex conditions as per site visit June 2017.
Modelling period	117-year period of SILO rainfall data (near the lakes) – from 1 January 1900 to 19 June 2017.
Modelling time step	Daily.
Bathymetry	Bathymetry (i.e. elevation, area, volume) assumes vertical batters and a normal water level (NWL) as identified during the site visit in June 2017. Waterbody surface area approximated by linear interpolation.
Initial lake volume	The initial lake volume is assumed to be ‘full’ – the nominated water volume as identified during the site visit in June 2017 for all scenarios. The full volume of Lake Freeman is approximately 28.4 ML and the full volume of Lake Apex is approximately 87.5 ML.
Inputs	
Direct rainfall	Direct rainfall input a function of daily rainfall and waterbody area (dependent on daily volume and bathymetry).
Surface flows	Calculated by catchment model. This is unique for both the existing catchment conditions and the ultimate catchment conditions.
Lake Freeman Overflow	For modelling purposes, it has been assumed that, at the end of each timestep, any overflow from Lake Freeman is transferred to Lake Apex for the start of the next modelling timestep.
Groundwater flows	Assumed to be zero.
Outputs	
Evaporation	Potential evapotranspiration (PET), obtained from SILO data, is a function of daily PET and waterbody area (dependent on daily volume and bathymetry).
Seepage	Seepage has been assumed as 0.36 mm/hr, commensurate to the seepage rate of heavy clay (eWater 2012)
Water extraction	Assumed to be zero for scenarios 1 and 2. Assumed for scenario 3 to be 179 m^3/day when there was less than 10mm of rainfall in the previous 1 day and less than 50mm/week in the previous 7 days.
Overflow	At the end of each modelling time step, any volume in excess of the volume at Apex Lake’s spillway weir level is assumed to overflow (before the commencement of the next modelling timestep).

Table B-2 Summary of Catchment Model (Utilised for Calculating Surface Flows) for Lakes Freeman and Apex

Parameter	Comments
Catchment	Contributing catchment to Lakes Freeman and Apex. The existing catchment conditions are represented by Figure B-1, whilst the ultimate catchment conditions are represented by Figure B-2.
Modelling period	117-year period of SILO rainfall data (near the lakes) – from 1 January 1900 to 19 June 2017.
Modelling time step	Daily
Catchment area	Lake Freeman – 172.6 hectares Lake Apex – 27.9 hectares
Upstream Catchment	
Existing conditions	Land use areas identified by the Gatton Shire Planning Scheme (Lockyer Valley Regional Council 2007) with consideration of land use areas not yet developed.
Ultimate conditions	Land use areas identified by the Gatton Shire Planning Scheme (Lockyer Valley Regional Council 2007).
Surface flows	Calculated by BMT utilising MUSIC software, with rainfall runoff parameters from the *MUSIC Modelling Guidelines* (Water by Design 2010).



LEGEND

- Catchment
- Waterbody
- Open Space and Recreation
- Community Facility
- Urban Residential
- Emerging Communities
- Industrial
- Park Residential

Title:
Land Use - Existing Catchment Conditions

Figure: **B-1**

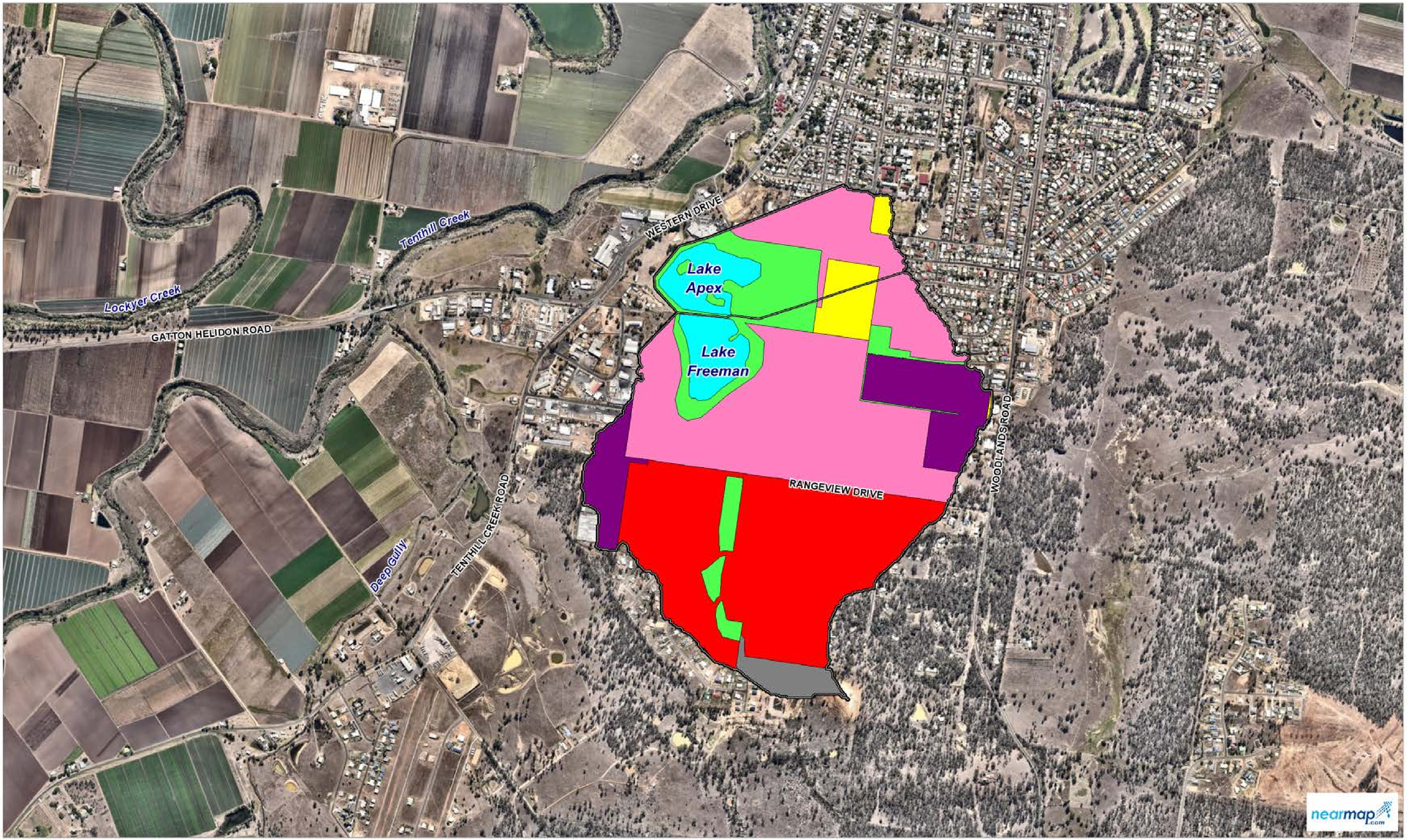
Rev: **A**

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.

N 0 400 800m
Approx. Scale

BMT
www.bmt.org

Filepath: I:\B22609.i.pd.Lakes_Freeman_&_Apex\DRG\UW_010_170719_LandUse_Existing.wor



LEGEND

Catchment	Open Space and Recreation
Waterbody	Community Facility
	Urban Residential
	Emerging Communities
	Industrial
	Park Residential

Title:
Land Use - Ultimate Catchment Conditions

Figure: B-2

Rev: A

N 0 400 800m
Approx. Scale

BMT
www.bmt.org

Filepath: I:\B22609.i.pd.Lakes_Freeman_&_Apex\DRG\UW_011_170719_LandUse_Ultimate.wor

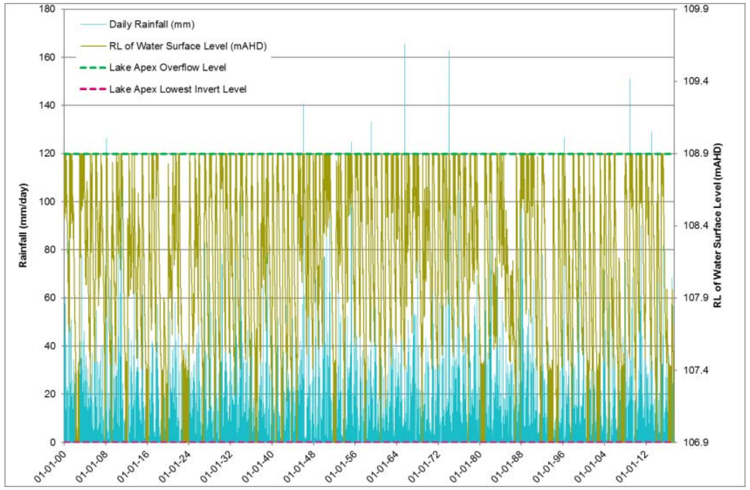


Figure B-3 Lake Apex Water Balance – Existing Condition

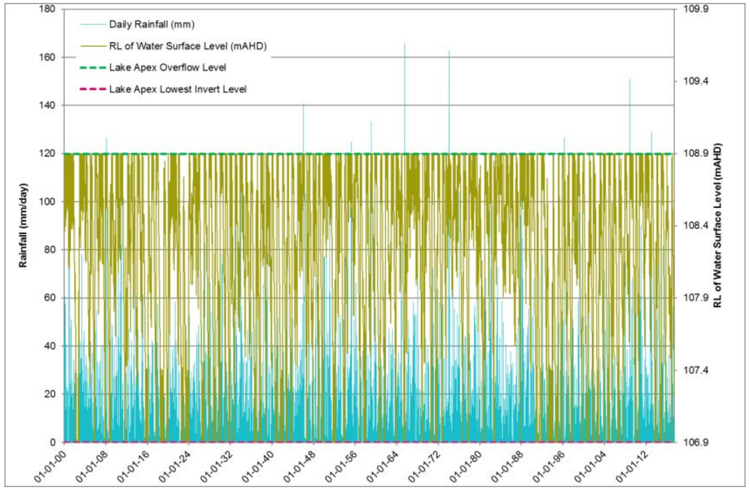


Figure B-5 Lake Apex Water Balance – Ultimate Condition with Harvesting

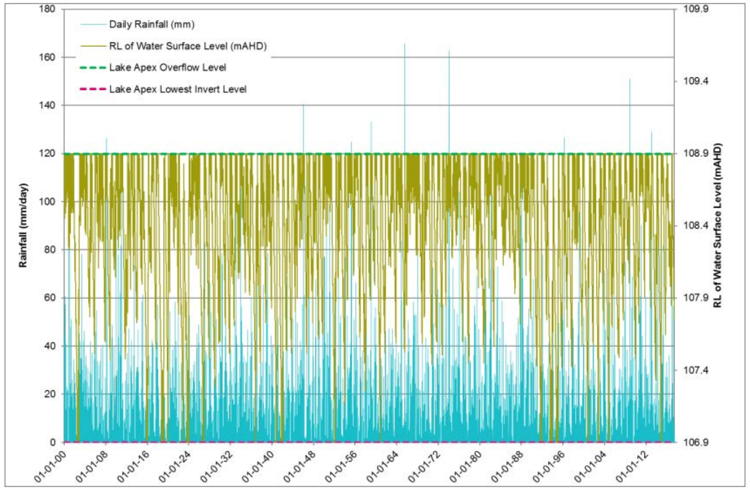


Figure B-4 Lake Apex Water Balance – Ultimate Condition

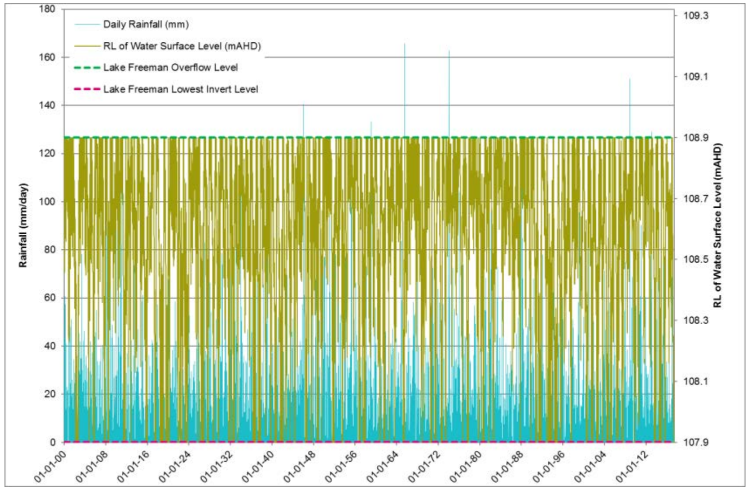


Figure B-6 Lake Freeman Water Balance – Existing Condition

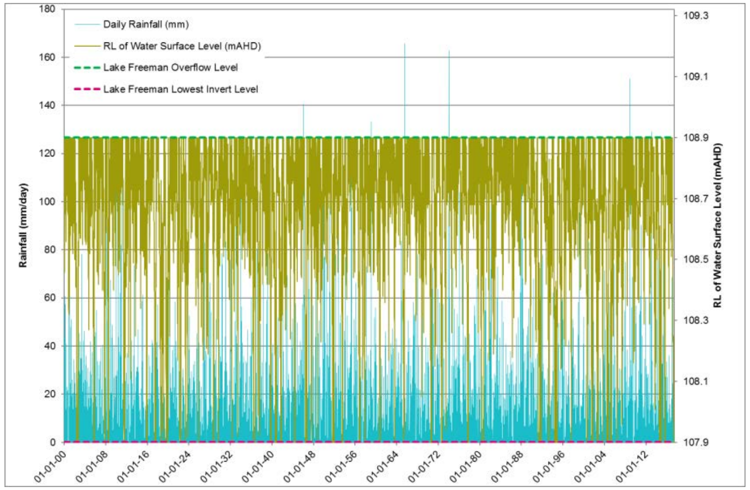


Figure B-8 Lake Freeman Water Balance – Ultimate Condition with Harvesting

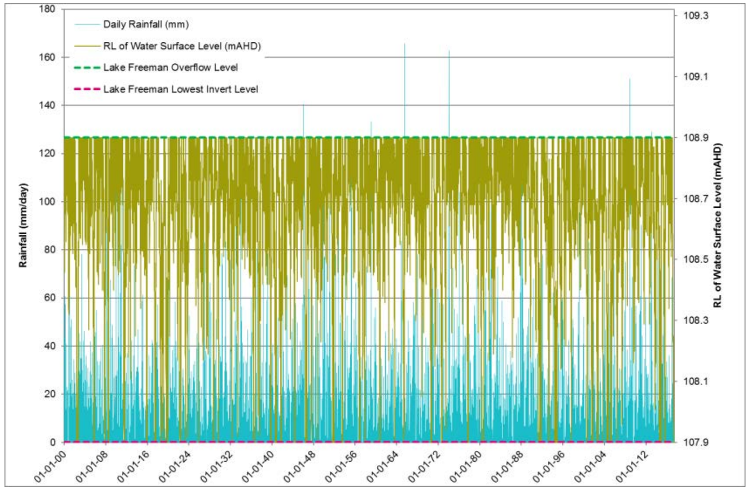


Figure B-7 Lake Freeman Water Balance – Ultimate Condition

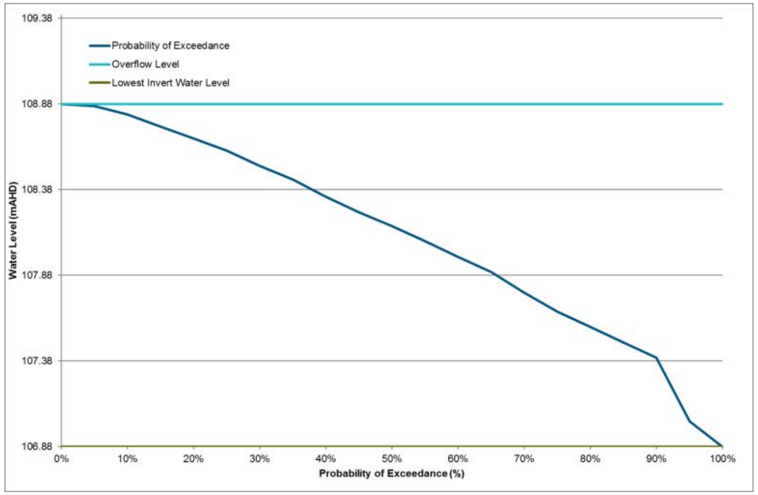


Figure B-9 Lake Apex Probability of Exceedance – Existing Condition

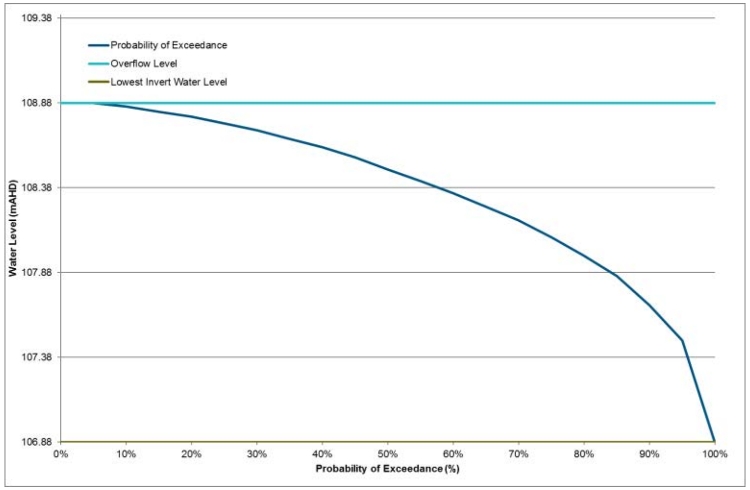


Figure B-10 Lake Apex Probability of Exceedance – Ultimate Condition

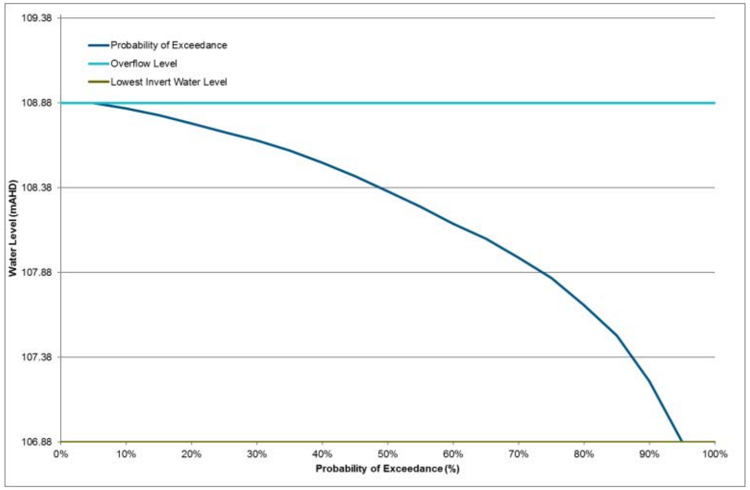


Figure B-11 Lake Apex Probability of Exceedance – Ultimate Condition with Harvesting

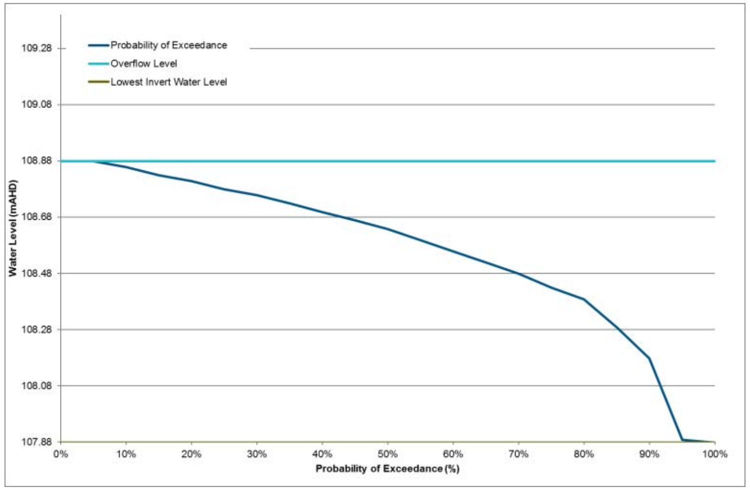


Figure B-12 Lake Freeman Probability of Exceedance – Existing Condition

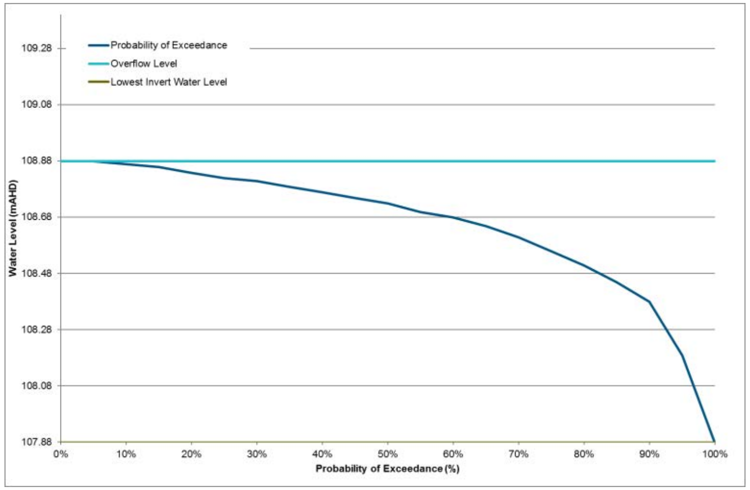


Figure B-14 Lake Freeman Probability of Exceedance – Ultimate Condition with Harvesting

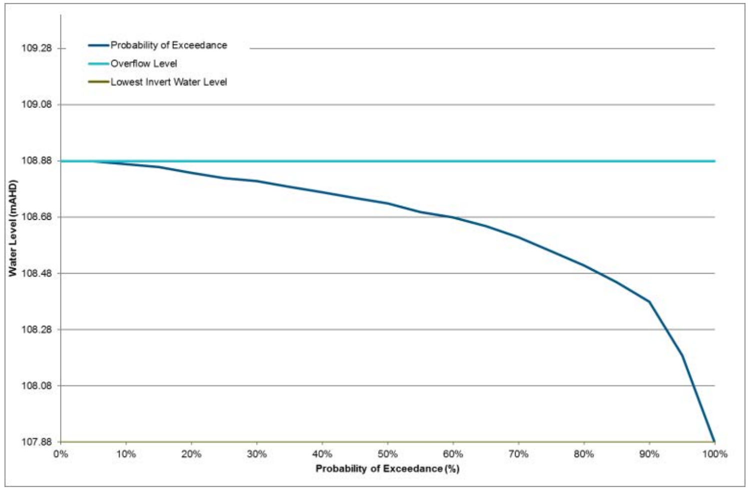


Figure B-13 Lake Freeman Probability of Exceedance – Ultimate Condition

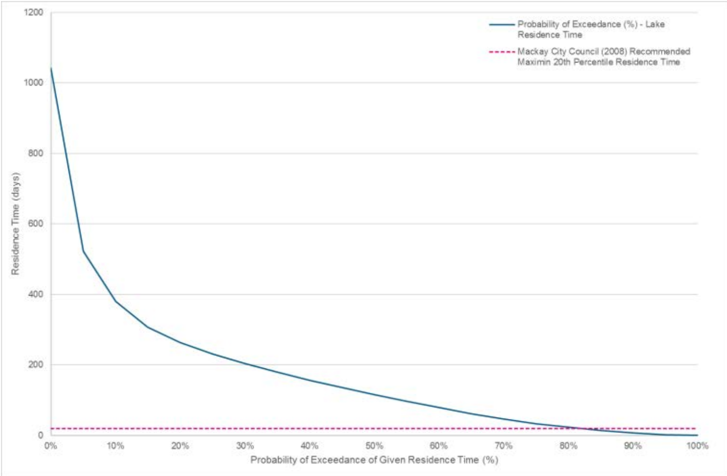


Figure B-15 Lake Apex Residence Time Probability of Exceedance – Existing Condition

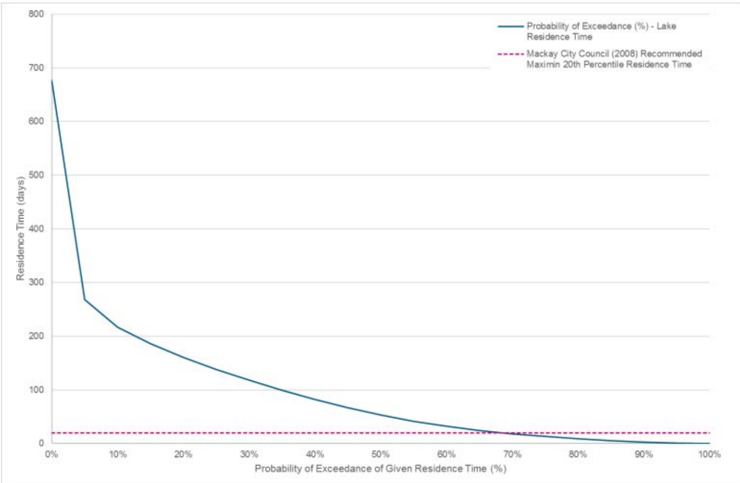


Figure B-16 Lake Apex Residence Time Probability of Exceedance – Ultimate Condition

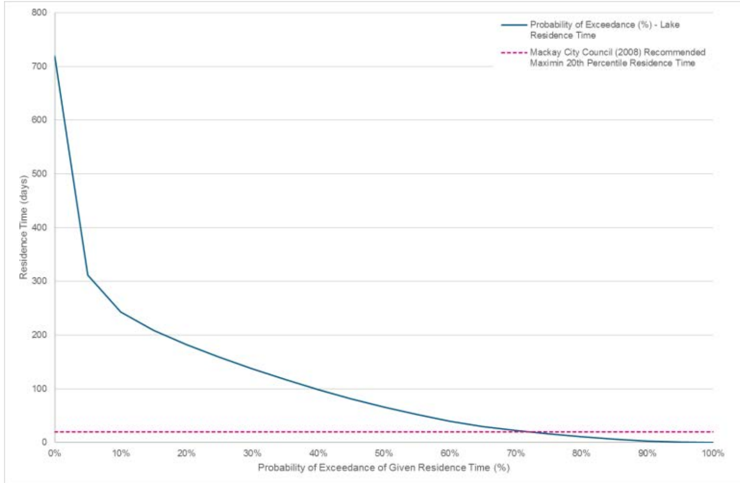


Figure B-17 Lake Apex Residence Time Probability of Exceedance – Ultimate Condition with Harvesting

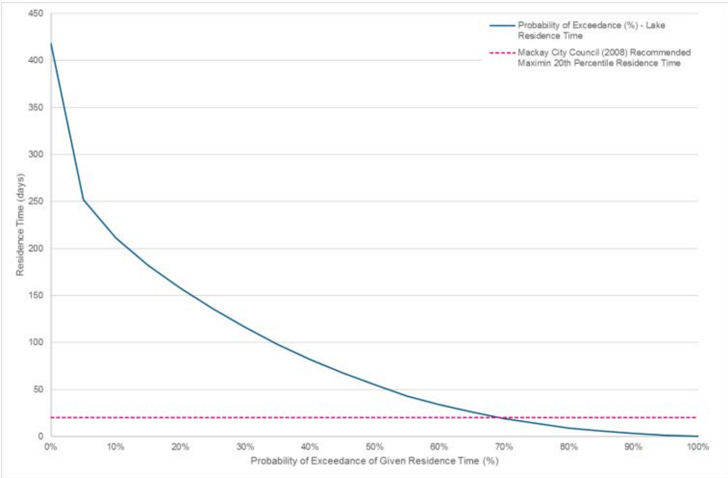


Figure B-18 Lake Freeman Residence Time Probability of Exceedance – Existing Condition

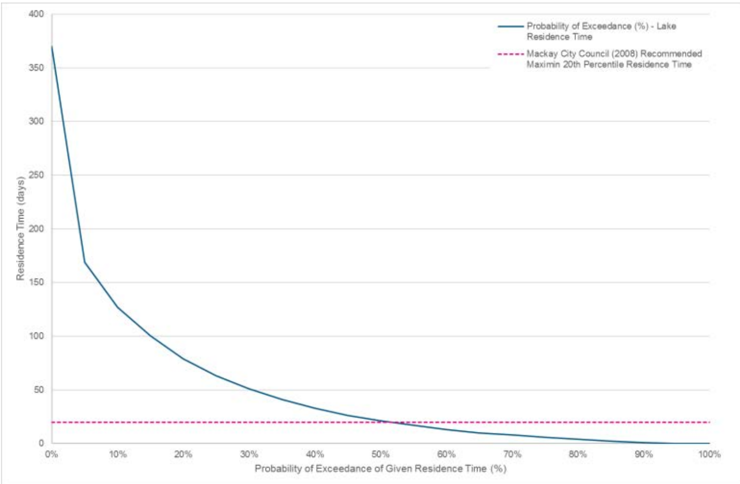


Figure B-19 Lake Freeman Residence Time Probability of Exceedance – Ultimate Condition

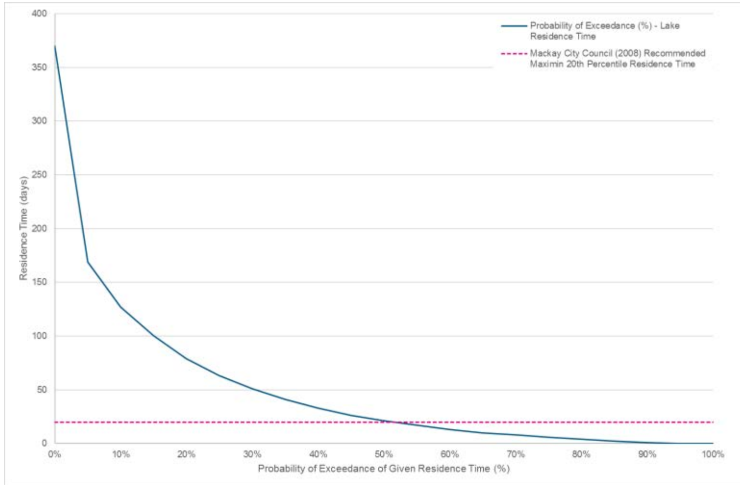


Figure B-20 Lake Freeman Residence Time Probability of Exceedance – Ultimate Condition with Harvesting

Appendix C Timeline of Historic Aerial Photography

This appendix provides the timeline of historic aerial photos. Observations based on this timeline are provided in Section 4.3.1.1 above.


Approximate
extent of
lakes
23 June 1951

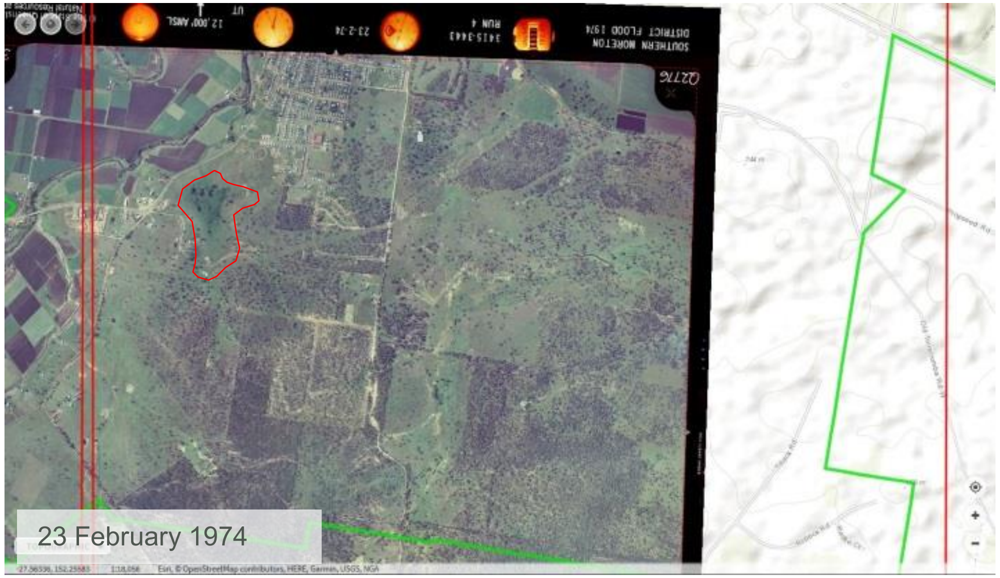

1 September 1970


1 September 1963


1 May 1971

Timeline of Historic Aerial Photography

20 May1972



23 February 1974

3 February 1974

1 June 1976


14 October 1979


1 June 1988


13 May 1982

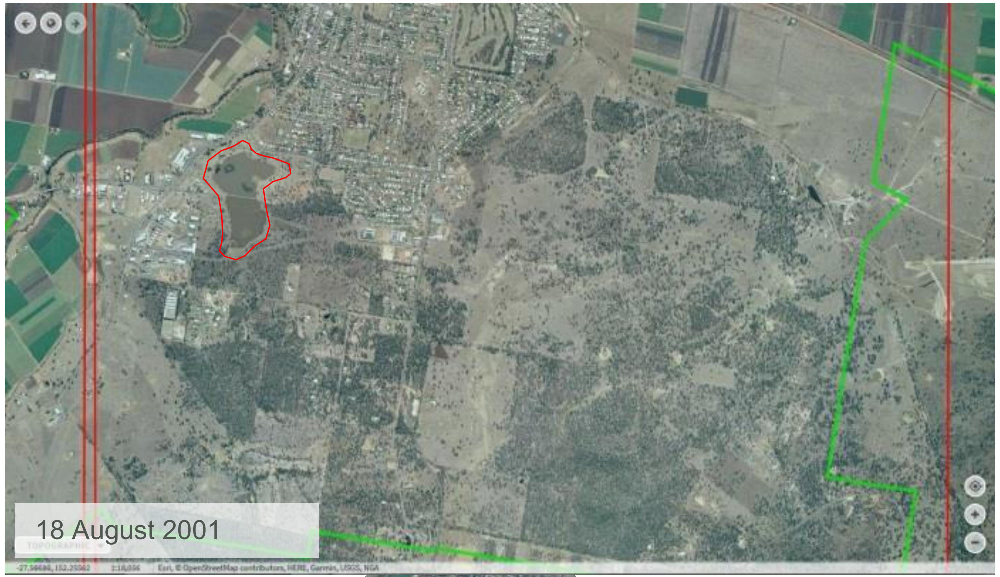

9 June 1992


6 October 1992


2 August 1997

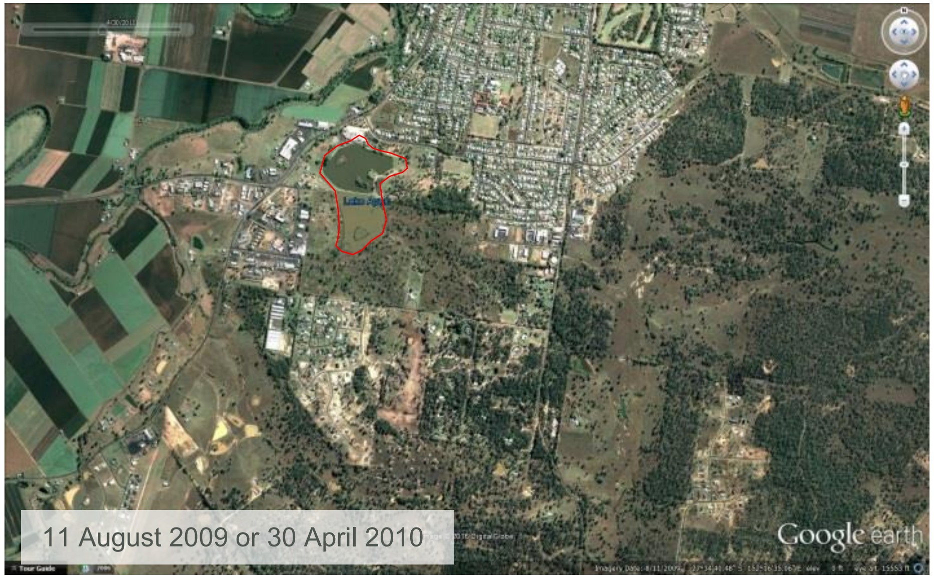

8 October 1994


22 June 2001


18 August 2001

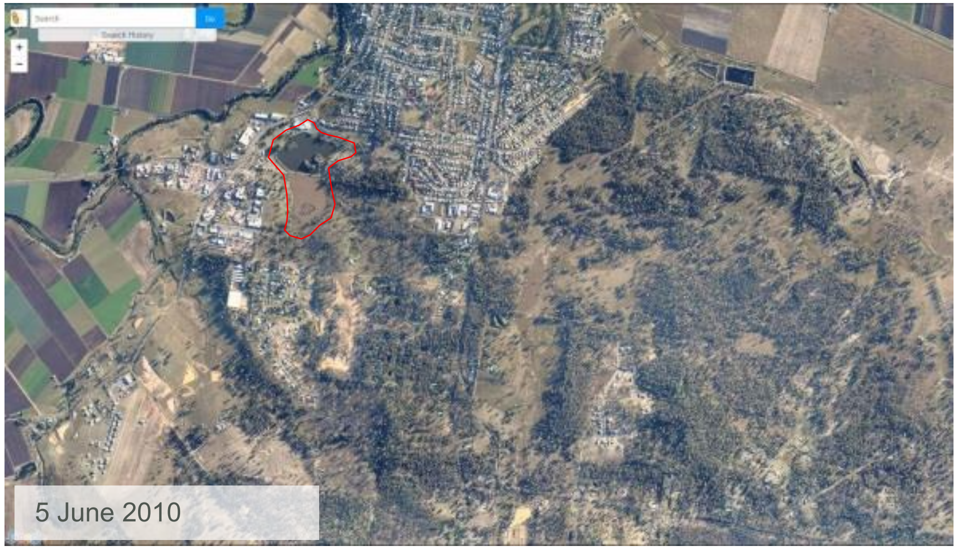
8 June 2006


27 July 2003



11 August 2009 or 30 April 2010

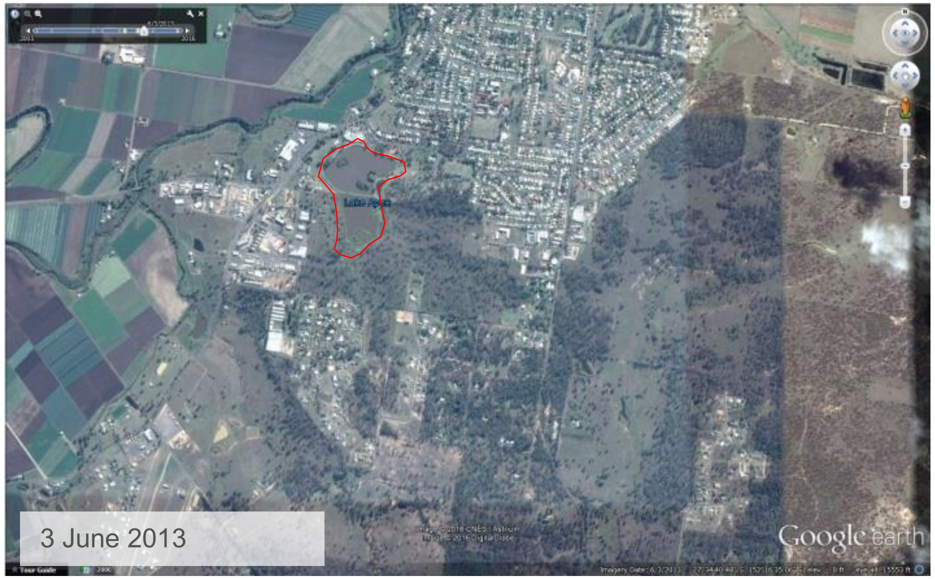
Timeline of Historic Aerial Photography


5 June 2010


12 August 2011


11 January 2013

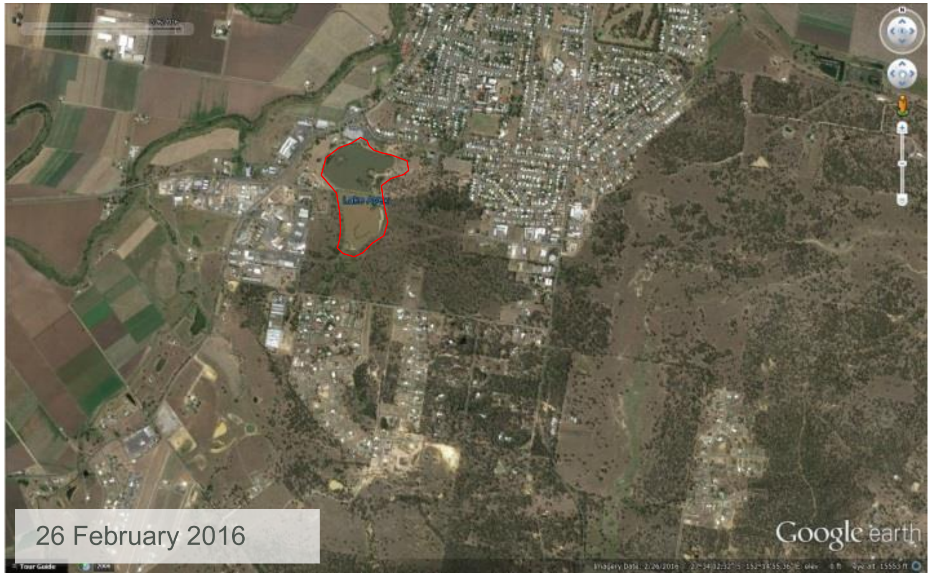

26 May 2013



3 June 2013


10 May 2015

16 March 2014



26 February 2016


17 May 2016

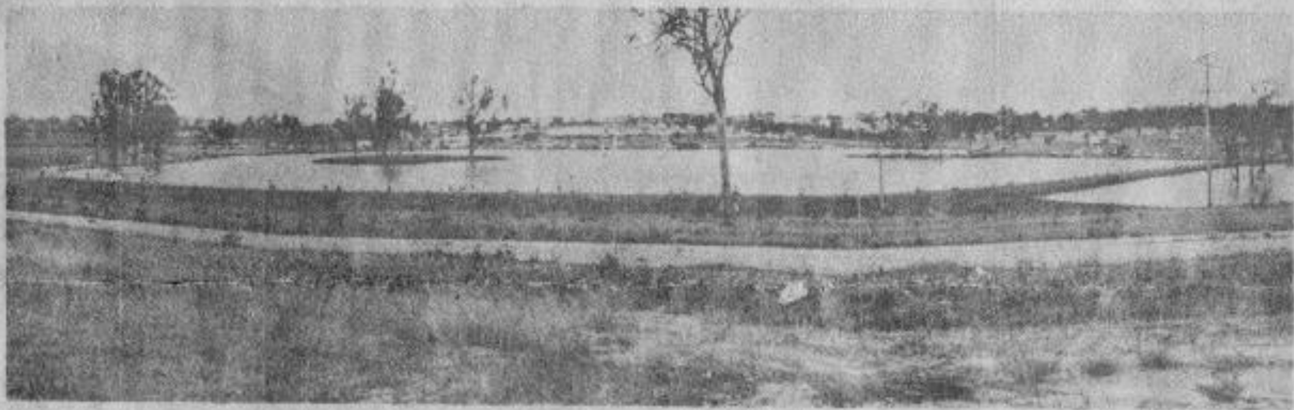

10 April 2017

Appendix D Historic Newspaper Articles

This appendix provides the historic newspaper articles related to the lakes assessed as part of the task described in Section 3.3.1.1 above.

SEE GATTON FIRST

Gatton situated 100 kilometers west of Brisbane, on the Warrego Highway, is the principal town in the picturesque and fertile Lockyer Valley. It is closely settled and is recognised as one of the richest areas in the state. The valley has a population of 20,000 while Gatton's population is approximately 4,300 and enjoys a growth rate of over 3 p.c. per year being one of the highest in the state. Potatoes, onions, beetroots, carrots and smallcrops are the main primary industries.



ON DAY OF OPENING OF "LAKE APEX" — 30th NOVEMBER, 1975.

THE GATTON "LAKE APEX"

"Lake Apex" is a major project constructed by the club. It was originally a bed of weeds and mud known as "Cleary's Swamp" but has since been converted into a picturesque recreation and picnic area adding to the beautification of the town. "The Lake" and surrounding area covers 20 hectares of land and has a 150,000,000 litre capacity. The surrounding area has been developed for the use of the picnicers and tourists with an amenities block and four shelter sheds, each with two barbeques. Recently, Lake Apex has been extended with the construction of a reserve lake upstream. Lake Apex, since its construction, has attracted many people from outside the local area, has been stocked successfully by Apexians with jewfish and has become an area endowed with many varieties of birdlife.

Article courtesy of
Jim Galletly via FOLA

Figure D-1 Newspaper article circa December 1975 describing the construction and opening of Lake Apex

Lake silting concerns

Recent rains cause large volumes of soil to wash into Lake Apex

Gatton Star 24 Dec 2014 By GARY WORRALL

RECENT storms in the Gatton area have members of the Friends of Lake Apex group concerned about runoff into the water system.

FOLA member Robert Wilson said the run-off originated in the area above the lake, and was washed down drainage gullies into the lake.

"Our concern is that the runoff from the Koala Park and Woodchester Estate areas will cause silting of Lakes Apex and Freeman, causing the loss of the birdlife sanctuary," Mr Wilson said.

Acknowledging previous work by Lockyer Valley Regional Council, Mr Wilson said a drain was built, but he was concerned a lack of ongoing maintenance was causing silt to build up and eventually flow into the lakes.

Mr Wilson said the initial plan used a "zig zag" design with "settling ponds" to allow silt to be trapped at intervals, preventing it from flowing into the two lakes.

Instead, the current design was implemented, but Mr Wilson said it was a straight line, which was not slowing the run-off before it entered the lake.

"There has been a change in the water quality in Lake Freeman since the storms began."

Barry O'Sullivan, managing director of Newlands Civil Construction, said the Woodchester Estate was the first development to meet new legislation governing the quality and quantity of stormwater discharge.

"This makes developers treat water for elements that affect fish life, creeks and the ocean," Mr O'Sullivan said.

Woodchester Estate used a sand filter and an underground detention basin to control water flows, Mr O'Sullivan said.

"We have an onsite manager – he lives there – who calls in work crews as soon as any run-off flowed onto roads within the estate."

Mr O'Sullivan said any silt "must go into the bio-retention basin", resulting in water quality "better than any other development".

Clint Christison, director of Ray White Rural Gatton, said FOLA members were to be "congratulated" for raising the concerns publicly.

Lockyer Valley Regional Council Mayor Steve Jones said the council wrote to representatives of FOLA addressing concerns relating to stormwater runoff from Woodchester Estate and Koala Park.

"I can confirm council has taken the matter seriously and has already addressed the issue with the developer, with a number of additional conditions relating to erosion, sediment and pollutant management being put into their approval," Cr Jones said.

"Council staff have been on site on a number of occasions and continue to work with the developer, who is keen to rectify the matter.

"Testing has found that sediment is being captured before it reaches Lake Freeman.

"Council is committed to implementing the Lake Apex Master Plan, evidenced by budget provisions to date, and will continue to work closely with Friends of Lake Apex and Lights on the Hill," Cr Jones said.

RUN-OFF: Robert Wilson stands where soil runoff has entered the gully.

Figure D-2 Newspaper article dated 24 December 2014 highlighting FOLA's concerns with sediment runoff to the lakes

Appendix E Lake Apex and Lake Freeman Flora and Fauna Database Species Lists

This appendix provides flora and fauna species lists for Lakes Freeman and Apex based on available databases as described in Section 4.3.1.5 above.

E.1 Flora Species List

Note: species marked with an asterisk are exotic species including weeds.

Table E-1 Flora species likely or known to occur at Lakes Freeman and Apex

Common name	Scientific name	Federal status	State status	Invasive status
Apiaceae (parsley family)				
Gotu cola	*Centella asiatica*	-	-	-
Aponcynaceae (dogbane family)				
Balloon cotton bush*	*Gomphocarpus physocarpus*	-	-	-
Araliaceae (ivy family)				
Large leaf pennywort	*Hydrocotyle acutiloba*	-	-	-
Asteraceae (sunflower family)				
Blue billygoat weed*	*Ageratum houstonianum*	-	-	-
Groundsel*	*Baccharis halimifolia*	-	-	Re 3
Cobbler's pegs*	*Bidens pilosa*	-	-	-
Thickhead*	*Crassocephalum crepidioides*	-	-	-
White eclipta	*Eclipta prostrata*	-	-	-
Chinese water chestnut*	*Eleocharis equisetina*	-	-	-
Scotch thistle*	*Onopordum acanthium*	-	-	-
Commonwealth weed*	*Senecio bipinnatisectus*	-	-	-
Boraginaceae (borage family)				
Blue heliotrope	*Heliotropium amplexicaule*	-	-	-
Cannabaceae (hackberries and hops)				
Chinese elm*	*Celtis sinensis*	-	-	Re 3

Common name	Scientific name	Federal status	State status	Invasive status
Casuarinaceae (she-oaks)				
Forest oak	*Allocasuarina torulosa*	-	-	-
Cyperaceae (sedges)				
Flax leaf fleabane	*Conyza bonariensis*	-	-	-
Mullumbimby couch	*Cyperus brevifolius*	-	-	-
Variable flat-sedge	*Cyperus difformis*	-	-	-
	Fimbristylis velata			
Euphorbiaceae (spurge family)				
Red caustic weed*	*Chamaesyce prostrata*	-	-	-
Fabaceae (legume family)				
Sally wattle	*Acacia salicina*	-	-	-
Siratro*	*Macroptilium atropurpureum*	-	-	-
Sesbania pea	*Sesbania cannabina*	-	-	-
Juncaceae (rush family)				
Common sedge	*Juncus continuus*	-	-	-
Common rush	*Juncus usitatus*			
Loranthaceae				
Long-flowered mistletoe	*Dendrophthoe vitellina*			
Marsileaceae (pepperwort family)				
Rainbow nardoo	*Marsilea mutica*			
Menyanthaceae				
Water snowflake	*Nymphoides indica*	-	-	-
Myrtaceae (myrtle family)				

Common name	Scientific name	Federal status	State status	Invasive status
Spotted gum	*Corymbia citriodora*	-	-	-
Moreton bay ash	*Corymbia tessellaris*	-	-	-
Cadagi*	*Corymbia torelliana*	-	-	-
Queensland blue gum	*Eucalyptus tereticornis*	-	-	-
Broad-leaved paperbark	*Melaleuca quinquenervia*	-	-	-
Weeping bottlebrush	*Melaleuca viminalis*	-	-	-
Onagraceae (willowherb family)				
Willow primrose	*Ludwigia octovalvis*	-	-	-
Water primrose	*Ludwigia peploides*	-	-	-
Water primrose subsp. montevidensis	*Ludwigia peploides subsp. montevidensis*			
Poaceae (grasses)				
Para grass*	*Brachiaria mutica*	-	-	-
Rhodes grass*	*Chloris gayana*	-	-	-
Couch*	*Cynodon dactylon*	-	-	-
Blue couch*	*Digitaria didactyla*	-	-	-
Swamp rice grass	*Leersia hexandra*	-	--	-
Green panic*	*Megathyrsus maximus var. maximus*	-	-	-
Johnson grass*	*Sorghum halepense*	-	-	-
Polygonaceae (knotweed family)				
Smartweed	*Persicaria attenuata*	-	-	-
Hairy knotweed	*Persicaria subsessilis*	-	-	-
Salicaceae (willow family)				
Willow*	*Salix babylonica*	-	-	-
Salviniaceae				
Red duck-weed	*Azolla rubra*	-	-	-
Solanaceae (nightshades)				
Wild tobacco*	*Solanum mauritianum*	-	-	-
Blackberry nightshade*	*Solanum nigrum*	-	-	-
Verbenaceae (verbena family)				
Lantana*	*Lantana camara*	-	-	Re 3
Lippia*	*Phyla canescens*	-	-	-
Verbena*	*Verbena litoralis*	-	-	-

E.2 Fauna Species List

Note: Bird species marked with an asterisk are confirmed at the lakes within the Lake Apex Bird Guide (Friends of Lake Apex Inc. 2015).

Table E-2 Fauna species likely or known to occur at Lakes Freeman and Apex

Common name	Scientific name	Federal status	State status	Invasive status
Bufonidae (true toads)				
Cane toad	*Rhinella marina*	-	-	Pr
Hylidae (tree frogs)				
Greenstripe frog	*Cyclorana alboguttata*	-	LC	-
Common green treefrog	*Litoria caerulea*	-	LC	-
Eastern sedgefrog	*Litoria fallax*	-	LC	-
Myobatrachidae (ground frogs)				
Striped marshfrog	*Limnodynastes peronii*	-	LC	-
Spotted grassfrog	*Limnodynastes tasmaniensis*	-	LC	-
Agamidae (dragons)				
Eastern water dragon	*Intellagama lesueurii*	-	LC	-
Bearded dragon	*Pogona barbata*	-	LC	-
Chelidae (side-neck turtles)				
Broad-shelled river turtle	*Chelodina expansa*	-	LC	-
Eastern snake-necked turtle	*Chelodina longicollis*	-	LC	-
Krefft's river turtle	*Emydura macquarii krefftii*	-	LC	-
Murray turtle	*Emydura macquarii macquarii*	-	LC	-
Saw-shelled turtle	*Wollumbinia latisternum*	-	LC	-
Colubridae (colubrid snakes)				
Freshwater snake	*Tropidonophis mairii*	-	LC	-
Acanthazidae (Australasian warblers)				
Yellow-rumped thornbill*	*Acanthiza chrysorrhoa*	-	LC	-
Yellow thornbill	*Acanthiza nana*	-	LC	-
White-throated gerygone	*Gerygone olivacea*	-	LC	-
Accipitridae (hawks and eagles)				
Brown goshawk*	*Accipiter fasciatus*	-	LC	-
Wedge-tailed eagle*	*Aquila audax*	-	LC	-
Swamp harrier	*Circus approximans*	-	LC	-
Black-shouldered kite	*Elanus axillaris*	-	LC	-
White-bellied sea-eagle*	*Haliaeetus leucogaster*	-	LC	-
Whistling kite*	*Haliastur sphenurus*	-	LC	-
Brahminy kite*	*Haliastur indus*	-	LC	-
Little eagle	*Hieraaetus morphnoides*	-	LC	-
Square-tailed kite*	*Lophoictinia isura*	-	LC	-
Black kite*	*Mivus migrans*	-	LC	-
Acrocephalidae (reed warblers)				
Australian reed-warbler*	*Acrocephalus australis*	Ma	LC	-
Alcedinidae (kingfishers)				
Laughing kookaburra*	*Dacelo novaeguineae*	-	LC	-
Forest kingfisher	*Todiramphus macleayii*	-	LC	-
Sacred kingfisher*	*Todiramphus sanctus*	-	LC	-

Common name	Scientific name	Federal status	State status	Invasive status
Anatidae (ducks, geese and swans)				
Chestnut teal	*Anas castanea*	-	LC	-
Grey teal	*Anas gracilis*	-	LC	-
Northern mallard	*Anas platyrhrnchos*	-	LC	-
Australasian shoveler*	*Anas rhynchotis*	-	LC	-
Pacific black duck*	*Anas superciliosa*	-	LC	-
Hardhead*	*Aythya australis*	-	LC	-
Australian word duck*	*Chenonetta jubata*	-	LC	-
Black swan*	*Cygnus atratus*	-	LC	-
Wandering whistling duck*	*Dendrocygna arcuata*	Ma	LC	-
Plumed whistling-duck*	*Dendrocygna eytoni*	-	LC	-
Pink-eared duck*	*Malacorhynchus membranaceus*	-	LC	-
Cotton pygmy-goose	*Nettapus coromandelianus*	-	LC	-
Blue-billed duck	*Oxyura australis*	-	LC	-
Freckled duck	*Stictonetta naevosa*	-	LC	-
Anhingidae (darters)				
Australasian darter*	*Anhinga novaehollandiae*	-	LC	-
Anseranatidae (magpie geese)				
Magpie goose*	*Anseranas semipalmata*	Ma	LC	-
Ardeidae (herons)				
Eastern great egret*	*Ardea alba modesta*	Ma	LC	-
Cattle egret*	*Ardea ibis*	Ma	LC	-

Common name	Scientific name	Federal status	State status	Invasive status
Intermediate egret*	*Ardea intermedia*	Ma	LC	-
White-necked heron*	*Ardea pacifica*	-	LC	-
Australasian bittern	*Botaurus poiciloptilus*	En	LC	-
Little egret*	*Egretta garzetta*	Ma	LC	-
White-faced heron*	*Egretta novaehollandiae*	-	LC	-
Nankeen night-heron*	*Nycticorax caledonicus*	Ma	LC	-
Artamidae (woodswallows, butcherbirds and currawongs)				
White-breasted woodswallow	*Artamus leucorynchus*	-	LC	-
Pied butcherbird*	*Cracticus nigrogularis*	-	LC	-
Australian magpie*	*Cracticus tibicen*	-	LC	-
Grey butcherbird	*Cracticus torquatus*	-	LC	-
Torresian crow*	*Corvus orru*	-	LC	-
Pied currawong*	*Strepera graculina*	-	LC	-
Cacatuidae (cockatoo)				
Sulphur-crested cockatoo*	*Cacatua galerita*	-	LC	-
Little corella*	*Cacatua sanguinea*	-	LC	-
Red-tailed black cockatoo*	*Calyptorhynchus banksii*	-	LC	-
Glossy black cockatoo	*Calyptorhynchus lathami*	Vu	V	-
Galah*	*Eulophus roseicapilla*	-	LC	-
Cockatiel*	*Nymphicus hollandicus*	-	LC	-
Campephagidae (cuckoo-shrikes)				
Ground cuckoo-shrike	*Coracina maxima*	-	LC	-
Black-faced cuckoo-shrike*	*Coracina novaehollandiae*	-	LC	-

Common name	Scientific name	Federal status	State status	Invasive status
White-winged triller	*Lalage tricolor*	-	LC	-
Charadriidae (plovers and lapwings)				
Red-capped plover	*Charadrius ruficapillus*	Mi	LC	-
Black-fronted dotterel*	*Elseyornis melanops*	-	LC	-
Red-kneed dotterel*	*Erythrogonys cinctus*	-	LC	-
Pacific golden plover	*Pluvialis fulva*	Mi, Ma	SLC	-
Masked lapwing (southern subspecies)*	*Vanellus miles novaehollandiae*	-	LC	-
Banded lapwing	*Vanellus tricolor*	-	LC	-
Masked lapwing	*Vanellus miles*	-	LC	-
Ciconiidae (storks)				
Black-necked stork	*Ephippiorhynchus asiaticus*	-	LC	-
Cisticolidae (cisticolas)				
Golden-headed cisticola*	*Cisticola exilis*	-	LC	-
Columbidae (pigeons and doves)				
Rock dove	*Columbia livia*	-	LC	-
Diamond dove	*Geopelia cuneata*	-	LC	-
Peaceful dove	*Geopelia striata*	-	LC	-
Crested pigeon*	*Ocyphaps lophotes*	-	LC	-
Spotted dove	*Streptopelia chinensis*	-	LC	-
Coraciidae (rollers)				
Dollarbird*	*Eurystomus orientalis*	-	LC	-
Cuculidae (cuckoos)				

Common name	Scientific name	Federal status	State status	Invasive status
Fan-tailed cuckoo	*Cacomantis flabelliformis*	-	LC	-
Pallid cuckoo	*Cacomantis pallidus*	-	LC	-
Pheasant coucal*	*Centropus phasianinus*	-	LC	-
Horsfield's bronze-cuckoo	*Chalcites basalis*	-	LC	-
Pacific koel*	*Eudynamys orientalis*	-	LC	-
Channel-billed cuckoo	*Scythrops novaehollandiae*	-	LC	-
Dicaeidae (flowerbeckers)				
Mistletoebird*	*Dicaeum hirundinaceum*	-	LC	-
Estrilidae (waxbills and munias)				
Double-barred finch*	*Taeniopygia bichenovii*	-	LC	-
Falconidae (falcons)				
Brown falcon*	*Falco berigora*	-	LC	-
Nankeen kestrel*	*Falco cenchroides*	-	LC	-
Australian hobby	*Falco longipennis*	-	LC	-
Peregrine falcon	*Falco peregrinus*	-	LC	-
Hirundinidae (swallows)				
White-backed swallow	*Cheramoeca leucosterna*	-	LC	-
Welcome swallow*	*Hirundo neoxena*	-	LC	-
Fairy martin	*Petrochelidon ariel*	-	LC	-
Tree martin	*Petrochelidon nigricans*	-	LC	-
Jacanidae (jacanas)				
Comb-crested jacana	*Irediparra gallinacea**	-	LC	-
Laridae (gulls and terns)				

Common name	Scientific name	Federal status	State status	Invasive status
Whiskered tern	*Childonias hybrida*	-	LC	-
White-winged black tern	*Childonias leucopterus*	-	SLC	-
Silver gull	*Chroicocephalus novaehollandiae*	Ma	LC	-
Caspian tern	*Hydroprogne caspia*	Mi, Ma	SLC	-
Locustellidae (grass warblers, grassbirds and bush warblers)				
Tawny grassbird*	*Megalurus timoriensis*	-	LC	-
Maluridae (wrens)				
Superb fairy-wren*	*Malurus cyaneus*	-	LC	-
Variegated fairy-wren	*Malurus lamberti*	-	LC	-
Red-backed fairy-wren*	*Malurus melanocephalus*	-	LC	-
Meliphagidae (honeyeaters)				
Spiny-cheeked honeyeater	*Acanthagenys rufogularis*	-	LC	-
Blue-faced honeyeater*	*Entomyzon cyanotis*	-	LC	-
Brown honeyeater*	*Lichmera indistincta*	-	LC	-
Noisy miner*	*Manorina melanocephala*	-	LC	-
Scarlet honeyeater	*Myzomela sanguinolenta*	-	LC	-
Little friarbird*	*Philemon citreogularis*	-	LC	-
Noisy friarbird*	*Philemon corniculatus*	-	LC	-
Striped honeyeater*	*Plectorhyncha lanceolata*	-	LC	-
Meropidae (bee-eaters)				
Rainbow bee-eater*	*Merops ornatus*	Mi, Ma	LC	-
Monarchidae (monarchs)				
Magpie-lark*	*Grallina cyanoleuca*	-	LC	-
Restless flycatcher	*Myiagra inquieta*	-	LC	-
Motacillidae (wagtails, longclaws and pipits)				
Australasian pipit	*Anthus novaeseelandiae*	-	LC	-
Pardalotidae (pardalotes)				
Striated pardalote*	*Pardalotus striatus*	-	LC	-
Pelecanidae (pelicans)				
Australian pelican*	*Pelecanus conspicillatus*	Ma	LC	-
Phalacrocoracidae (cormorants)				
Little pied cormorant*	*Microcarbo melanoleucos*	-	LC	-
Great cormorant	*Phalacrocorax carbo*	-	LC	-
Little black cormorant*	*Phalacrocorax sulcirostris*	-	LC	-
Pied cormorant	*Phalacrocorax varius*	-	LC	-
Podicipedidae (grebes)				
Great crested grebe*	*Podiceps cristatus*	-	LC	-
Hoary-headed grebe	*Poliocephalus poliocephalus*	-	LC	-
Australasian grebe*	*Tachybaptus novaehollandiae*	-	LC	-
Psittaculidae (lories and lorikeets)				
Musk lorikeet*	*Glossopsitta concinna*	-	LC	-
Little lorikeet	*Parvipsitta pusilla*	-	LC	-
Pale-headed rosella*	*Platycercus adscitus*	-	LC	-

Common name	Scientific name	Federal status	State status	Invasive status
Red-rumped parrot	*Pseuphotus haematonotus*	-	LC	-
Scaly-breasted lorikeet*	*Trichoglossus chlorolepidotus*	-	LC	-
Rainbow lorikeet*	*Trichoglossus moluccanus*	-	LC	-
Oriolidae (Old World orioles)				
Olive-backed oriole	*Oriolus sagittatus*	-	LC	-
Australasian figbird*	*Sphecotheres vieilloti*	-	LC	-
Rallidae (rails)				
Eurasian coot*	*Fulica atra*	-	LC	-
Dusky moorhen*	*Gallinula tenebrosa*	-	LC	-
Buff-banded rail**	*Gallirallus philippensis*	-	LC	-
Purple swamphen	*Porphyrio melanotus*	-	LC	-
Baillon's crake	*Porzana pusilla*	Ma	LC	-
Australian spotted crake	*Porzana fluminea*	Ma	LC	-
Black-tailed native-hen	*Tribonyx verntralis*	-	LC	-
Recurvirostridae (avocets and stilts)				
Black-winged stilt	*Himantopus Himantopus*	Ma	LC	-
Red-necked avocet*	*Recurvirostra novaehollandiae*	Ma	LC	-
Rhipiduridae (fantails)				
Grey fantail*	*Rhipidura albiscapa*	-	LC	-
Willie wagtail*	*Rhipidura lecuophrys*	-	LC	-
Scolopacidae (sandpipers)				

Common name	Scientific name	Federal status	State status	Invasive status
Common sandpiper	*Actitis hypoleucos*	Mi, Ma	LC	-
Sharp-tailed sandpiper	*Calidris acuminata*	Mi, Ma	SLC	-
Curlew sandpiper	*Calidris ferruginea*	CE, Mi, Ma	E	-
Pectoral sandpiper	*Calidris melanotos*	Mi, Ma	LC	-
Latham's snipe*	*Gallinago hardwickii*	Mi, Ma	SLC	-
Black-tailed godwit	*Limosa limosa*	Mi, Ma	SLC	--
Eastern curlew	*Numenius madagascariensis*	CE, Mi	E	-
Common greenshank	*Tringa nebularia*	Mi, Ma	SLC	-
Marsh sandpiper	*Tringa stagnatilis*	Mi, Ma	SLC	-
Threskiornithidae (ibises and spoonbills)				
Glossy ibis*	*Plegadis falcinellus*	Mi, Ma	LC	-
Yellow-billed spoonbill*	*Platalea flavipes*	-	LC	-
Royal spoonbill	*Platalea regia*	-	LC	-
Australian white ibis*	*Threskiornis molucca*	Ma	LC	-
Straw-necked ibis*	*Threskiornis spinicollis*	-	LC	-
Neoceratodontidae (lungfish)				
Australian lungfish	*Neoceratodus forsteri*	Vu	V	-
Anguillidae (freshwater eels)				
Longfin eel	*Anguilla reinhardtii*	-	LC	-
Cyprinidae (carps and minnows)				
Goldfish	*Carassius auratus*	-	LC	-
Eleotridae (sleeper gobies)				

Common name	Scientific name	Federal status	State status	Invasive status
Western carp gudgeon	*Hypseleotris klunzingeri*	-	LC	-
Melanotaeniidae (rainbowfish)				
Crimson-spotted rainbowfish	*Melanotaenia duboulayi*	-	LC	-
Percichthyidae (temperate perches)				
Golden perch	*Macquaria ambigua*	-	LC	-
Plotosidae (eeltail catfish)				
Freshwater catfish	*Tandanus tandanus*	-	LC	-

Appendix F Lake Apex and Lake Freeman Recorded Flora Species List

This appendix provides the list of species identified during the botanical survey of the lakes as described in Sections 3.4.4 and 4.4.4 above.

F.1 Recorded Flora Species List

Note: species marked with an asterisk are exotic species including weeds.

Table F-1 Recorded Flora Species List

Habitat	Species	Common Name	Lake Apex	Lake Freeman
Macrophyte zone	*Nymphoides indica*	Water Snowflake		*
	Ludwigia peploides *	Water Primrose	*	*
	Persicaria attenuata	Smartweed	*	*
	Eclipta prostrata	White Eclipta	*	*
	Ludwigia octovalvis	Willow Primrose	*	*
	Juncus continuus	Common Sedge	*	*
	Leersia hexandra	Swamp Rice Grass		*
	Persicaria subsessilis	Hairy Knotweed		*
	Cyperus brevifolius	Mullumbimby Couch	*	*
	Eleocharis equisetina	Chinese Water Chestnut	*	*
	*Conyza bonariensis**	Flax leaf Fleabane	*	*
	*Verbena litoralis**	Verbena	*	*
	Senecio bipinnatisectus	Commonwealth Weed	*	*
	Cyperus difformis	Variable Flat-sedge	*	*
	*Digitaria didactyla**	Blue Couch	*	*
	Hydrocotyle acutiloba	Large leaf Pennywort	*	*
	*Crassocephalum crepidioides**	Thickhead	*	*
	Aristida sp.		*	*
	Bothriochloa sp.		*	*
Steep-sided banks subject to periodic flooding	*Brachiaria mutica**	Para Grass	*	*
	Persicaria attenuata	Smartweed	*	*
	*Conyza bonariensis**	Flax leaf Fleabane	*	*
	*Verbena litoralis**	Verbena	*	*
	*Cynodon dactylon**	Couch	*	*
	*Bidens pilosa**	Cobbler's Pegs	*	*
Riparian fringe *Trees*	*Eucalyptus tereticornis*	Queensland Blue Gum	*	*
	Acacia salicina	Sally Wattle	*	*
	Melaleuca viminalis	Weeping Bottlebrush	*	*
	Melaleuca quinquenervia	Broad-leaved Paperbark	*	*
	Allocasuarina torulosa	Forest Oak	*	*
	Corymbia citriodora	Spotted Gum	*	*
	Corymbia tessellaris	Moreton Bay Ash	*	*
	*Corymbia torelliana**	Cadagi	*	*
	*Celtis sinense**	Chinese Elm	*	*
	*Solanum mauritianum**	Wild Tobacco	*	*
	*Salix babylonica**	Willow	*	*
			*	*
Riparian fringe *Shrubs*	*Baccharis halimifolia**	Groundsel	*	*
	*Gomphocarpus physocarpus**	Balloon Cotton Bush	*	*
	*Lantana camara**	Lantana	*	*

Habitat	Species	Common Name	Lake Apex	Lake Freeman
	*Solanum nigrum**	Blackberry nightshade	*	*
	*Sesbania cannabina **	Sesbania Pea	*	*
Riparian fringe *Groundcover*	*Ageratum houstonianum**	Blue Billygoat Weed	*	*
	Centella asiatica	Gotu Cola	*	*
	Chamaesyce prostrata	Red Caustic Weed	*	*
	*Chloris gayana**	Rhodes Grass	*	*
	*Cynodon dactylon**	Couch	*	*
	*Heliotropium amplexicaule**	Blue Heliotrope	*	*
	*Macroptilium atropurpureum**	Siratro	*	*
	*Megathyrsus maximus var. maximus**	Green Panic	*	*
	*Onopordum acanthium**	Scotch Thistle	*	*
	*Passiflora sp.**	Passionfruit	*	*
	*Phyla canescens**	Condamine Couch	*	*
	*Sorghum halepense**	Johnson Grass	*	*

Appendix G Condition Assessment Summary

This appendix summarises the various issues identified in Section 4 above and provides appropriate performance indicators, a condition rating score, priority rating and management/maintenance responses for each issue.

Table G-1 Condition assessment summary

ID	Item	Performance Indicator (PI)	Condition 1 - Good (PI exceeded) 2 - Adequate (PI met) 3 - Average (requires rectification or investigation) 4 - Poor (rectification required)	Assessment of Issue / Observational Reasoning	Priority rating for management 1 - Management not required 2 - Low priority 3 - Moderate priority 4 - High priority	Management/maintenance response
Public Heath and Safety						
1	Lake edge batters	Batter slopes leading down into the lakes should be no steeper than 5H:1V	2	Generally shallower than 5H:1V although some areas in Lake Apex particularly around the southern and western perimeters may be steeper. These areas are however, characterised by dense vegetation which acts as a deterrent for access and minimises public safety risks	2	No management currently required. If peripheral vegetation were removed, including for weed control, reassessment may be required to ensure adequate safety of public. Weed control and replanting may require temporary measures (e.g. signage, fencing) to limit public safety risks
2	Barriers / fences	Barriers and/ or fencing present where required (i.e. at batter slopes steeper than 5H:1V, on top of walls greater than 0.5m in height)	2	As noted in above point, dense vegetation around the key areas of potential non-compliance (southern and western perimeters of Lake Apex in particular) limit public access. The separation distance between the footpaths and water's edge also minimises risks. It is important to consider that there have been no known public safety issues with the current designs since the construction of the lakes in 1975 suggesting good design legibility and understanding of risks by the community and visitors. Recent barriers have also been installed to limit vehicular access including timber bollards and a locking rail	2	No management currently recommended. If weeds/vegetation is cleared, see above point for management
3	Mosquitoes	An excessive adult mosquito population is not observed or reported by Council or community members	1	No mosquitoes or larvae observed during inspection. Although they are likely to occur, they are not excessive given fish and macroinvertebrate predation.	1	No management currently required. Any change of observation would require reassessment of management requirements. Improved lake ecology would aid in mosquito larvae predation by fish and macroinvertebrates
4	Community access	Adequate community access is provided in accordance with community's desired level of recreation	1	Concrete path exists around Lake Apex and is in good repair. The need for additional access around Lake Freeman was not supported during the project workshop due to potential conflict with sensitive bird species	1	No apparent evidence of disrepair of existing path. No management currently required
5	Offensive odours	No offensive odours are detected	2	Offensive odours were detected by field staff around the Lake Apex islands. The source of this odour was the bird droppings. The odour was not however detectable around the periphery of the lakes at the time of field investigations.	2	No immediate action required
		Overall Score	**1.60**			
Water Quality						
6	Visible coatings, sheen or scum on water surface	No visible coatings, sheens or scum on the surface of the water.	1	The only visible substance on the water surface during the field work was algae which is addressed separately on point 16 below	1	No management currently required
7	Total suspended solids (TSS)	6 mg/L according to the ANZECC Guidelines	4	Results from water quality testing indicate that at the time of monitoring, the average TSS concentration in Lake Freeman was 9 mg/L and in Lake Apex was 12.5 mg/L	4	Concentrations at the time of monitoring exceeded the PI. Given the relationship between TSS and turbidity managing TSS is a high priority
8	Turbidity	<5 NTU for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the average turbidity in Lake Freeman was 119 NTU and in Lake Apex was 345 mg/L	4	Turbidity levels considerably exceeded the PI at the time of monitoring. The levels are also significantly higher than expected long term levels (based on water quality monitoring from 2001, aerial photos and photos from FOLA). Given the influence of turbidity on ecological health of the lakes and the visual impact from a social perspective, management of turbidity through revegetation is considered a high priority. Creating melaleuca zones within each of the wetland could also limit wind-induced stirring of the benthic sediments further minimising turbidity
9	Dissolved oxygen (DO)	Percent saturation levels do not exceed 85 - 105 % saturated for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the depth averaged DO in Lake Freeman was 82.1% saturated and in Lake Apex was 75.5% saturated	4	DO was slightly below the performance indicator at the time of monitoring. This limits the capacity of some fish species to survive in the lakes and increasing the DO is considered moderately urgent. Replacing macrophytes will improve the DO as well as the overall condition of the lakes
10	Total nitrogen (TN)	Concentration level does not exceed 0.3 mg/L for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the average TN concentration in Lake Freeman was 1.55 mg/L and in Lake Apex was 2.5 mg/L	4	TN was significantly higher than the performance indicator at the time of monitoring. This increases the risks of algal blooms. The risk of algal blooms is further increased as turbidity decreases, so reducing TN particularly through increased plant uptake is a high priority
11	Total phosphorus (TP)	Concentration levels do not exceed 0.01 mg/L. for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the average TP concentration in Lake Freeman was 0.33 mg/L and in Lake Apex was 0.8 mg/L	4	TP was significantly higher than the performance indicator at the time of monitoring. This increases the risks of algal blooms. The risk of algal blooms is further increased as turbidity decreases, so reducing TP particularly through increased plant uptake is a high priority
12	Oxidised N	Concentration levels do not exceed 0.01 mg/L. for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the average oxidised NOx concentration in Lake Freeman was 0.45 mg/L and in Lake Apex was 0.345 mg/L	4	NOx was significantly higher than the performance indicator at the time of monitoring. This increases the risks of algal blooms. The risk of algal blooms is further increased as turbidity decreases, so reducing NOx particularly through increased plant uptake is a high priority
13	Ammonia N	Concentration levels do not exceed 0.01 mg/L. for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the average NH3 concentration in Lake Freeman was 0.05 mg/L and in Lake Apex was 0.11 mg/L	4	NH3 was significantly higher than the performance indicator at the time of monitoring. This increases the risks of algal blooms. The risk of algal blooms is further increased as turbidity decreases, so reducing NH3 particularly through increased plant uptake is a high priority

Condition Assessment Summary

ID	Item	Performance Indicator (PI)	Condition 1 - Good (PI exceeded) 2 - Adequate (PI met) 3 - Average (requires rectification or investigation) 4 - Poor (rectification required)	Assessment of Issue / Observational Reasoning	Priority rating for management 1 - Management not required 2 - Low priority 3 - Moderate priority 4 - High priority	Management/maintenance response
14	Organic N:	Concentration levels do not exceed 0.27 mg/L. for 'freshwater lakes/reservoirs' according to EPP (Water)	4	Results from water quality testing indicate that at the time of monitoring, the average organic N concentration in Lake Freeman was 1.5 mg/L and in Lake Apex was 2.04 mg/L	4	TN was significantly higher than the performance indicator at the time of monitoring. This increases the risks of algal blooms. The risk of algal blooms is further increased as turbidity decreases, so reducing total nitrogen particularly through increased plant uptake is a high priority
15	pH	pH levels remain within 7.0 - 8.4 units. for 'freshwater lakes/reservoirs' according to EPP (Water)	1	Results from water quality testing indicate that at the time of monitoring, the average pH level in Lake Freeman was 7.48 and in Lake Apex was 7.28	1	pH levels recorded generally meet the prescribed WQOs and as such no management or rectification actions are recommended
16	Thermal stratification	There is no evidence of thermal stratification of the lakes	1	There was no evidence of thermal stratification of the lakes at the time of monitoring although monitoring was undertaken in winter when stratification is unlikely. Notwithstanding, the lakes are at an acceptable depth and changing the depth would not be recommended. Other methods of mixing may not be justified given shallow depths	1	No management or rectification actions are recommended
17	Thermal stratification	There is no evidence of dissolved oxygen stratification of the lakes	1	There was no evidence of dissolved oxygen stratification of the lakes at the time of monitoring although monitoring was undertaken in winter when stratification is unlikely. Notwithstanding, the lakes are at an acceptable depth and changing the depth would not be recommended. Other methods of mixing may not be justified given shallow depths	1	No management or rectification actions are recommended
18	Conductivity	An appropriate conductivity is recorded. It is suggested that an appropriate threshold for freshwater lake systems is 1500 µs/cm (Nielsen, D.L et al. 2003)	1	Results from water quality testing indicate that at the time of monitoring, the average conductivity in Lake Freeman was 206 mS/cm and in Lake Apex was 273 mS/cm . This would suggest acceptable fresh water	1	No management or rectification actions are recommended
19	Algae or cyanobacteria	Water does not appear green and there are not excessive algae present	3	No cyanobacteria found in Lake Apex at the time of monitoring although low concentrations identified in Lake Freeman including 4000 cells/mL of total chroococcales and total cyanophytes species. None of the species identified are potential toxin producing (PTP). Low biovolumes were also detected although this was confounded by the morphological characteristics of the cyanobacteria detected in the sample - small cyanobacteria approximately 1µm in diameter. Historic evidence of algae blooms exists although these do appear to have been overly severe. Given high nutrient levels and long residence times, algal blooms remain a high risk as turbidity decreases so any management action needs to address both issues	3	Measures required to provide constant/ controlled influent flows to reduce residence time and potential for algal blooms although viable options may be limited. Instead, establishment of dense vegetation may be more viable for greater levels of shaded water and competition for nutrients. Creating melaleuca zones within each of the wetland would greatly assist in reducing nutrient levels and minimising risks of algal blooms
		Overall Score	**2.86**			
Flooding						
20	Recent flooding	No indication of recent flooding on or around the site	1	No immediate evidence of recent flooding around the lakes	1	No action required. Any future development in the catchment will need to managed by on-site treatment systems
		Overall Score	**1.00**			
Understanding, education and custodianship						
21	Public perception	The community place a high degree of value on the lakes demonstrated by increased levels of engagement	3	There is very strong level of engagement currently through the FOLA demonstrating that this section of the community has a good understanding of the lakes' value. Other community groups and individuals use and benefit from the lakes but are less active in demonstrating custodianship. Poor water quality also minimises the value of the lakes which in turn, reduces the broader community's appreciation and involvement with the lakes	3	Interactive education techniques targeted at different age groups is required to increase education and develop greater custodianship over the lakes. Partnerships with community groups and schools would improve the quality of such education and directly engage key groups in the community. Improving water quality and riparian vegetation will increase value placed on lakes
22	Public education	The community have a good understanding of the ecology of the lakes and respond appropriately to education	3	Signage has been provided highlighting bird species which inhabit the lakes and discouraging people from feeding the birds. More interactive education techniques targeted at different age groups is however required to increase education and develop greater custodianship over the lakes	3	Interactive education techniques targeted at different age groups is required to increase education and develop greater custodianship over the lakes. Partnerships with community groups and schools would improve the quality of such education and directly engage key groups in the community. Improving water quality and riparian vegetation will increase value placed on lakes
23	Developer perceptions and education	Developers within the catchment of the lakes place a high level of emphasis on protecting water quality in the lakes including by applying best practice Erosion and Sediment Control (ESC) and Water Sensitive Urban Design (WSUD) practices during all stages of development	3	During the inspection of the catchment a number of areas of exposed soils were identified as were soil stockpiles without adequate ESC measures. Attempts at WSUD did not appear to be best practice. Water quality is likely exceeding regulatory targets and developers are likely in breach of environmental regulations. The newspaper article which included quotations from the developer suggest that they do not understand the limitations of existing devices. The development likely remains the highest source of sediment to the lakes in the catchment	4	A combined education and enforcement campaign is required. Immediate action is required on exposed soils and stockpiles
24	Builder perceptions and education	Builders within the catchment of the lakes place a high level of emphasis on protecting water quality in the lakes including by applying best practice ESC	3	During the inspection of the catchment most active building sites were observed to have inadequate ESC measures	4	A combined education and enforcement campaign is required. Immediate action is required on exposed soils
25	Litter	No floating litter in the lakes or litter surrounding the lakes with bins and gross pollutant traps (GPTs) provided and easily maintained	3	Small amount of litter detected although very regular litter collection by FOLA undertaken. Bins are provided in the Lake Apex Park but there are an inadequate number of bins around Lake Apex. There are no GPTs or trash rack installed upstream of the lakes	3	Increased number of bins required around Lake Apex. Further assessment is required to test if it is feasible to integrate a GPT or trash rack with the upstream sediment basin (refer to Figure 5-2).
		Overall Score	**3.00**			

Condition Assessment Summary

ID	Item	Performance Indicator (PI)	Condition 1 - Good (PI exceeded) 2 - Adequate (PI met) 3 - Average (requires rectification or investigation) 4 - Poor (rectification required)	Assessment of Issue / Observational Reasoning	Priority rating for management 1 - Management not required 2 - Low priority 3 - Moderate priority 4 - High priority	Management/maintenance response
Hydraulic Function						
26	Water level	Water level is within 0.3m of the nominal water level	4	Photo evidence and water balance modelling indicate that water levels within the lakes decrease to the point of complete drying particularly during drought conditions. The probability, frequency, duration and extent of drying have all likely increased as sedimentation has reduced water storage volume. It is expected that has contributed to a decline in macrophyte cover and the prolonged drying and combined with increased turbidity, has limited natural regeneration. The effect of this has been a decline in vegetation cover and decline in overall biodiversity in the lakes. Council has excavated some deeper trenches within Lake Apex during the 2003 drought to provide refuge for aquatic species	2	As the catchment becomes more developed, the level of imperviousness will also increase which will result in greater volumes of water flowing into the lakes.
27	Inlets	Appropriate pre-treatment of stormwater is provided to the lakes	4	There is one swale leading into Lake Apex which is located along its northern boundary near the information centre and another swale located in the north east corner of the lake. The northern swale is in good condition and does not require any rectification. The north eastern swale is degraded although a detailed design for the rectification of the channel has been undertaken. There are two well-defined swales which flow into Lake Freeman including the south east and south west swales. Both are in good condition and do not require any rectification. There are also two sediment basins leading into Lake Freeman however these only take flows from the south west swale which is undersized to provide adequate pre-treatment. Stormwater from the south east swale therefore bypasses these basins. Further, the northern basin becomes submerged during high water levels minimising its performance function.	4	The Lake Apex north-east channel requires rectification in accordance with the existing detailed design (Bligh Tanner and Yurrah 2014). The Lake Freeman sediment basins and local ground levels require reconfiguration to improve their function including increasing the storage volume and reprofiling ground levels around the basins to ensure both swales flow into the enlarged southern basin. The northern basin is not considered an actual sediment basin given it forms part of Lake Freeman following high rainfall. The batters of the basin should be planted with native species rather than turfed although some turfing is likely to be required for the maintenance access path
28	Outlet	No blockage or damage to the outlet	1	The outlet weir/culverts in Lake Apex appeared to be in good repair and no rectification is required	1	No management action is required
29	Hydraulic connection	The hydraulic connection between the lakes facilitates good flow conditions	3	The swale which joins the two lakes is very shallow and heavily overgrown with para grass. This has likely been exacerbated by sediment inputs over recent years. This limits the hydraulic connection between the lakes may be limiting fish migration between the lakes	3	The swale should be maintained including removal of accumulated sediment and replanting. The depth of the water in the swale should be at least 0.5 m.
30	Sediment accumulation	No excessive sediment accumulation	4	Excessive sediment accumulation is evident in both lakes. This requires catchment based solutions (managing sediment inputs) and adequate pre-treatment (through sediment basins).	4	Refer to responses for items 23, 24 and 27 above.
		Overall Score	**3.20**			
Maintenance						
31	Access to edge of lake	There is adequate access to edge of the lakes for appropriate weed management	2	Banks of the lakes are accessible for weed maintenance activities to take place. While access to the edges of Lake Freeman is more limited (i.e. there is no fomalised path around the lake), the northern edge remains accessible via the constructed path, the southern edge remain accessible by authorised vehicles and the eastern and western edges remain accessible on foot	1	No management action is required
32	Delineation between turf and macrophyte zone	The delineation between turf areas to be mown and macrophyte habitat is physically delineated to minimise inappropriate maintenance activities	4	Mowing around Lake Freeman does not appear to be undertaken so the edge habitat is in better condition compared to Lake Freeman. Around Lake Apex there is no delineation between the mown turf zone and the macrophyte habitat zone and it appears that maintenance contractors may be mowing over riparian habitat	3	Around Lake Apex there is a need to provide some physical delineation between the mown turf zone and the macrophyte habitat zone. This should also include the northern edge of Lake Freeman which also adjoins turf. Similarly, if turf is used around the new sediment basin (see item 27 above), a planting edge should be installed
33	Maintenance of the macrophyte and littoral zones of the lakes	There macrophyte and littoral zones of the lakes are on Council's maintenance register and maintained by suitably qualified staff or contractors	3	It is unclear how the maintenance of the macrophyte and littoral zones is undertaken by Council or its contractors however given that the lakes previously featured more healthy macrophyte habitats which are now limited and dominated by weeds, this is an issue that will require further attention by Council. This is especially the case given the investment to be placed in revegetation works.	3	An new maintenance plan needs to be developed for the macrophyte zone and suitably qualified persons with skills in managing wetland habitats appointed to managing the macrophytes in the lakes. The maintenance plan should be based on Integrated Pest Management (IPM) techniques which minimise the use of chemical sprays
34	Access to sediment basins	Appropriate access and sediment dewatering area is provided for the sediment basins	4	While access to the southern sediment basins is feasible, the access path is heavily overgrown and not well delineated. There is adequate room for dewatering but the dewatering area is not delineated meaning any dewatering activities could impact on surrounding vegetation and fauna	3	In the design of the new sediment basin (refer to item 27 above), include formalised/delineated maintenance access path and dewatering area
35	Maintenance of sediment basins	The sediment basins are formally recognised on Council's asset register and added to the maintenance schedule. Maintenance works are undertaken in accordance with the recommendations of the designer	4	Based on feedback from Council during the workshop, it is unclear whether the existing sediment basins are on Council's asset register or maintenance schedule and whether the existing sediment basins have actually ever been maintained	3	Ensure that new sediment basin (refer to item 27 above) is formally recognised on Council's asset register and added to the maintenance schedule. Undertake maintenance works in accordance with the recommendations of the designer
		Overall Score	**3.4**			

ID	Item	Performance Indicator (PI)	Condition 1 - Good (PI exceeded) 2 - Adequate (PI met) 3 - Average (requires rectification or investigation) 4 - Poor (rectification required)	Assessment of Issue / Observational Reasoning	Priority rating for management 1 - Management not required 2 - Low priority 3 - Moderate priority 4 - High priority	Management/maintenance response
Flora						
36	Native macrophytes and littoral vegetation	Lake Freeman is at least 80% covered by submergent and emergent macrophytes during the wet season. Lake Apex is at least 60% covered by submergent and emergent macrophytes during the wet season. This includes each of the zones shown in Figure 5-3 (not inlcuding the pool zone which is not proposed to be vegetated). The vegetation recovers well following drought conditions. There is good tree cover of the littoral zone around both lakes to asset in shading out weeds and providing habitat.	4	Aerial photos and photos taken by FOLA members document a high rate of macrophyte mortality compared to pre-impact conditions (taken to be 2005). At the time of aquatic macrophyte survey undertaken as part of this project, the distribution, abundance and diversity of macrophytes observed within the lakes was very limited. In the areas which are vegetated, there a very high abundance of weed species. The macrophytes have not recovered well through natural regeneration most likely due to high turbidity and inundation of the soil seed bank by sediment. This has resulted in overall decline in ecosystem health. Although there are few patches of trees around the littoral zone of both lakes, most of the lake edges are devoid of tree cover	4	Replanting is required to re-establish the macrophyte habitat and return native seed back into the surface soil layer. Extensive weed management is also required prior to planting. This action is considered to be one of the most important responses recommended as it has the potential to strongly influence water quality, ecology and community custodianship over the lakes. The tree cover of the littoral zone of both lakes should be substantially increased (at least 200 new trees around Lake Apex and 400 new trees around Lake Freeman) with water favouring tree species
37	Macrophytes and littoral weeds	Weeds are limited and do not feature more than 20% cover in any one area. Patches of weeds are no greater than $20m^2$. No declared weeds are observed	4	Weeds heavily dominate many areas within the lakes and around the littoral zone.	4	Weeds are to be controlled and maintenance activities put in place for future weed management (refer to item 33 above). This is noted as a high priority as it needs to occur prior to revegetation works
		Overall Score	**4.00**			
Fauna						
38	Native fish species	There is good diversity and abundance of native fish species supported by good habitat in both lakes	3	There were six (6) native fish species recorded as part of the fish survey undertaken for this project. The species, abundance and diversity were relatively representative of freshwater lakes in south east Queensland although most lakes in the region are relatively degraded so this does not indicate good biodiversity. The poor water quality means that only the common, hardy species are surviving. Also, it was noted than Lake Apex features fish of various sizes but Lake Apex featured mostly juvenile fish suggesting potential habitat issues or problems with fish migration between the lakes. Fish habitat is quite limited with low macrophyte cover and almost no specific habitat features such as logs and rocks present in either lake	2	Undertake revegetation works as noted in item 36 above. Clean out and revegetate the swale connecting the lakes as noted in item 29 above. Add habitat features such as logs and rocks in various zones of both lakes to improve biodiversity values
39	Exotic fish species	Exotic fish species are not likely to have a significant detrimental impact upon the ecology of the lakes	3	The only noxious fish species recorded as part of the fish survey undertaken for this project included the mosquitofish (*Gambusia holbrooki*) and a single goldfish (*Carassius auratus*). Noxious fish compete with native species for resources, can be associated with poor water quality and can cause direct damage to a lake bed and macrophytes. The mosquito fish is not expected to be creating a sufficient impact to warrant management responses. As only a single goldfish was captured, it is not expected that a sustainable population exists but this should be further investigated as goldfish can have significant impacts and are classed as noxious	3	A follow up targeted fish survey is recommended for goldfish in Lake Apex including in the deeper waters
40	Bird species	Birds species diversity and abundance is representative of pre-2005 conditions	3	FOLA members noted that there are numerous bird species which have previously been recorded at the lakes but have not been seen since the changes in water quality and macrophyte cover after 2009	4	Undertake water quality improvement works as noted in item 27 above. Undertake revegetation works as noted in item 36 above. Undertake habitat improvements works as noted in item 38 above.
41	Amphibian species	Frog species diversity and abundance is representative of pre-2005 conditions	3	The only known survey undertaken of amphibians was a snapshot survey undertaken as part of the Lockyer Valley Directory which identified two uncommon species recorded at the lakes. As such, pre-2005 conditions are unknown. In any case, the decline in macrophyte habitat and water quality would undoubtedly have impacted upon frog species	3	Undertake water quality improvement works as noted in item 27 above. Undertake revegetation works as noted in item 36 above. Undertake habitat improvements works as noted in item 38 above.
		Overall Score	**3.00**			
		Total Score	**2.76**			

Appendix H Indicative Plant Species for Recommended Revegetation Works

This appendix provides a conceptual list of species to be planted within the lakes. The list has been arranged according to the bathymetric zones of the lakes and is based on species known to occur in the lakes as well as other species which occur in other waterbodies in the region. The planting density should be four (4) plants per square metre or greater (subject to funding) otherwise the revegetation works could become dominated by weed growth.

This list should be refined during the detailed landscape design. It should be noted that the bathymetric zones are based on the bathymetric survey and planting may need to be adjusted according to the expected hydrology as the lakes experience more frequent drying compared to a typical ‘wetland’ with these zones.

Table H-1 Indicative plant species for recommended revegetation works

Bathymetric zone	Species	Common Name
Deep marsh	*Baumea articulata*	Jointed Twig-rush
	Bolboschoenus fluviatalis	Marsh Club-rush
	Eleocharis sphacelata	Tall Spike-rush
	Schoenoplectus litoralis	Shore Club-rush
	Schoenoplectus validus	River Club-rush
	Lepironia articulata	Grey Rush
Marsh	*Baumea arthrophylla*	Fine Twig-rush
	Baumea rubiginosa	Soft Twig-rush
	Bolboschoenus caldwellii	Club-rush
	Schoenoplectus mucronatus	Star Club-rush
Shallow Marsh	*Juncus subsecundus*	Finger Rush
	Juncus usitatus	Common Rush
	Restio pallens	Cord Rush
	Restio tetraphyllus	Tassel Cord-rush
	Baumea juncea	Bare Twig-rush
	Eleocharis pusilla	Small Spike-rush
	Phylidrium lanuginosum	Woolly Water Lily
Ephemeral marsh	*Leersia hexandra*	Swamp Rice Grass
	Carex appressa	Tall Sedge
	Carex inversa	Knob Sedge
	Carex polyantha	Creek Sedge
	Cyperus gunnii	Flecked Flat Sedge
	Juncus flavidus	Yellow Rush
	Juncus pristmatocarpus	Branching Rush
	Lepidosperma laterale var. laterale	Variable Sword-sedge
	Lepidosperma longitudinale	Common Sword-sedge
	Juncus continuus	Common Sedge
Batters (riparian fringe)	*Ludwigia octovalvis*	Willow Primrose
	Cyperus difformis	Variable Flat-sedge
	Schoenus apogon	Common Bog-rush
	Viola hederacea	Native Violet
	Ranunculus inundatus	River Buttercup
	Carex breviculmis	Short-stem sedge
	Carex pumila	Coastal Sedge
	Cyperus polystachyos	Bunchy Sedge
	Dianella longifolia var. longifolia	Pale Flax-lily
	Gahnia clarkei	Tall Saw-sedge
	Gahnia siberiana	Red-fruited Sword Sedge
	Lomandra filiformis spp. filiformis	Wattle Mat-rush
	Lomandra longifolia	Spiny-headed Mat Rush
	Gahnia aspera	Saw Sedge
	Baeckea virgata	Twiggy Heath Myrtle
	Callistemon sieberi	River Bottlebrush
	Gahnia siberiana	Red-fruited Sword Sedge
	Eucalyptus tereticornis	Queensland Blue Gum
	Acacia salicina	Sally Wattle
	Melaleuca viminalis	Weeping Bottlebrush
	Melaleuca quinquenervia	Broad-leaved Paperbark
	Allocasuarina torulosa	Forest Oak
	Corymbia citriodora	Spotted Gum
	Corymbia tessellaris	Moreton Bay Ash

BMT has a proven record in addressing today's engineering and environmental issues.

We aim to continue to enhance our services, capabilities and areas of application to meet the community's future development and environmental protection needs.

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