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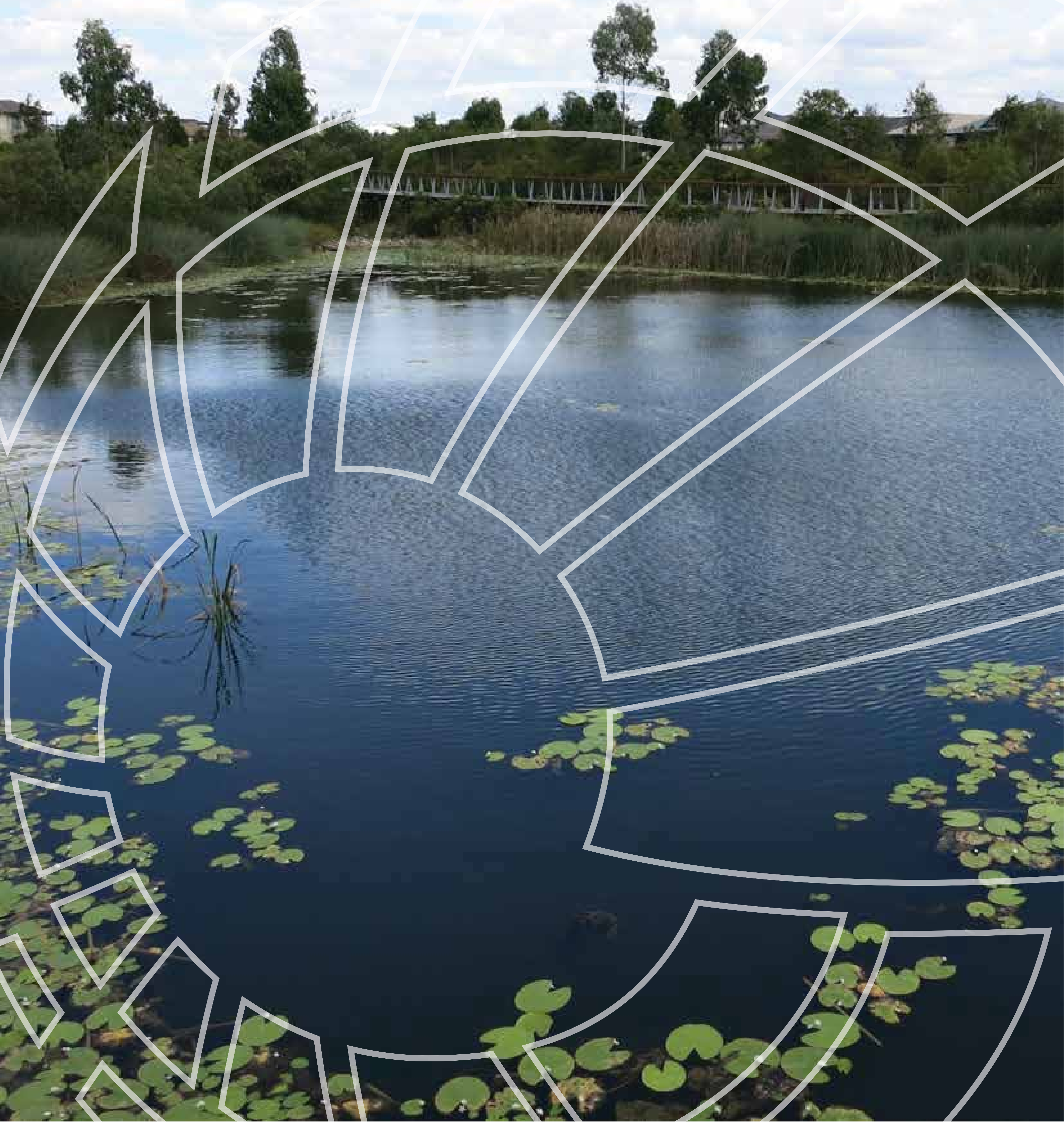
Date: 25 October 2017

Queensland Government

Flinders Precinct 1:
Concept Lake Management Plan

April 2017



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Client:	Pacific International Development Corporation
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Client Reference:	
Synopsis:	Concept management plan for the proposed lake within Precinct 1 of the Flinders Master Planned Community. This plan has been prepared in response to the Terms of Reference from Economic Development Queensland (EDQ) and to augment the successful planning, design, implementation and management of the proposed lake.

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	7 September 2015	Brad Dalrymple		Lucy Peljo	
1	6 May 2016	Brad Dalrymple		Lucy Peljo	
2	15 June 2016	Martin Giles		Lucy Peljo	
3	12 April 2017	Martin Giles		Lucy Peljo	
4	24 April 2017	Martin Giles		Lucy Peljo	

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Executive Summary

The Flinders Master Planned Community is a 4,000 hectare landholding proposed for development by the Pacific International Group. The site is located in Undullah, south west of Logan City and includes a 1,000 hectare area known as Precinct 1, which is to feature a lake. The primary functions of the lake are amenity and secondary contact recreation including uses such as canoeing, boating and fishing.

It is anticipated that the lake will be predominantly open water with mostly fringing vegetation and some 'hard edge' treatments, including (for example) boardwalks and rock walls. Boat ramps, jetties, pontoons, canoe launching facilities and other community facilities are also likely to maximise recreation opportunities.

The objectives of this report are to:

- Augment the design and operation of the lake
- Respond to items within the Terms of Reference (TOR) given by Economic Development Queensland (EDQ) in relation to the proposed lake. This primarily includes:
  - Identification of key risks associated with design, construction, establishment and operation of the lake
  - Identification of performance criteria which are to be included in approval conditions aimed at minimising the identified risks
  - Conceptual design verification for matters specifically requested by the TOR
  - Developing a Concept Lake Management Plan which includes:
    - Concept Water Quality and Sediment Monitoring Program
    - Concept Lake Maintenance Plan.

A summary of responses to the TOR items related to the lake is provided in Table 1.

Table 1 Summary of Responses to TOR Lake-Related Items

TOR Item	Has TOR item been addressed?	Report Section	Comments
Flooding	Yes	4.14	• The management of flooding is being addressed concurrently to this report in the 'Flinders Precinct 1: Flood Impact Assessment' (BMT WBM, 2017).
Lake Water Quality and Reliability	Yes		• The key objective of this report is to address this item (i.e. the need for a 'concept lake report', as specified in the TOR). • Section 4 identifies issues, risks and performance criteria for the proposed lake (and associated water quality and reliability).
Lake Water Balance	Yes	4.11	• Water balance modelling undertaken using 60-years of climate data. • Results predict that water level variation will be minimal for developed catchment conditions. • Prior to the proposed development of the contributing catchment (to the proposed lake), additional (albeit temporary) sources of water (of appropriate quality) are anticipated to be required to prevent unacceptable water level variation. An average 'top-up' of 500m^3/day would be required under existing catchment conditions to achieve an acceptable water level variation, with this required 'top-up' volume reducing as the catchment is developed.
Amenity and Safety	Yes	4.4 & 4.5	
Lake Water Quality – Overall, Poor Water Quality and Dry Periods	Yes	4.10	
Rate of Sedimentation	Yes	4.9	• During its operational phase, the rate of sedimentation in the lake is predicted to be minimal, with a maximum possible depth of accumulated sediment calculated (using MUSIC) to be approximately 0.011 m (or 11cm) over a period of fifty (50) years.
Maintenance Costs	Yes	5	• Typical lake maintenance costs are estimated to be between $391,000 and $522,000 per annum. It is noted that the costs will be refined as part of detailed design.
Water Quality Monitoring Program	Yes	Appendix C	A monitoring program has been provided, and it has been proposed to include: • Pre-development (baseline) water quality monitoring • Construction phase water quality monitoring • Operational phase water quality and sediment monitoring.
Lake Management Plan	Yes	Appendix D	An indicative maintenance plan for the proposed lake has been provided.

Both the TOR and this plan recognise that more detailed investigations will need to be completed as part of subsequent Infrastructure Master Plans (IMP's) and Overarching Site Strategy (OSS) to confirm that all of the identified criteria can be achieved in the long term. This plan should not therefore be considered the Detailed Lake Design Report, which is a separate but complimentary document to be developed during detailed design.

However, based on previous experience and the best practice techniques proposed to manage water quality within the lakes, it is considered that meeting the performance criteria nominated in this report will be readily achievable in the long term.

In particular, the issues associated with some existing lakes in south-east Queensland and Australia will be avoided by:

- Adopting a lake depth that minimises the potential for stratification (although it is still intended to provide destratification devices in the lakes);
- Treating runoff from developed areas to meet the water quality objectives nominated in the *State Planning Policy* prior to its discharge to the lakes;
- Maintaining good water quality in the lakes by the recirculation (turnover) and treatment of water in the lakes using a combination of vegetated (natural) systems and physical treatment systems; and
- Developing a comprehensive lake management and monitoring plan as part of further design and then implementing the plan in order to provide appropriate and regular maintenance of the lake rather than the ad-hoc approach adopted with respect to many waterbodies.

The *Flinders Precinct 1: Concept Lake Management Plan* will be revised commensurate with the development of the *Detailed Lake Design Report* when further information is available.

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1 Introduction

1.1 Preamble

This section of the plan describes the proposed Flinders Master Planned Community, Precinct 1 Lake, and objectives and limitations of this concept lake management plan. It also introduces the key reference materials used in developing this plan that will be applicable to subsequent planning and design associated with the lake and surrounding land uses.

1.2 Proposed Development

The Flinders Master Planned Community (hereafter referred to as 'Flinders') is a 4,000 hectare landholding being developed by the Pacific International Group. Flinders is located in Undullah, south west of Logan City as shown in Figure 1-1.

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

The remainder of the Flinders site (located to the west of Precinct 1) is referred to as the 'Balance Land'. The overall project will result in approximately 20,000 dwellings with 50,000 residents. Proposed land uses are further described in Section 2.5.

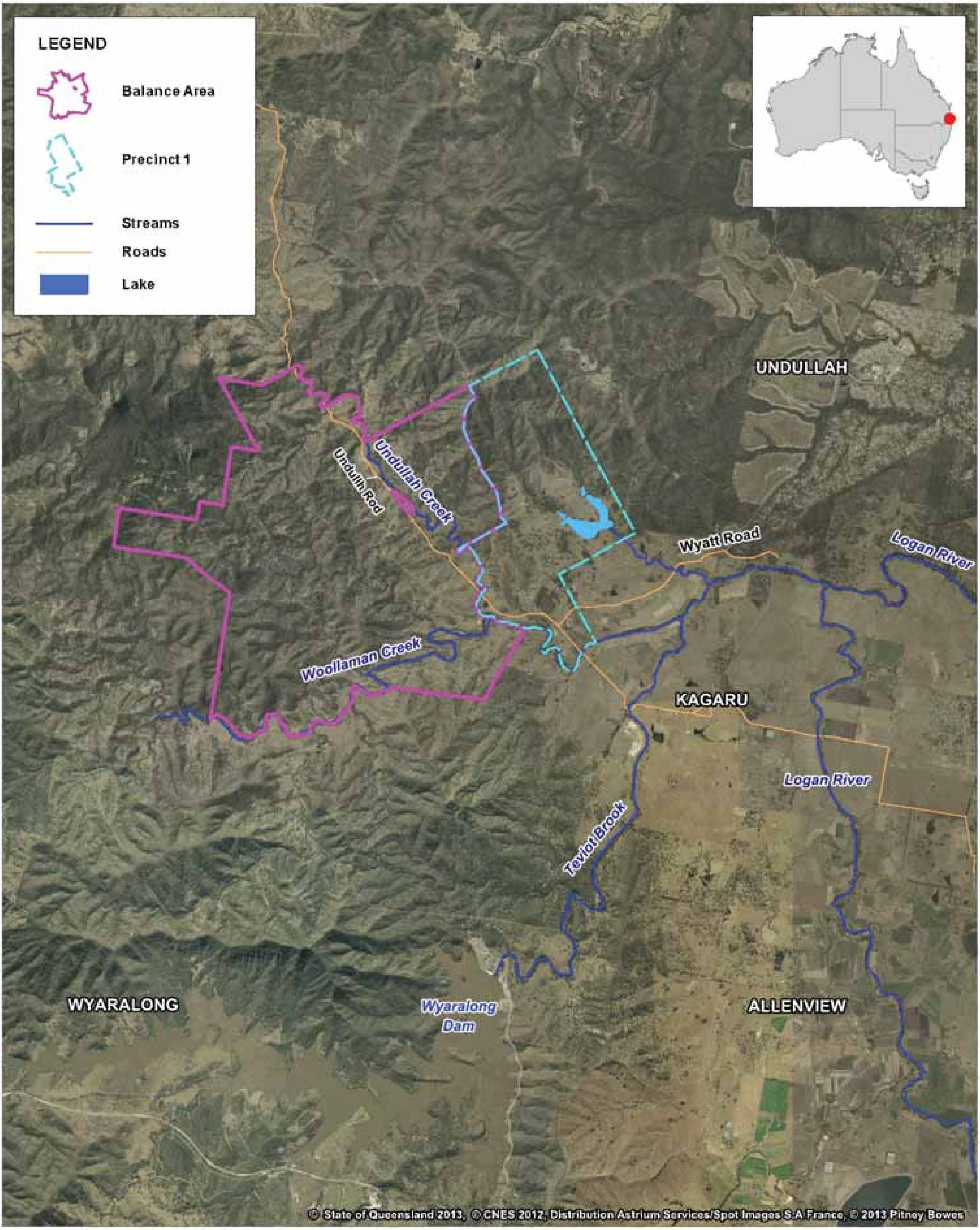
It is proposed that a lake will be integrated into Precinct 1 to enhance amenity for the benefit of the local community and to provide recreational opportunities for future residents. The lake is proposed to be located in the south-east corner of Precinct 1 at the headwaters of an unnamed creek.

As the lake and most of its catchment are located within Precinct 1 (refer to Section 2.4 for further description of site topography and drainage), discussion about the 'site' in this report hereafter refers to Precinct 1.

1.3 General Lake Description

The lake is intended to be constructed in the lowest area of the site as shown in Figure 2-4. It is to be formed by constructing a dam across the unnamed tributary upstream of the southern site boundary. The lake is comprised of one larger waterbody, with an approximate area of 22.2 hectares and a smaller waterbody located upstream, with an area of approximately 3.7 hectares. Both waterbodies will have an average typical water depth of the order of 4 metres. Note that although the lake is made up of two waterbodies, for the purposes of this report they will be referred to as 'the lake'.

It is anticipated that the lake will be predominantly open water with mostly fringing vegetation and some 'hard edge' treatments, including (for example boardwalks) and rock walls. Boat ramps, jetties, pontoons, canoe launching facilities and other community facilities are also likely to integrated adjacent to the lake to augment recreational values.



Title:

Location of Site

Figure: 1-1

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1.4 Report Objective and Limitations

The primary objective of this report is to respond to the Terms of Reference (TOR) set by Economic Development Queensland (EDQ) as provided in Appendix A. This includes defining the performance criteria that will need to be satisfied as part of subsequent reporting, including both Infrastructure Master Plans (IMP's) and the Overarching Site Strategy (OSS), to facilitate the successful operation and management of the lake. The criteria detailed in this plan are to be reflected in the conditions of approval for the development.

This report also provides some 'initial calculations' requested in the TOR to test the feasibility of achieving some of the recommended performance criteria. Both the TOR and this plan recognise that more detailed investigations will need to be completed as part of subsequent reporting to confirm that all of the identified criteria can be achieved in the long term. This plan should not therefore be considered a detailed lake design report.

Nevertheless, the plan does provide some initial planning and design guidance for the lake. It will therefore be an important reference document which guides detailed design of the lake, land use and layout design planning of the site and development of the final detailed management plan.

1.5 Design and Operation Reference Materials

This plan has been developed with due regard for local, regional, and national best practice guidance materials current at the time of drafting, including (but not limited to) the following references:

- *Concept Design Guidelines for Water Sensitive Urban Design* (Water by Design, 2010).
- *Framework for the Integration of Flooding and Stormwater Management into Open Space* (Water by Design, 2011).
- *Urban Lakes Discussion Paper: Managing the Risk of Cyanobacterial Blooms* (Water by Design, 2012a).
- *MUSIC Modelling Guidelines* (Water by Design, 2010).
- *Engineering Design Guidelines: Constructed Lakes – Planning Policy No. 15.15* (Mackay City Council, 2008).
- *Townsville Constructed Lakes Design Guideline* (DesignFlow and RPS, 2010).
- *Guidelines for Managing Risks in Recreational Water* (National Health and Medical Research Council (NHMRC), 2008).
- *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands* (Water by Design, 2010).
- *Waterbody Management Guideline* (Water by Design, 2013).

Subsequent versions of this plan should also consider the above guidelines or more current advice available at that time. It should also be noted that the design and management recommendations of this plan should be considered preliminary only. As described above, further planning, design and assessment is required to maximise the sustainability of the proposed lake.

2 Site Description

2.1 Preamble

This section provides an overview of the site, including a description of existing land uses, topography, drainage and soils.

It should be noted that additional investigations will be required to more accurately characterise the site prior to further design including, for example, land surveys and geotechnical investigations.

2.2 Site Location

As noted above, Flinders is located in Undullah, south west of Logan City as shown in Figure 1-1. Undullah is a locality divided between the City of Logan and the Scenic Rim Region however Precinct 1 is located wholly within Logan City Council. The Balance Land is predominantly located within Logan City Council with a small section located within Scenic Rim Regional Council.

The site is located approximately 6 kilometres north-east of the Wyaralong Dam, which may be a source of water supply for the initial filling of Flinders Lake (discussed further in Section 4.11). The main access to the site is currently via Undullah Road aligned approximately northwest to southeast in close proximity to the boundary of Precinct 1 and the Balance Land.

2.3 Existing Land Usage

The existing site comprises large tracts of land being actively grazed by cattle. The agricultural land use is confined by the steeper topography of the Teviot Range, which is the upper catchment for the site. The upper catchment is undeveloped and features open forest woodlands.

Photos showing existing conditions of the site are provided in Figure 2-1 below.

2.4 Topography, Drainage and Soils

The site features steep, densely-wooded terrain to the north including peaks of the Teviot Range (also referred to as the Flinders Peak Group) up to 320 metres Australian High Datum (AHD). The site drains towards the south where topography becomes flatter towards its lowest point of approximately 25 metres AHD. A digital elevation model (DEM) showing the topography of the site is shown in Figure 2-3.

Flinders is located within the Logan River Drainage Basin. Two major creeks abut the boundary of the site, including Undullah Creek which flows from north to south through the Flinders site and Woollaman Creek, which joins Undullah Creek along the southern boundary of the Flinders site.

Teviot Brook flows from Wyaralong Dam in a north easterly direction past the south east corner of the site. Woollaman Creek flows into Teviot Brook approximately 1.4 kilometres downstream of the site and then flows into the Logan River a further 3.2 kilometres downstream of the confluence of these two waterways. The ultimate receiving environment for Flinders is southern Moreton Bay.

The site drains to the south-east via an unnamed tributary to its junction with Teviot Brook approximately 1.3 kilometres downstream of the site boundary and also downstream of the junction between Woollaman Creek and Teviot Brook.

Flinders features highly dispersive soils and many of the drainage corridors across the site are deeply eroded including cuts of approximately 3-5 metres in the upper to mid catchment and approximately 6+ metres in the lower catchment. In the upper catchment, erosion is often down to sandstone bedrock while in the lower catchment creek bed erosion is down to granite bedrock. Eroded material covers the base of the drainage paths and creeks and has resulted in high turbidity in all waterways discharging from the site.

Other notable drainage features include a large weir structure which currently limits flows in Undullah Creek and a series of farm dams located across the site. Photos of the key drainage features of the existing Flinders site are shown in Figure 2-2.

The integration of the lake requires the construction of a dam across the unnamed tributary. The undeveloped catchment of the proposed lake is approximately 557 hectares, which is located wholly within Precinct 1 apart from an area in the upper catchment of approximately 51 hectares that is located north east of the site. The location of the lake and its contributing catchment boundary are presented in Figure 2-4.

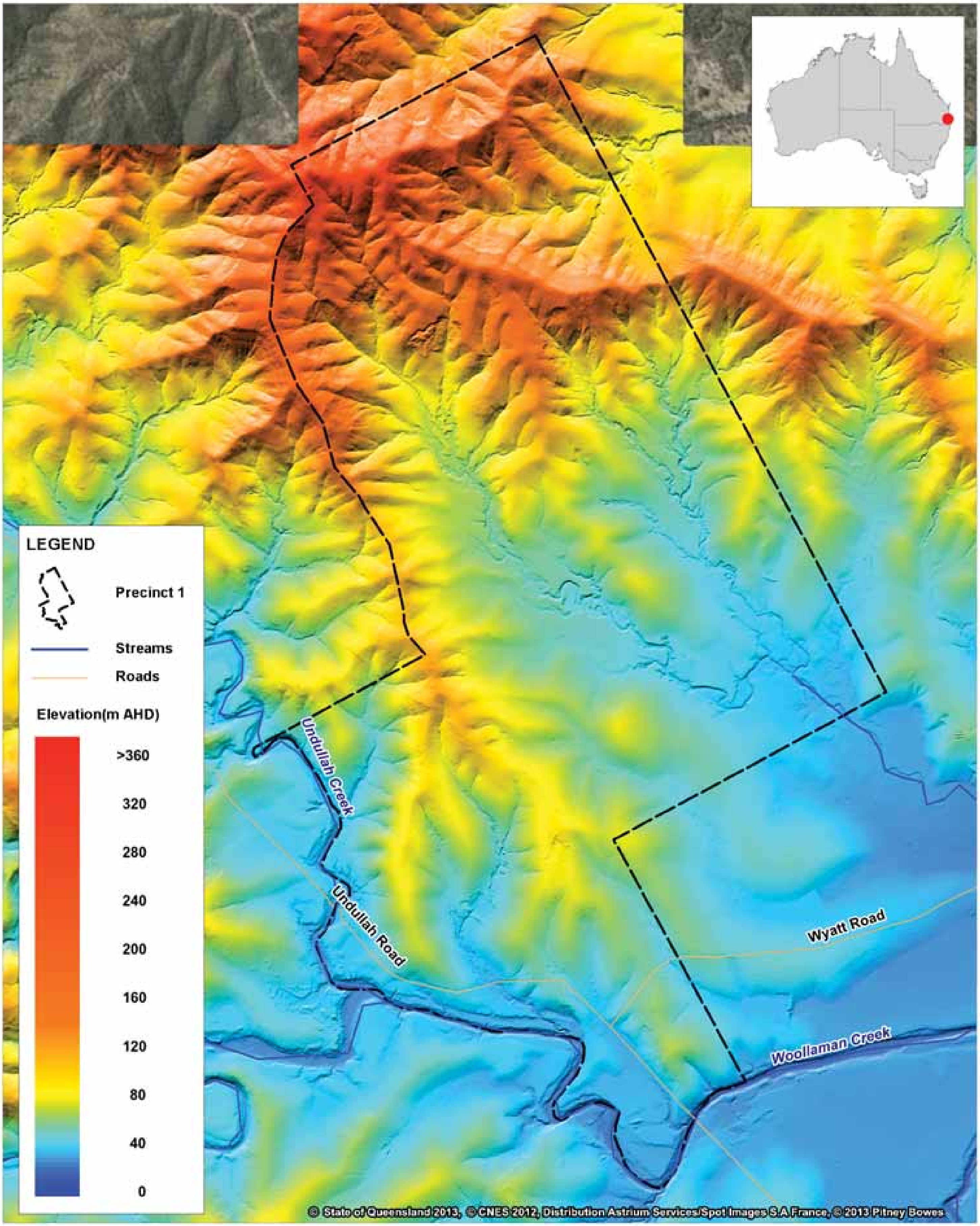
Figure 2-1 Photos of Precinct 1

Examples of 3-5 m deep eroded drainge paths in the upper to mid catchments

Exposed sandstone bedrock in the upper catchment (L) and deposition of eroded material in mid catchment (R)

Example of farm dam

Figure 2-2 Photos Showing Key Drainage Features in the Lake Catchment



Title:
Digital Elevation Model Showing Existing Topography

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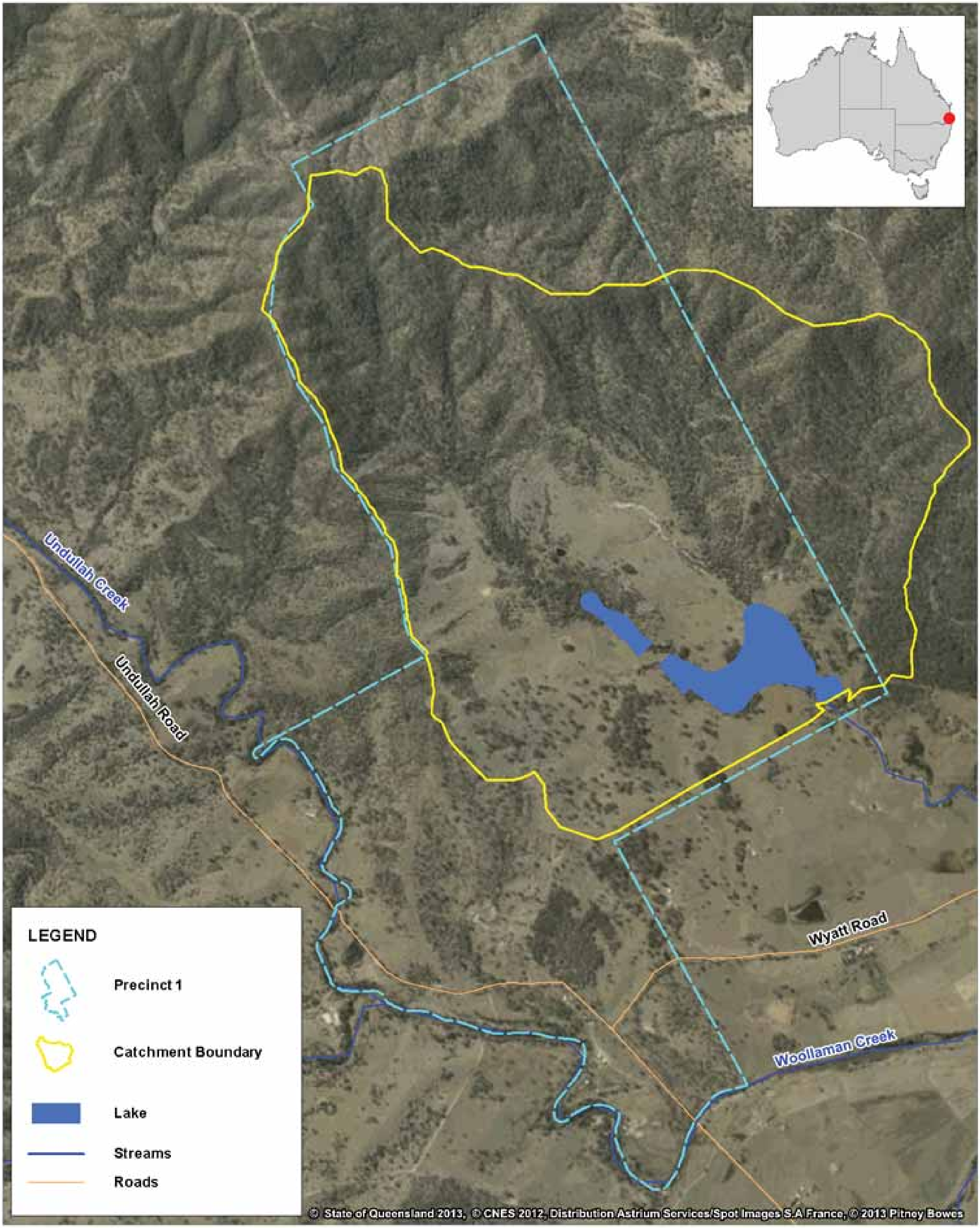

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Proposed Lake and Catchment Boundaries

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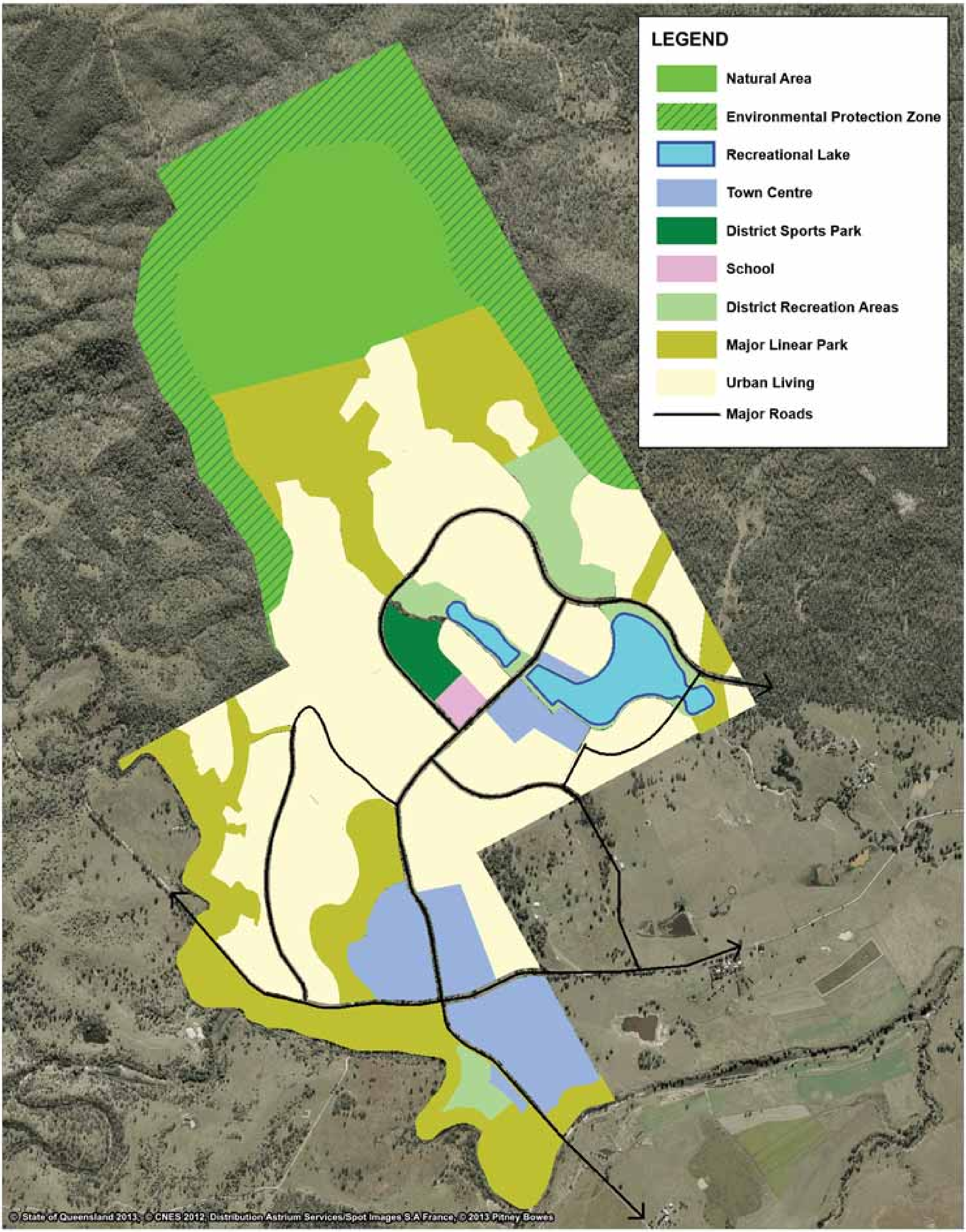
2.5 Proposed Land Use

A proposed land use plan has been developed for the site (Precinct 1) and conceptually for the Balance Land as part of a Section 242 Material Change of Use (MCU) application to LCC. The land use plan for Precinct 1 is shown on Figure 2-5, and proposed land uses for the site include:

- community use area
- conservation area
- environmental protection
- neighbourhood centre
- neighbourhood residential
- public utility
- recreation sports
- riparian corridors
- town centre

The lake is expected to be surrounded by recreation/sports land uses with the neighbourhood centre and a community use area also fronting the lake. Two open space 'spines' will provide the primary pathway for stormwater to drain into the lake. It is expected a series of smaller such spines may also be identified during subsequent planning and design exercises.



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Precinct 1 Proposed Land Use Plan

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3 Lake Intent and Guiding Principles

3.1 Preamble

This section identifies the intent for the proposed lake. A set of guiding principles for the design, construction, establishment and operation of the lake that will augment the realisation of the stated intent are also presented.

3.2 Intent for the Lake

The primary functions of the lake are amenity and secondary contact recreation, including uses such as canoeing, boating and fishing. The lake is intended to provide the following services:

- cultural services
- regulating services
- provisioning services
- supporting services

Identifying these services is important to guide both the design and long-term operation of the lake. The services which the lake is intended to deliver are outlined below. While the below list is provided in no particular order, there is likely to be a strong emphasis on the cultural services in the design and operation of this lake, particularly given its urban context.

Cultural services:

- sense of arrival and sense of place
- high level of amenity and aesthetics
- broad range of recreational opportunities (fishing, boating, walking, cycling etc.)
- cultural experiences such as public artworks and community events
- community stewardship opportunities
- improved community understanding of the local water cycle
- improved community health and well-being
- educational opportunities

Regulating services:

- minimising turbidity, sediments and nutrients discharged from site
- recharge of groundwater downstream of site
- microclimate regulation particularly temperature
- flood detention
- biological processes including growth, reproduction, recruitment, migration and dispersal

Provisioning services:

- potential water supply for construction water, irrigation of open space, and emergency fire-fighting uses
- potential food source (from recreational fishing)

Supporting services:

- water cycling, storage, recycling and reuse
- nutrient and carbon cycling
- biodiversity
- diversity of wetland habitats and urban terrestrial habitat types

3.3 Guiding Principles

Further to the intent listed above, a set of principles for the design, construction, establishment and operation of the lake and surrounding land uses have been drafted. The following principles are intended to also guide development of appropriate performance criteria as presented in Section 4.

(1) The values and services reflected in the design intent are maximised in the design, construction, establishment and operation of the lake.

(2) The design, construction, establishment and operation of the lake ensure that it achieves and continues to achieve the amenity and safety criteria stated in this report.

(3) The design, construction, establishment and operation of the lake ensures that water quality in the lake is likely to achieve the water quality objectives stated in this report. This includes managing lake water quality and adequate pre-treatment of inflows using additional treatment measures integrated throughout the site.

(4) The design, construction, establishment and operation of the lake ensures that lake hydrology (including inflows and outflows) satisfies the design criteria stated in this report. This includes managing lake hydrology, securing adequate top-up sources (where necessary) and managing downstream impacts.

(5) The lake is designed, constructed, established and operated to be resilient, including to adverse climatic conditions (e.g. extended dry periods, major rainfall events).

(6) Ongoing monitoring and adaptive management of the lake are undertaken to ensure the stated intent, principles and performance criteria are being achieved.

(7) Risks are reduced in the design, construction, establishment and operation of the lake.

(8) Planned and responsive maintenance are undertaken in response to the intent, principles and performance criteria stated in this report.

4 Key Issues, Risks and Performance Criteria

4.1 Preamble

This section includes information in relation to the key issues for the potential lake system, including:

- general description of the issue
- identification of key risks associated with the design, construction, establishment and/or operation of the lake
- identification of performance criteria which are to be included in approval conditions aimed at minimising the identified risks
- conceptual design verification

As this plan is not a detailed lake design report, conceptual design verification is only provided where specifically requested by the TOR

4.2 Identification of Issues

The key issues for the potential lake system are anticipated to be as follows:

- General Design, Construction and Establishment of Lake and Stormwater Treatment Devices
- Recreation, Amenity and Aesthetics
- Physical Hazards and Safety
- Lake Ecology
- Treatment of Stormwater Inflows
- Lake Water Quality
- Lake Water Balance
- Lake Residence Time
- Lake Mixing
- Flooding

These issues are described in the following sections.

4.3 General Design, Construction and Establishment of Lake and Stormwater Treatment Devices

This section addresses the general issues associated with the design, construction and establishment of lakes and associated stormwater treatment devices. The key risks associated with the design, construction and establishment processes are outlined below along with criteria which can be refined through ongoing monitoring of the lake.

4.3.1 Risks

Inappropriate design, construction and establishment processes can result in the following common risks:

- limited realisation of the ecosystem services (identified in Section 3.2)

- re-design and development assessment costs (e.g. due to non-compliance with design standards, information requests and approval conditions)
- increased land holding costs (e.g. due to prolonged development assessment timeframes)
- increased construction and establishment costs (including rectification costs, e.g. due to failing to follow appropriate construction and establishment, and certification)
- human health and safety risks
- risks to lake ecology
- increased operational and maintenance issues/costs
- risks to downstream ecological values
- decrease in local property values

4.3.2 Performance criteria

Recommended performance criteria to address potential design, construction, establishment and operational issues are provided in Table 4-1.

Table 4-1 Performance Criteria for General Design, Construction, Establishment of the Lake and Stormwater Treatment Devices

Performance criteria for general design, construction, establishment and operational issues	
Objective	To minimise the risks associated with inappropriate design, construction, establishment, or operation of lake and stormwater treatment devices.
Background	The performance criteria have been based on best practice guidelines as noted below.

Design, Construction and Establishment Performance criteria	• The lake, recreation facilities and surrounding open space areas are designed for multiple purposes that are well-integrated and meet expected recreation needs of the public.
	• Design and operation of stormwater management measures (SMMs, e.g. bioretention basins) follow the guidance provided in best practice guidelines particularly Water by Design (2010a) and Water by Design (2011).
	Design Standards
	• Concept design of the lake and its surrounds is undertaken in accordance with the *Concept Design Guidelines for Water Sensitive Urban Design* (Water by Design, 2010a)
	• Catchment water quality modelling is undertaken in accordance with *the MUSIC Modelling Guidelines* (Water by Design, 2010b)
	• Design of SMMs is undertaken in accordance with the *Water Sensitive Urban Design Technical Design Guidelines* (Healthy Waterways, 2006)
	• Design of bioretention systems is undertaken in accordance with the *Bioretention Technical Design Guidelines* (Water by Design, 2014)
	• Lake design is undertaken with due consideration of the *Waterbody Management Guideline* (Water by Design, 2013) and, in the absence of locally specific guidance, Mackay City Council and Townsville City Council constructed lakes design guidelines.
	• A lake design report is prepared that documents the detailed design investigations and concept detailed designs which reflect these guidelines.
	Construction and Establishment Standards
	• Construction and establishment of vegetated stormwater treatment devices is undertaken in accordance with the *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands* (Water by Design, 2010c). This will need to be adapted for the lake itself and adaptions included on project drawings and reflected in contractor contracts.
	Asset Handover Standards
	• Asset handover of vegetated stormwater assets is undertaken in accordance with the guideline *Transferring Ownership of Vegetated Stormwater Assets* (Water by Design, 2012).
	Civil and Landscape Plans Standards
	• Both civil and landscape plans of SMMs are undertaken in accordance with the standard drawings published by Water by Design/IPWEAQ (2014). Both sets of drawings include detailed advice in accordance with the standard drawings with regard to compliance, asset handover and certification.
	Civil and Landscape Contractors Contracts Standards
	• To ensure all parties are aware of the certification requirements, the tender and contracts with civil and landscape contractors includes:
	  ○ Construction and establishment specifications in accordance with the above standards
	  ○ Preferred construction and establishment method of each bioretention system specifications in accordance with the above standards
	  ○ Sign-off forms with the as-constructed survey and drawing requirements detailed in accordance with the above standards
	  ○ Certification requirements in accordance with the above standards.

4.4 Recreation, Amenity and Aesthetics

The lake is intended to be suitable for secondary contact usage (e.g. paddling activities, wading, boating, fishing, model boat usage), and may not be suitable for primary contact usage (e.g. swimming and water skiing). It will also be an important focal point for the community providing opportunities for passive recreation such as scenic appreciation, picnicking/barbeques, walking/jogging and cycling.

Example photos of constructed lakes in South East Queensland with good amenity are provided in Figure 4-1.

The key risks identified are outlined below along with preliminary performance criteria which can be refined through ongoing monitoring of the use of the lake by residents.

4.4.1 Risks

The *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) introduce the concept of grading waterbodies according to their suitability for recreational use, based on contamination with microorganisms, cyanobacteria or algae and mosquitoes. Each of these stressors presents a number of risks, including (for example):

- limitation to recreational uses of the lake
- human health risks including from:
  - microbial contaminants, e.g.:
    - respiratory infections
    - pathogenic microorganisms, such as viruses, bacteria and protozoa
    - other more serious diseases such as gastroenteritis, hepatitis, giardiasis, cryptosporidiosis, campylobacteriosis, salmonellosis.
  - algae and cyanobacteria, e.g.:
    - irritations to the skin, eye or mucous membranes
    - acute toxicity when ingested or absorbed through the skin.
  - Mosquitoes, e.g.
    - Ross River virus and dengue fever.

Performance criteria for managing microorganisms, cyanobacteria and mosquitoes are provided in Table 4-2, Table 4-3 and Table 4-4 respectively.

These risks are also linked closely with pre-treatment of inflows, lake hydraulic residence time and lake turnover time which are all addressed in detail further below.

Roma Street Parklands, Brisbane
Central Lakes, Caboolture
Cascades, Springfield Lakes
Spring Lake, Springfield Lakes
Willowglen Court, Bunya
Halpine Lake, Mango Hill

Figure 4-1 Examples of Constructed Freshwater Lakes in South East Queensland with Good Amenity

Figure 4-2 Examples of Constructed Lakes with Reduced Values Due to Poor Water Quality

4.4.2 Performance criteria

Recommended performance criteria for microbial water quality and algae are provided in Table 4-2 and Table 4-3 respectively, while mosquito control is addressed in Table 4-4. Other water quality issues are addressed in Section 4.10.

Table 4-2 Microbial Water Quality Performance Criteria

Microbial water quality	
Objective	To minimise risks to human health from microbial contamination – particularly the primary health risks, which come from enteric viruses and protozoa.
Background	The design performance criteria has been based on the *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008), while operational performance criteria are developed based on experience in the management of other lake systems.
Design Performance criteria	• The *Flinders Precinct 1: Concept Lake Management Plan* is revised during detailed design to include an adaptive management strategy for faecal pollution of the lake. • Preventive risk management practices are adopted in the design of the lake and other water cycle infrastructure and systems to minimise risks that the lake would be contaminated with fresh faecal material, particularly of human or domesticated animal origin.
Operational Performance criteria	• Microbial water quality is monitored and managed in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* and an adaptive management strategy for faecal pollution of the lake. • The lake and all sewage infrastructure are managed to maximise compliance with water quality objectives for secondary contact recreation as provided in the *Flinders Precinct 1: Concept Lake Management Plan.*

Table 4-3 Cyanobacteria and Algae Performance Criteria

Cyanobacteria and algae	
Objective	To minimise the risk that cyanobacteria and algae that may multiply to the point of becoming visible (i.e. creating 'algal blooms') or be a health risk to users of the lake (e.g. residents and native fauna).
Background	The design performance criteria have been based on Mackay City Council (2008), while the operational performance criteria have been derived from NHMRC (2008). A single guideline value is not appropriate. Instead, two guideline values have been established, based on known risks associated with known toxins and probability of health effects caused by high levels of cyanobacterial material. According to NHMRC (2008): *The first level recognises the probability of adverse health effects from ingestion of known toxins, in this case based on the toxicity of microcystins. A second guideline level is also required for circumstances where high cell densities or scums of 'nontoxic' cyanobacteria are present — that is, where the cyanobacterial population has been tested and shown not to contain known toxins (microcystin, nodularin, cylindrospermopsin or saxitoxins). Where the microcystin-related biovolume guideline is exceeded and no microcystin or other toxins are present, it is appropriate to issue warnings if either the total biovolume of all cyanobacterial material exceeds 10 mm^3/L or scums are consistently present (i.e. scums are seen at some time each day at the recreational site). Increased cyanobacterial densities increase the likelihood of non-specific adverse health outcomes, principally respiratory, irritation and allergy symptoms.* *Cell counts (and biovolumes) must be regarded as an indicator or 'surrogate' for a potential toxin hazard. The counts should be used to prompt actions, such as toxin monitoring, that are outlined in the alert levels framework described in Section 6.4.2* (of NHMRC (2008).
Design Performance criteria	• The *Flinders Precinct 1: Concept Lake Management Plan* is revised during detailed design to include an Algal Bloom Management Strategy for the lake in accordance with the "Adaptive Management of Algal Bloom Risk" section of Mackay Regional Council (2008). ○ This includes adaptive management guided by a 'situation assessment and alert levels framework' for the management of algae/cyanobacteria which allows for a staged response to the presence and development of blooms. • Preventive risk management practices are adopted in the design of the lake and other water cycle infrastructure and systems to manage causes of algal blooms including: ○ treatment of stormwater inflows (refer to Table 4-7 for detailed criteria) ○ reducing lake residence time through recirculation of lake waters (e.g. through upstream waterways), if appropriate (refer to Table 4-11 for detailed criteria) ○ maximising lake mixing (refer to Table 4-12 for detailed criteria).
Operational Performance criteria	• Cyanobacteria/blue green algae are monitored and managed in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* (refer to B.1 for a preliminary version of the Water Quality and Sediment Monitoring Program). • Performance objectives include the following: Level 1 guideline:[1] ○ ≥10 µg/L total microcystins or ○ ≥50 000 cells/mL toxic *Microcystis aeruginosa* or biovolume equivalent of ≥4 mm^3/L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or[2] Level 2 guideline ○ ≥10 mm^3/L for total biovolume of all cyanobacterial material where known toxins are not present or ○ cyanobacterial scums are consistently present[3]. • The recommended chlorophyll-*a* objective listed in Table C-1 is 30 ug/L. The adaptive management however is to be implemented in the event that elevated chlorophyll-*a* levels are recorded above >10 ug/L in the lake. • In the event of an algal bloom (i.e. phytoplankton cell density as noted above, it will be necessary to formulate a rehabilitation plan for the lake.

[1] In practical terms the biovolume definition component of the Level 1 guideline (i.e. total cyanobacterial biovolume of known toxigenic cyanobacteria >4 mm^3/L) may be used to initially trigger the action mode (red level) before toxicity or toxin analysis is available. If this is the case and the subsequent toxin analysis is negative, the mode may revert to alert mode (amber level) in the biovolume range >0.4 - < 10 mm^3/L. If cell numbers continue to increase, the Level 2 guideline definition applies if either the total biovolume of all cyanobacterial material exceeds 10 mm^3/L or cyanobacterial scums are consistently present.

[2] This applies where high cell densities or scums of 'nontoxic' cyanobacteria are present, i.e. where the cyanobacterial population has been tested and shown not to contain known toxins (microcystin, nodularin, cylindrospermopsin or saxitoxins).

[3] This refers to the situation where scums occur at the recreation site each day when conditions are calm, particularly in the morning. Note that it is not likely that scums are always present and visible when there is a high population, as the cells may mix down with wind and turbulence and then reform later when conditions become stable.

Table 4-4 Mosquito Control Performance Criteria

Mosquito control	
Objective	To minimise the risk of limited recreation opportunities due to mosquitoes.
Background	The design performance criteria have been based on best practice guidelines, while the operational performance criteria have been derived from NHMRC (2008).
Design Performance criteria	• A detailed landscape plan is developed which demonstrates that lake edge habitats are designed which support a healthy and functioning lake ecosystem. ○ This includes submerged native planting and dense (8-12 plants/m^2) macrophyte edge habitats which sustain mosquito predators. • The profile of the lake is configured to ensure that all of the macrophyte zones are connected to the deeper open water zone to allow mosquito predating fish to access the shallow areas. • The bathymetry of the lake is designed such that water draws down evenly so isolated pools are avoided. • The *Flinders Precinct 1: Concept Lake Management Plan* is revised during detailed design to describe the species and quantities of fish to be stocked to aid in mosquito control. Only native fish are permitted using local genetic stock where available. Species should be selected on their local occurrence, mosquito predation potential and recreational fishing potential. NB: not all species selected must satisfy all three criteria.

Operational Performance criteria	• The water should be free from substances and conditions which support mosquitoes including:
	  ○ floating weed and other debris
	  ○ scum and other matter.
	• The lake is stocked with native, mosquito-predating fish species in accordance with the *Flinders Precinct 1: Concept Lake Management Plan*.
	• Mosquitoes are monitored and managed in accordance with the *Flinders Precinct 1: Concept Lake Management Plan*. This includes adaptive management guided by monitoring of mosquito larvae.
	  ○ Mosquito larvae should not exceed 1 larvae per 2 ladle dips (300 mL ladle) on average.
	• Where it does not limit other operational requirements, resident feedback is used to guide the suitability of water for recreational use.

4.5 Physical Hazards and Safety

This section addresses the physical risks to the health and wellbeing of lake users (e.g. through trauma and injury). The key risks identified are outlined below along with preliminary performance criteria which can be refined through ongoing monitoring of the lake. Physical risks associated with water level fluctuation are addressed in Section 4.11, while risks associated with flooding (velocities, volume and depth) are addressed separately in Section 4.14.

4.5.1 Risks

The key risk associated with the lake is that a member of the public, construction or operational staff would suffer death, injury, drowning or near drowning as a result of physical hazards associated with the lake. This risk is most prevalent where:

- the risk of danger is not obvious (e.g. a structure hidden beneath the water)
- the design of the lake increases the likelihood that an incident would occur (e.g. steep batters which increase the likelihood of somebody falling or slipping into the water)
- infrastructure increases the likelihood that an incident would occur (e.g. a stormwater inlet pipe that is un-grated, meaning a person could be swept or pulled into the pipe and drown)

- the ability for somebody to avoid the risk of injury and death as result of design (e.g. steep batters which limit the ability of somebody to readily exit the lake)
- there is a high likelihood of interaction with the open water, particularly by vulnerable members of the community

Interaction with the lake may be either accidental (e.g. falling into water) or deliberate (e.g. canoeing in the lake). For the most part, these risks can be either avoided or mitigated through environmental design, although additional measures are often required (particularly where site constraints are limiting).

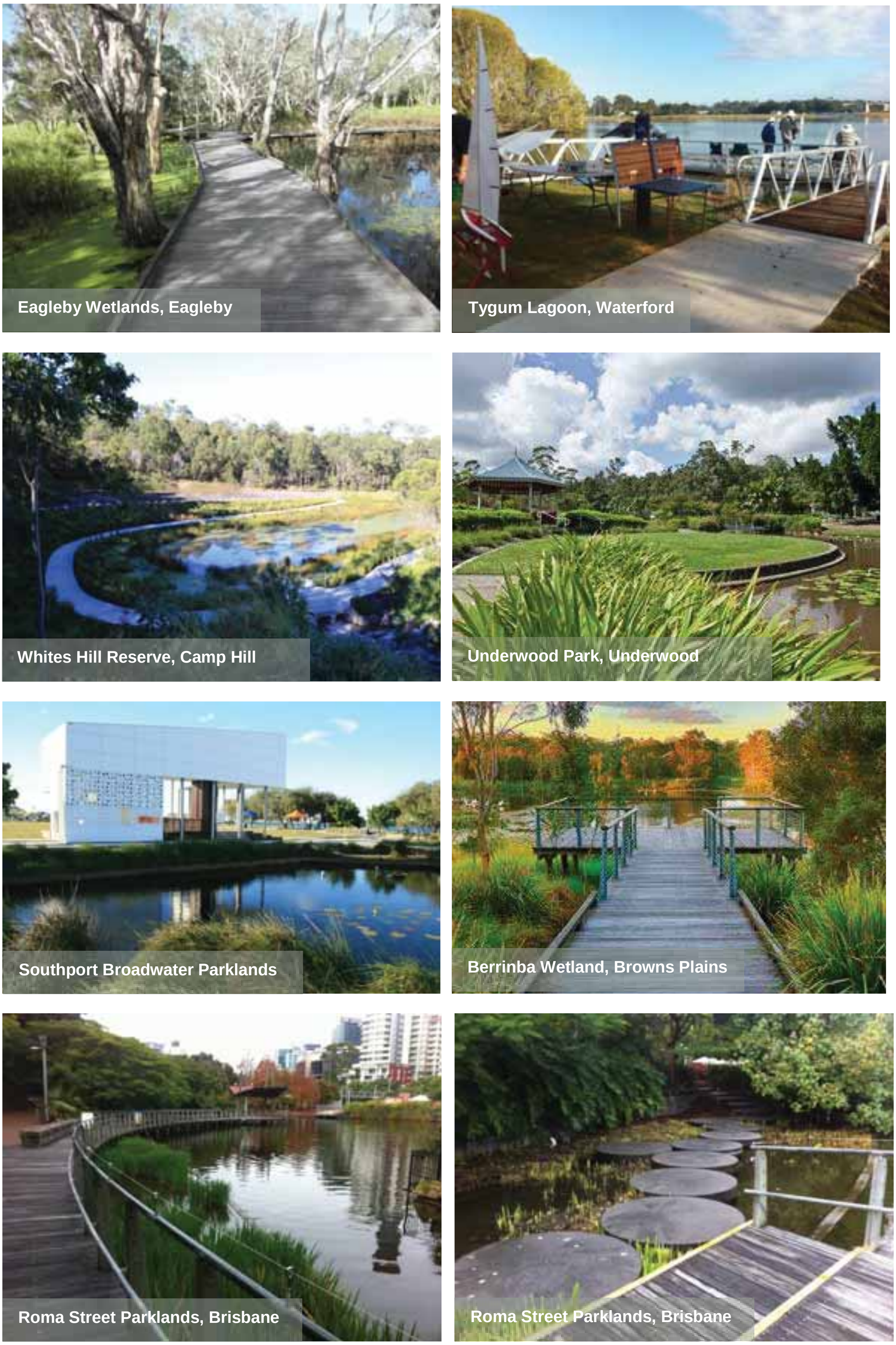

Figure 4-3 Examples of Recreational Infrastructure Near/ Within Lakes and Wetlands in South East Queensland

4.5.2 Performance criteria

Recommended performance criteria for managing risks associated with physical hazards is provided in Table 4-5.

Table 4-5 Physical Hazard and Safety Performance Criteria

Physical hazards and safety	
Objective	To minimise the risk of hazards to lake users due to known or expected physical hazards.
Background	The design performance criteria have been based on best practice guidelines as noted below.
Design Performance criteria	• The design of the lake, recreation facilities and surrounding open space is designed for multiple purposes which are well-integrated using the guidance provided in best practice guidelines particularly Water by Design (2010) and Water by Design (2011). • A *Detailed Lake Design Report* is prepared which documents how these two guidelines have been used to design the lake, including integration with surrounding land uses. • The report includes a 'safety in design assessment' and 'safety risk assessment' with due consideration of guidance provided in the *Queensland Urban Drainage Manual* (QUDM) or equivalent and NHMRC (2008) which suitably assesses: ○ environmental design options (edge treatment, batter slopes, safety ledges, planting) ○ structural design options (e.g. fencing, safety signage, outlet safety screens etc.) ○ non-structural design options (e.g. public education) ○ operational responses. • The safety risk assessment includes input from various design disciplines (including at a minimum: engineering (civil and environmental); environmental science; planning; and landscape architecture) and is certified by a Registered Professional Engineer in Queensland (RPEQ). • Environmental design responses reflect best practice guidance, particularly DesignFlow and RPS (2010) and the standard drawings published by Water by Design/IPWEAQ (2014). • Based on the *Detailed Lake Design Report*, the *Flinders Precinct 1: Concept Lake Management Plan* is revised during detailed design to include detailed operational risk advice.
Operational Performance criteria	The lake and associated infrastructure are maintained to the same risk level as nominated in the *Detailed Lake Design Report* which should be based on a 'safety in design assessment' and 'safety risk assessment' (to be prepared).

4.6 Lake Ecology

This section addresses the physical risks to the health of the lake ecology due to biological factors. Healthy lake ecology is essential in order to maintain good water quality and protect recreation, amenity and aesthetic values. The key risks to lake ecology are outlined below along with appropriate performance criteria. Risks associated with the chemical factors of water quality which impact lake ecology are addressed separately in Sections 4.8, 4.9 and 4.10, while lake hydrologic impacts to lake ecology are addressed in Sections 4.11, 4.12 and 4.13.

4.6.1 Risks

The risks associated with poor lake ecology are closely related to the risks associated with recreation, amenity and aesthetics (identified in Section 4.4.1). Specifically, a decline in lake ecology is typically associated with a decline in recreation, amenity and aesthetic values. Poor lake ecology can also have a direct impact on lake water quality, which results in further decline in lake ecology in an ongoing negative feedback loop. Risks of poor lake ecology (including lake edge habitat and aquatic habitat) include:

- disease and mortality in native and desirable species
- proliferation of undesirable aquatic life and pest species (e.g. mosquitoes, pest fish species and floating and submerged weeds)
- poor water quality (e.g. introduction of carp species which increase resuspension of sediments and subsequently reduces oxygen levels in lake waters)
- loss or decline in amenity and aesthetics due to poor water quality including surface scums, algal blooms and odours
- reduced recreational values due to poor water quality and/or change in species compositions (e.g. loss of recreational fishing potential)
- downstream ecological impacts (e.g. spread of pest fish species)

Figure 4-5 provides examples of both good lake edge habitat and poor lake edge habitat.

Figure 4-4 Examples of Good Lake Edge Habitat

Figure 4-5 Examples of Poor Lake Edge Habitat

4.6.2 Performance criteria

Recommended performance criteria for managing risks associated with lake ecology is provided in Table 4-6. It should be noted that lake ecology is a function of a range of factors, including (for example) inflow water quality and lake residence time. Appropriate criteria for related matters are provided in the respective tables throughout Section 4, and are not therefore repeated here.

Table 4-6 Lake Ecology Performance Criteria

Physical hazards and safety	
Objective	The lake is designed and managed to support a healthy aquatic habitat for the life of the lake.
Background	The design performance criteria have been based on Water by Design (2012a) and professional experience with urban water bodies.
Design, Construction and Establishment Performance criteria	• A detailed landscape plan is developed which demonstrates that habitat zones are created for a broad range of native aquatic species. These zones may include: ○ densely planted submerged and emergent native macrophyte beds ○ maximising the lake edge planting including submerged, emergent and terrestrial native plant species ○ recycling of tree trunks, root balls and rock as submerged/emergent habitat features ○ a range of substrate types in habitat zones which match stocked fish species biological needs. • Plants in aquatic habitat zones are established using appropriate lake water level control over a 12 month period. • Design of habitat zones is commensurate with expected recreation activities and facilities (e.g. does not clash with boat launching facilities). • Design of habitat zones is commensurate with expected maintenance activities and facilities (e.g. does not clash with sediment clean out zones). • The lake is stocked with locally native fish and crustacean species in consultation with the primary industries and environment state departments including: ○ using only locally occurring genetic stock (where available) ○ species selected on a combination of their local occurrence, mosquito predation potential and recreational fishing potential. Note: not all species selected must satisfy all three criteria ○ stocking occurs only once habitat zones are established and water chemistry is suitable. • A *Detailed Lake Design Report* is prepared during detailed design which documents how each of the above criteria have been integrated with the lake. • The *Flinders Precinct 1: Concept Lake Management Plan* is revised during detailed design to describe the species and quantities of fish to be stocked. Only native fish are permitted using local genetic stock where available. Species should be selected on their local occurrence, mosquito predation potential and recreational fishing potential. Note: not all species selected must satisfy all three criteria.
Operational Performance criteria	Lake ecology is managed in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* and standards current at the time including the guideline *Maintaining Vegetated Stormwater Assets* (Water by Design, 2012b) or equivalent.

4.7 Climate Resilience

This section addresses key considerations with respect to the functioning of the lake in response to climate change and how to build resilience into the design so as to minimise risks. The key risks identified are outlined below along with preliminary performance criteria which can be refined through ongoing monitoring of the lake.

4.7.1 Risks

A changing climate is expected to affect the lake through various mechanisms which may include (based on Queensland Climate Change Centre of Excellence, 2010).

- reduction in the total number of wet days but increased frequency of large rainfall events and lower total annual rainfall
- higher temperatures; extended periods of high temperature; more frequent hot days and warm nights; less frequent cold days and nights
- higher frequency of prolonged droughts

The impacts of these changes on the lake may include (for example) the following risks:

- reduced overall inflow volumes (or extended 'drought periods') and increased evaporation/evapotranspiration from the lake could result in lower lake turnover frequency (potentially leading to issues with cyanobacterial algae), lower water levels and increased water level variation
- changes in pollutant loads from the catchment into the lake could result in increased risk of cyanobacterial algal blooms and other water quality problems
- higher velocities and increased risks of damage from flooding and erosion
- reduced likelihood of availability of top-up water from other potential water sources (e.g. groundwater)
- risks to lake ecology including for example plant die off/disease, more favourable conditions for pest species, fish kills and loss of fauna habitat

4.7.2 Performance criteria

With the exception of flood modelling (addressed separately in Section 4.14), there are currently no standards or tools available which allow full consideration of potential impacts noted above. The key knowledge gap is a lack of available data on expected rainfall and evaporation rates.

Therefore, while it is important to recognise risks and consider potential impacts when designing the lake, performance criteria for managing climate change risks have not been specified. The resilience of the lake to changes in catchment inflows (that could be impacted by climate change) is discussed further in Section 4.11.3.2.

It is expected that managing climate change impacts on the ecology of the lake could be undertaken through normal operating procedures. For example, if a particular weed species is favoured due to changes in water temperature, this would most likely be addressed through normal weed management practices.

4.8 Treatment of Stormwater Inflows

This section addresses the key issues associated with water quality in the lake as it relates to the quality of stormwater inflows. The lake system will be considered as a 'receiving waterbody' and as such, will require stormwater inflows to be treated prior to discharge into the lake.

It is anticipated that the preferred stormwater quality management strategy for the operational phase will involve a range of design responses. The preliminary concept 'treatment train' has been summarised in Figure 4-6. This strategy will likely rely primarily on the integration of bioretention basins into open space areas (immediately downstream of development areas). Examples of bioretention basins are provided in Figure 4-7.

Bioretention basins have been selected due to the following reasons:

- bioretention basins currently provide the greatest treatment per unit area compared to other best practice treatment measures
- bioretention basins are expected to be the most cost effective solution (i.e. lowest cost per unit of stormwater pollutant removed relative to other typical stormwater treatment devices)
- bioretention basins can provide a range of other benefits consistent with the ecosystem services (identified in Section 3.2 above)
- steep topography limits opportunities for 'at source' treatment (e.g. 'at source' bioretention systems)
- a lack of large flat open land limits opportunities for stormwater treatment wetlands (it should be noted that a range of wetland habitats are expected to be created within the lake to provide similar benefits to wetlands).

In addition to the integration of bioretention systems downstream of development areas, it will be important to identify potential pollutant loads from areas that are to remain undeveloped and areas external to the site. This will be undertaken through the proposed pre-development baseline water quality monitoring program (refer to Appendix C) with an appropriate strategy to mitigate any potential issues to be developed as required.

In accordance with the TOR, stormwater quality modelling and other investigations will be completed as part of subsequent reporting to confirm whether the performance criteria identified in Table 4-7 can be achieved in the long term. While it is acknowledged that compliance with best practice load-based pollutant reduction targets alone (as identified in Table 4-7) may be insufficient to achieve a healthy lake environment, a number of other actions are being investigated to manage stormwater runoff and lake water quality as detailed in Figure 4-6.

During the construction phase, it is expected that sediment will be managed through a combination of best management practices including high-efficiency sediment basins.

The key risks identified are outlined below along with preliminary performance criteria which can be refined through ongoing monitoring of the lake.

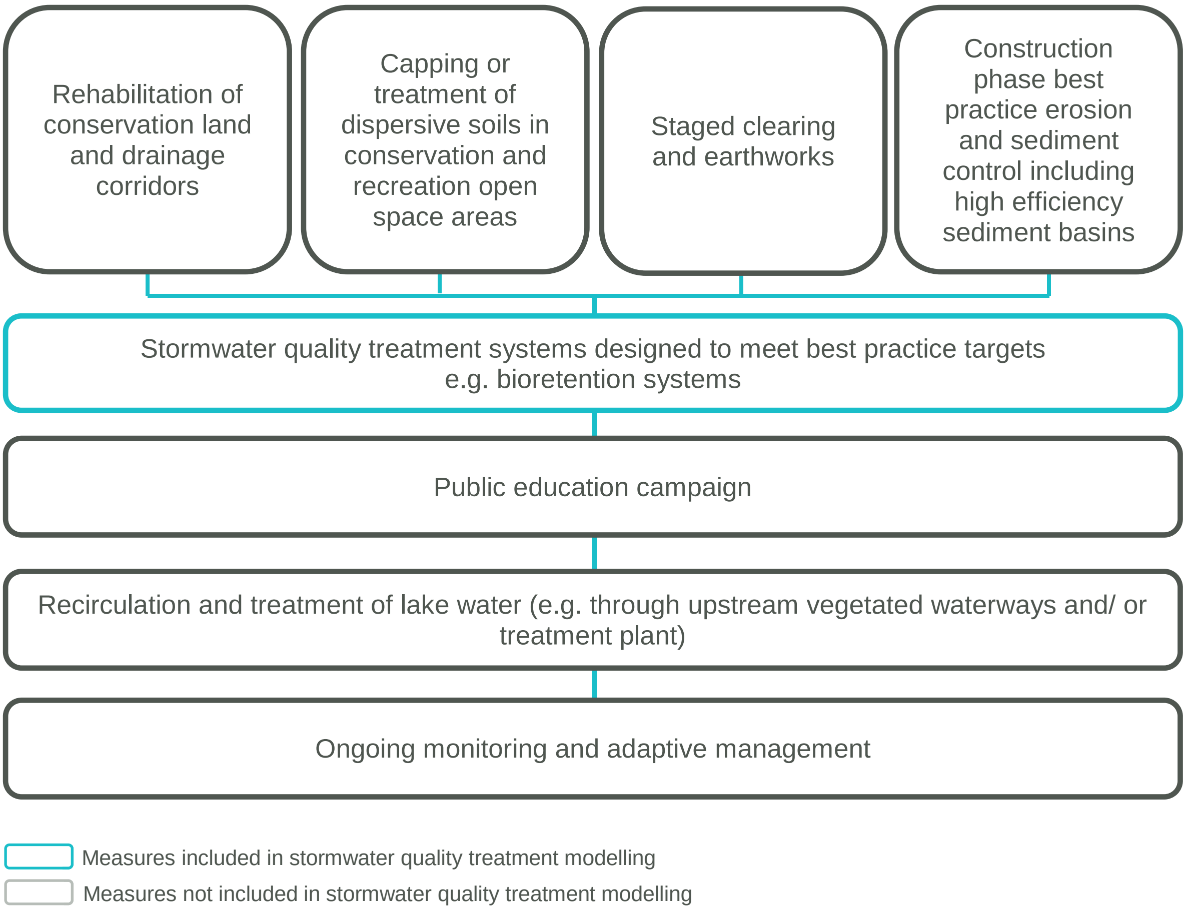

Figure 4-6 Stormwater Quality 'Treatment Train' (and Additional Water Quality Management Actions)

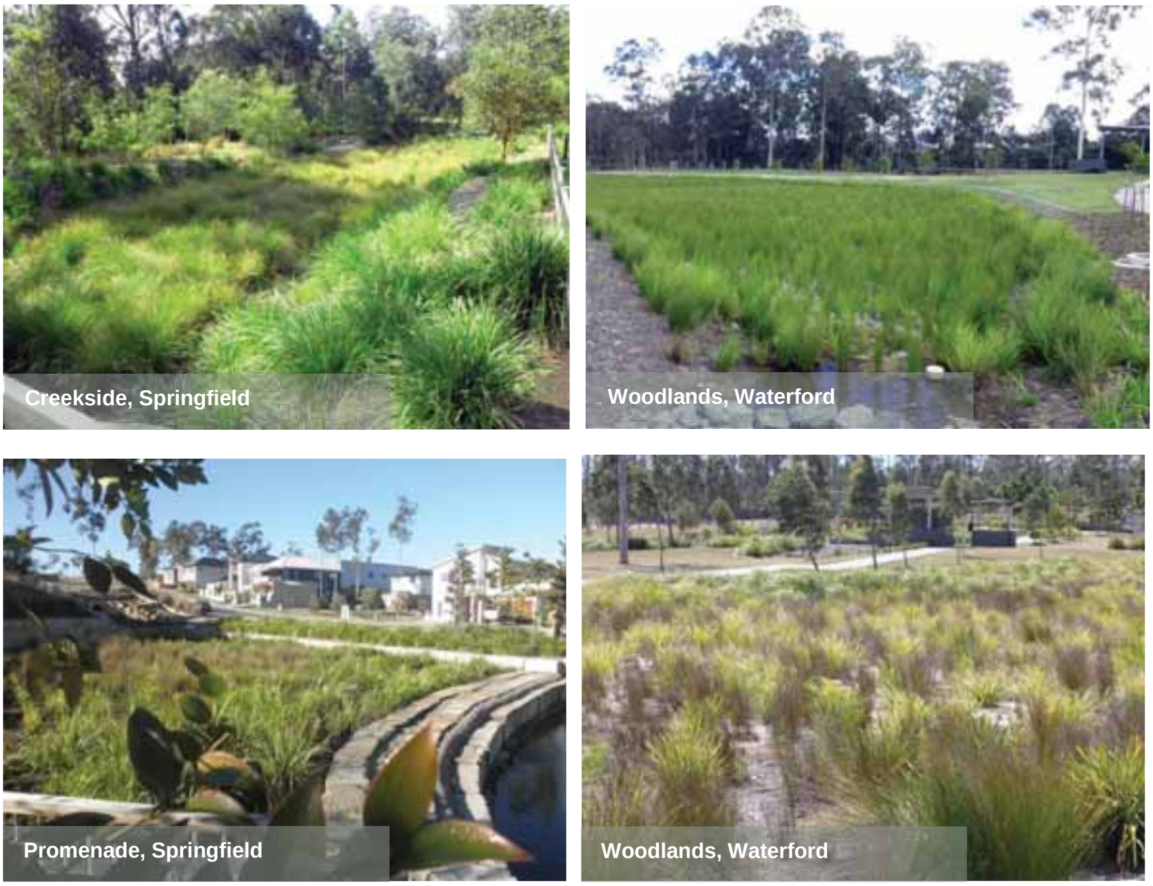

Figure 4-7 Examples of Bioretention Basin (Raingardens)

4.8.1 Risks

Treatment of stormwater flows into the lake is essential in order to mitigate the following potential risks:

- reduced recreation uses and amenity associated with poor lake water quality
- resident complaints associated with poor lake water quality
- human health risks
- risks to lake ecology
- higher operational costs associated with reduced lake water quality
- risks to downstream ecological values
- decrease in local property values.

4.8.2 Performance criteria

Recommended performance criteria for managing risks associated with treatment of stormwater inflows is provided in Table 4-7.

Table 4-7 Treatment of Stormwater Inflows Performance Criteria

<table>
<tr><th colspan="2">Pre-treatment of inflows</th></tr>
<tr><td>Objective</td><td>To minimise the risk of poor lake water quality due to poor inflow water quality.</td></tr>
<tr><td>Background</td><td>The design performance criteria have been based on best practice guidelines as noted below.</td></tr>
<tr><td rowspan="4">Design, Construction and Establishment Performance criteria</td><td>Standards Performance Criteria
• Compliance with the following criteria:
○ design standards performance criteria
○ construction and establishment standards performance criteria
○ asset handover standards performance criteria
○ civil and landscape plans standards performance criteria
○ civil and landscape contractors contracts standards performance criteria.</td></tr>
<tr><td>Design Phase Water Quality Performance Criteria
• A Detailed Lake Design Report is prepared during detailed design which documents how each of the criteria in this table have/will be met. Note: only conceptual information is required for the construction phase in this report with further detail to be prepared during the reconfiguration of lot and operational works applications.</td></tr>
<tr><td>Operational Phase Water Quality Performance Criteria
• The following average annual pollutant reduction targets are achieved for all developed areas (comparing the post development unmitigated to the post development mitigated scenarios):
○ 80% reduction in total suspended solids (TSS)
○ 60% reduction in total phosphorus (TP)
○ 45% reduction in total nitrogen (TN)
○ 90% Gross pollutants >5 mm
• Identification and appropriate management of potential pollutant loads from areas that are to remain undeveloped and areas external to the site.</td></tr>
<tr><td>Construction Phase Stormwater Runoff Performance Criteria
• All existing areas of the catchment which are currently cleared, eroded and/or which feature dispersive soils are stabilised including for example through:
○ development of land
○ rehabilitation and stabilisation of conservation land use and drainage corridors
○ capping or treatment of dispersive soils in recreation open space areas.
• Compliance with the construction phase performance criteria in the following table:
<table>
<tr><th>Issue</th><th>Construction Phase Performance Criteria</th></tr>
<tr><td>Drainage control</td><td>1. Design life and design storm of temporary drainage works:
• Disturbed area open for <12 months—1 in 2yr ARI.
• Disturbed area open for 12-24 months—1 in 5yr ARI.
• Disturbed area open for > 24 months—1 in 10yr ARI.
2. Design capacity excludes minimum 150 mm freeboard
3. Temporary culvert crossing—minimum 1 in 1yr ARI hydraulic capacity</td></tr>
<tr><td>Erosion control</td><td>1. Minimise exposure of disturbed soils at any time
2. Divert water run-off from undisturbed areas around disturbed areas
3. Avoid or minimise large construction activities in the wet season
4. Use erosion risk ratings to determine appropriate erosion control measures.
5. Implement erosion control methods corresponding to identified erosion risk rating</td></tr>
</table></td></tr>
</table>

Pre-treatment of inflows		
		6. Prepare a staged earthworks and clearing plan which minimises (as much as considered reasonable and practical) the extent and duration of active areas (those areas subject to operational works)
	Sediment control	1. Determine appropriate sediment control measures using: • potential soil loss rate, or • monthly erosivity, or • average monthly rainfall 2. Collect and drain stormwater from disturbed soils to sediment basin for design storm event: • design storm for sediment basin sizing is 80th percentile five-day event or similar 3. Site discharge during sediment basin dewatering: • TSS < 50 mg/L TSS, and • Turbidity not >10% receiving waters turbidity, and • pH 6.5–8.5
	Water quality	1. Avoid wind-blown litter; remove gross pollutants 2. Ensure there is no visible oil or grease sheen on released waters 3. Dispose of waste containing contaminants at authorised facilities
	Waterway stability and flood flow management	Take all reasonable and practicable measures to minimise changes to the natural waterway hydraulics and hydrology from:- • Peak flow for the 1-year and 100-year ARI event (respectively for aquatic habitat and flood protection). • Run-off frequency and volumes entering receiving waters. • Uncontrolled release of contaminated stormwater.
Operational Performance criteria	The stormwater treatment measures are maintained in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* and standards current at the time, including the guideline *Maintaining Vegetated Stormwater Assets* (Water by Design, 2012b) or equivalent.	

4.9 Sedimentation

The transport of sediment through the catchment is a natural process. The construction of the proposed lake will, however, cause some sediment loads to be retained within the lake. Excessive sediment accumulation can have a number of undesirable impacts including high turbidity and reduced hydraulic capacity of structures (e.g. inlets, outlet).

The key risks associated with sedimentation are identified below along with conceptual performance criteria aimed at managing sedimentation. Additionally, discussion about the pre-treatment of inflows is provided in Section 4.8.

4.9.1 Risks

The key risk associated with sedimentation are the same as the water quality risks already identified in Section 4.8.1 and are therefore not repeated here. Photos showing excessive sedimentation and turbidity in waterbodies are provided in Figure 4-8.

Figure 4-8 Examples of Excessive Sediment Accumulation and High Turbidity in Waterbodies

4.9.2 Performance criteria

Recommended performance criteria for managing excessive sedimentation are provided in Table 4-8. Additional criteria including further investigation into existing soils which will inform the management of sediment are provided in Table 4-10.

Table 4-8 Sedimentation Performance Criteria

Sedimentation	
Objective	To minimise risks associated with excessive sediment accumulation in the lake.
Background	The design performance criteria have been based on Mackay City Council (2008).
Design and Construction Performance criteria	**Design Performance Criteria** • Refer to the 'Standards performance criteria' and the 'Operational phase water quality performance criteria' identified in Table 4-7. • Refer to the 'Soil and groundwater investigations' identified in Table 4-10. • Following completion of the soil and groundwater investigations and subsequent revised inflow water quality modelling, the *Flinders Precinct 1: Concept Lake Management Plan* and/or the *Detailed Design Report* are revised to account for likely sediment loads in terms of design and operation of the lake. • The detailed *Water Quality and Sediment Monitoring Program* (refer to Appendix C for a preliminary version of this program), clearly explains how the program should be reflected in the construction environmental management planning (particularly the erosion and sediment plan/drawings). **Construction Performance Criteria** • Refer to the 'Construction Phase Stormwater Runoff Performance Criteria' identified in Table 4-7. • Monitoring and responsive actions are undertaken in accordance with the Lake Management plan documented in the *Flinders Precinct 1: Concept Lake Management Plan.*
Operational Performance criteria	Sediment removal is regulated in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* and standards current at the time including the guideline *Maintaining Vegetated Stormwater Assets* (Water by Design, 2012b) or equivalent.

4.9.3 Conceptual design verification

4.9.3.1 Operational phase

The rate of sedimentation during the operational phase has been calculated (partly in response to the 'rate of sedimentation' item within the TOR). To determine the sedimentation rate (for the operational phase of the development), the following methodology was used:

- The average annual input of total suspended sediments (kg/year) from stormwater runoff (during the operational phase of the development) into the lake was calculated using the MUSIC software package (Version 6.1) developed by the CRC for Catchment Hydrology and now supported by eWater. This was calculated to be 72.2 tonnes/year.
- The weight of sediment was converted to an annual volume of sediment (m^3/year) assuming settlement of all incoming total suspended sediment and using a typical *in situ* sand/silt density of 1.0 tonnes/m^3. Average annual sediment volume input to the lake is estimated to be 72.2 m^3/year.
- The average annual increase in depth across the bottom of the lake was calculated, assuming a lake bottom surface area of 33.6 hectares and even distribution of sediments across the lake.

The results of the above analysis are presented in Figure 4-9.

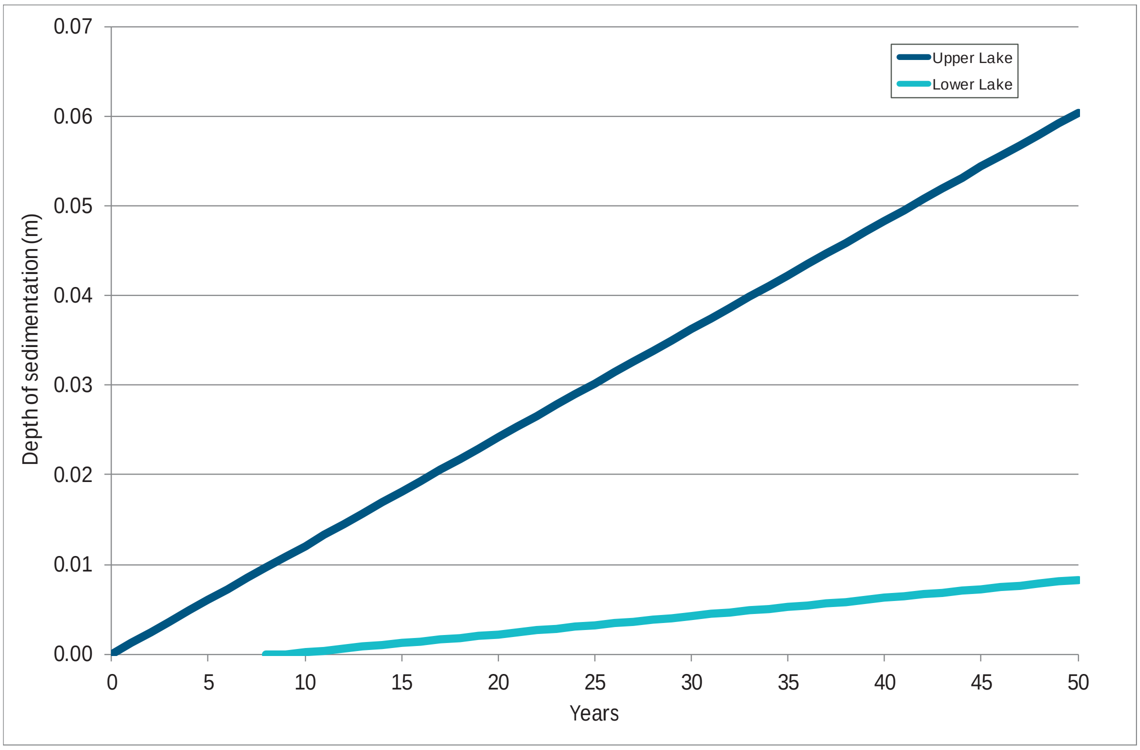

Figure 4-9 Estimated sedimentation rates of the lakes (during development operational phase)

As demonstrated in the above figure, the rate of sedimentation in the lakes (during the operational phase of the development) is predicted to be minimal, with an approximate depth of accumulated sediment calculated to be approximately 0.06 m (or 6cm) in the upper lake and 0.01m (or 1cm) in the lower lake over a period of fifty (50) years.

4.9.3.2 Construction phase

The rate of sedimentation during the construction phase of the development has been calculated based on the following assumptions:

- Total suspended solid (TSS) loads from unmitigated construction sites: 31.2 tonnes/ha/year (Weber et al., 2014)
- Estimated area of disturbance upstream of the lake: 145 hectares in the upper lake catchment and 150 hectares in the lower lake catchment
- Timeframe of exposure: 2 years
- Sediment removal rates using high efficiency sediment basins: 92-99.9% (Auckland Regional Council, 2004). For the purposes of this study it was assumed to be 92%.
- The average annual increase in depth across the bottom of the lake was calculated, assuming a lake bottom surface area of 33.6 hectares and even distribution of sediments across the lake.

Based on the above assumptions, it was estimated that there would be a total of 1,475 tonnes of sediment generated over the construction period of the Flinders development. This equates to an approximate depth of accumulated sediment of 1.96cm in the upper lake and 0.34cm in the lower lake.

4.10 Lake Water Quality

Lake water quality will be primarily driven by the quality of stormwater inflow water quality (addressed in Section 4.8 above) and the quality of the proposed 'top up' water source. The water required for the temporary 'top up' has been acquired through the purchase of Medium Priority (MP) allocations for use in the TVBSB zone of the Logan Basin (from Wyaralong Dam via diversion from Teviot Brook).

As the quality of water from Wyaralong Dam is currently unknown, developing appropriate performance criteria for lake filling/top up water will be subject to further investigations. Similarly, downstream water quality is unknown and receiving water quality monitoring will be essential to develop appropriate performance criteria.

Organic Carbon Loads

Organic carbon is a major contributor of poor water quality within lakes. A significant portion of carbon entering lake systems can come from floating aquatic vegetation growing within the lakes. When this organic carbon decomposes, available oxygen within the lake can be significantly depleted. Furthermore, organic material on the lake beds can release significant nutrient supplies to the water column, contributing to algal blooms.

To minimise the accumulation of organic carbon and the release of nutrients from lake sediments, floating plants must be avoided within the potential lake systems and submerged plants and/or emergent plants encouraged.

Lake Discharge Water Quality

Lake discharges are likely to occur following high flows (when the lake is full and overtopping). Discharges may also occur (albeit rarely) in controlled scenarios.

Controlling the water quality of discharges is critical to protect downstream receiving environments. For example, discharges from water storages can impact critical waterway biological processes such as fish breeding which is regulated by temperature. Discharge criteria should therefore include consideration of potential water quality impacts on receiving waterways.

4.10.1 Risks

The key risk associated with lake water quality reflect the water quality risks already identified in Section 4.8.1 and are therefore not repeated in this section. Examples of poor lake water quality are provided in Figure 4-10.

Byron Lake, Suffolk Park
Coomera Waters, Gold Coast
Pacific Pines, Gold Coast
Moreton Bay Regional Council
Unnamed pond, Gold Coast
Unnamed lake, Gold Coast
Bowies Flat, Coorparoo
Riverstone Lake, Gladstone

Figure 4-10 Examples of Poor Lake Water Quality

4.10.2 Performance criteria

Recommended performance criteria for lake water quality are provided in Table 4-9.

Table 4-9 Lake Water Quality Performance Criteria

<table>
<tr><th colspan="2">Lake Water Quality</th></tr>
<tr><td>Objective</td><td>To minimise risks associated with poor lake water quality.</td></tr>
<tr><td>Background</td><td>The design performance criteria have been based on ANZECC (2000), DERM (2009) and Mackay City Council (2008).</td></tr>
<tr><td>Design and Operation and Construction Performance criteria</td><td>• Refer to the microbial water quality criteria (Table 4-2)
• Refer to the cyanobacteria and algae performance criteria (Table 4-3)
• Refer to the inflow stormwater quality criteria (Table 4-7)
• Water quality monitoring and responsive management are undertaken in accordance with the Water Quality and Sediment Monitoring Program (see B.1 for a preliminary version of this plan) to ensure protection of downstream receiving ecological values.
• The water quality criteria recommended in Water Quality and Sediment Monitoring Program (see B.1 for a preliminary version of this plan), are revised to ensure that objectives are achievable in the long term and that they protect downstream receiving ecological values.
• The Water Quality and Sediment Monitoring Program is undertaken to establish:
  ○ downstream water quality objectives (with due consideration of objectives scheduled under the Environmental Protection (Water) Policy (2009)).
  ○ appropriate lake filling and top-up water quality criteria (e.g. for groundwater, diversion from Wyaralong Dam/Teviot Brook etc.)
  ○ appropriate discharge water quality criteria from the lake to receiving environments which ensure protection of downstream ecological values.
• A detailed landscape plan is developed which demonstrates that all floating plant species are avoided in the landscape design and emergent macrophytes within the lake edge macrophyte zone are maximised (planted at 8-12 plants/m^2) to minimise organic carbon loads.
• Concept design drawings and detailed design drawings are prepared which demonstrate that the lake outlet controls are designed so that controlled discharges can occur from the top of the lake surface at any time in order to minimise downstream temperature changes.
• Monitoring and responsive actions are undertaken in accordance with the Water Quality and Sediment Monitoring Program documented in the Flinders Precinct 1: Concept Lake Management Plan.</td></tr>
<tr><td>Operational Performance criteria</td><td>• The lake water quality is regulated and monitored in accordance with the Flinders Precinct 1: Concept Lake Management Plan and standards current at the time including the guideline Maintaining Vegetated Stormwater Assets (Water by Design, 2012b) or equivalent. This includes monitoring and managing filling/top-up water and lake discharge water quality.
• Controlled discharges do not result in downstream temperature changes of greater than 2° Celsius except in emergency situations.</td></tr>
</table>

4.11 Lake Water Balance

This section provides a preliminary assessment of the predicted water balance of the lake, including an analysis of lake water level variation.

The key risks associated with changes in water level are also identified below along with preliminary performance criteria which can be refined through ongoing monitoring of the lake.

4.11.1 Risks

Frequent or extended periods of low water levels (e.g. due to extended periods of limited rainfall) could result in the following potential risks:

- health and safety hazards (e.g. unsafe lake edge conditions)
- limited recreation uses (e.g. pontoons, jetties and boat ramps without direct connection to standing water)
- decline in amenity and aesthetics associated with dry edges and possible odours from sediments
- complaints from the public
- risks to lake biological processes and ecology (e.g. drying and death of edge planting)
- high operational costs associated with reliance on top-up water
- decrease in local property values
- reduced opportunities to extract lake water for reuse (e.g. open space irrigation)
- poor water quality due to resuspension of exposed benthic sediments as water levels fluctuate.

4.11.2 Performance criteria

Recommended performance criteria for managing risks associated with lake water balance is provided in Table 4-10.

Table 4-10 Water Balance Performance Criteria

Water Balance	
Objective	To minimise the risk of hazards associated within inappropriate lake water balance.
Background	As there are no accepted design performance criteria for lakes in South-East Queensland, reference is made to the *Engineering Design Guidelines: Constructed Lakes – Planning Policy No. 15.15* (Mackay City Council, 2008). The lake water balance performance criteria from this guideline are considered appropriate in managing risks regardless of geographic and climatic variations. Groundwater monitoring performance criteria have been included in this table to ensure the correct investigations are undertaken so that a reliable data set is collected with regard to groundwater inflow and exfiltration. Given that water balance modelling is highly sensitive to groundwater movement, this will be critical knowledge for subsequent detailed water balance modelling.
Design Performance criteria	**General Lake Water Balance Performance Criteria** • A temporary source of water is identified for lake filling and top up (as required) prior to construction of the lake. **Soil and Groundwater Investigation Performance Criteria** • To confirm the site's capability to support a permanent waterbody, a 'Site and Soil Evaluation' is undertaken in accordance with AS/NZS 1547:2000 Clause 4.1.3. The evaluation provides the following: ○ Soil type ○ Hydraulic conductivity (must be measured in accordance with AS/NZS 1547:2000 Appendix 4.1F) ○ Dispersivity ○ Presence of rock shale ○ Slope of terrain (%) ○ Groundwater details (depth, quality and values). • Further appropriate groundwater monitoring will be undertaken if necessary as part of the *Detailed Lake Design Report*. **Design Criteria** • Following completion of the soil and groundwater investigations, the *Flinders Precinct 1: Concept Lake Management Plan* is revised if necessary. • A *Detailed Lake Design Report* is prepared during detailed design which documents the detailed water balance modelling methodology, results and design responses. • Limit the periodic (yearly) water level variation to 0.3-0.4 m below normal water level. • Limit infrequent (1 in 5 years or less frequent) water level variation to 0.5 m below the normal water level. • Ensure severe water level drawdown (i.e. >0.5 m below normal water level) does not occur more than once every 20 years (on average).
Construction, Establishment and Operational Performance criteria	The lake water level is regulated in accordance *with Flinders Precinct 1: Concept Lake Management Plan* and standards current at the time including the guideline *Maintaining Vegetated Stormwater Assets* (Water by Design, 2012b) or equivalent.

4.11.3 Conceptual design verification

A customised spreadsheet-based water balance model has been developed for the potential lake to provide an understanding of anticipated water inputs and outputs (including inputs from stormwater and outputs due to seepage and evaporation) and water level variation. The model has also been used to assess water residence (or lake 'turnover') times with comparisons to recommended guideline values for lakes (see Section 4.12.3 for the residence time assessment).

Appendix E describes the applied methodology and results for the water balance modelling. In summary:

- The majority of water inputs to the lake are predicted to be from catchment flows.
- For developed catchment conditions (with the proposed development of the site), the predicted water level variation for the proposed lake achieves the performance criteria given in Table 4-10 with no additional 'top-up' from any source (and assuming a seepage rate of 0.8mm/day).
- Prior to the proposed development of the contributing catchment (to the proposed lake), additional (albeit temporary) sources of water (of appropriate quality) are anticipated to be required to prevent unacceptable water level variation. Assuming a seepage rate of 0.8mm/day, an average 'top-up' of 500m^3/day would be required under existing catchment conditions to achieve an acceptable water level variation. This required 'top-up' volume would reduce as the catchment is developed. Section 4.11.3.1 provides further information in relation to temporary sources of 'top-up' water to the lake.

4.11.3.1 Additional 'Top-Up' Water

As outlined above, prior to the proposed development of the catchment contributing to the lake, additional (albeit temporary) sources of water (of appropriate quality) are anticipated to be required to prevent unacceptable water level variation. The water required for the temporary 'top up' has been acquired through the purchase of Medium Priority (MP) allocations for use in the TVBSB zone of the Logan Basin.

The water balance modelling (see Appendix E) indicates that for existing catchment conditions, the predicted required annual average top-up water significantly varies, with a maximum of 1103m^3/day (top-up operating 233 days in 2002), minimum of 19m^3/day (operating 4 days in 1954) and average of 500m^3/day. Based on these values the MP allocations would provide sufficient 'top up' water to maintain an acceptable water level variation in the lake.

It should be noted that the water balance modelling should be considered preliminary and approximate only, and includes key assumptions that require further investigation (e.g. seepage). Therefore, additional 'top-up' water may be required (at higher rates than assumed in the modelling applied).

4.11.3.2 Lake water balance and climate change

As noted in Section 4.7.2, climate change may result in reduced overall inflow volumes (or extended 'drought periods') that could result in an increased frequency of low water levels (and/ or decreased total water depths). In the absence of clear advice/ guidance in relation to the likely impacts to climate conditions, an analysis of the potential impacts to lake water balance from climate change has not been undertaken.

Nevertheless, the greatest risk to lake water balance would be climate change contributing to an increased severity and/ or frequency of ‘droughts’. As described above (and in Appendix E), however, water levels were predicted to be at or near the overflow level for the vast majority of the time (for developed catchment conditions) – even throughout the ‘millennium drought’ period of the 2000’s.

4.12 Lake Residence Time

Excessive cyanobacteria (algal) growth is often the largest threat to health of a lake system. The rapid growth of cyanobacteria under optimal conditions means that cyanobacterial populations can rapidly reach bloom concentrations (Water by Design, 2012a). The rate of cyanobacteria and algal growth within lake systems is a function of available nutrients, light, temperature and hydrologic conditions. The longer water is held in a water body due to prolonged residence time and/or low hydraulic efficiency, the greater the risk of a bloom occurring.

Cyanobacterial growth in lakes is mediated by two mechanisms that are ultimately associated with lake retention time (Reynolds, 2006):

- dilution – known as flushing
- direct – displacement known as wash-out

Flushing occurs when baseflows or minor events enter the lake system and mix with the existing water, whereas washout occurs when large episodic events enter the lake system and a given volume is displaced (Water by Design, 2012a). By increasing flushing rates and/or wash-out, conditions become less favourable for cyanobacteria and phytoplankton.

An alternative to flushing or washout is treatment of water through either natural systems (e.g. wetlands) or treatment plants (e.g. a package treatment plant applied similar to that applied for sewage treatment). Importantly, the deeper and larger the lake, the larger the lake volume and therefore the potential for pretreatment costs.

The key risks associated with cyanobacteria and algal blooms are identified below along with conceptual performance criteria aimed at managing the probability of a bloom occurring. Additionally, a residence time analysis is required at this preliminary stage to test the feasibility of designing and operating the lake with an appropriate residence time. It is also expected that this analysis will inform planning initial design responses including for example filtration and recirculation options.

4.12.1 Risks

Excessive algal growth which results in blooms as a result of prolonged residence could result in the following potential risks:

- public health and safety hazards (e.g. through the production of cyanotoxins by the cyanobacteria)
- limited recreation uses
- decline in amenity and aesthetics
- resident complaints

- risks to lake biological processes and ecology (e.g. fish kills due to cyanotoxins, shading, increased pH, decreased dissolved oxygen due to respiration and degradation)
- high operational costs associated ongoing management of recurrent blooms and cleaning of lake infrastructure
- decrease in local property values
- limiting water supply opportunities.

Examples of lakes with excessive residence time and algal growth have previously been provided in Figure 4-2 and Figure 4-10.

4.12.2 Performance criteria

Recommended performance criteria for managing risks associated with lake water balance is provided in Table 4-11.

Table 4-11 Lake Residence Time Performance Criteria

Lake residence time	
Objective	To minimise the risk of hazards associated within inappropriate lake water balance.
Background	Mackay City Council (2008) recommends the following performance criteria: • *The 20%ile residence time (detention time) for the constructed lake should not exceed 20 days*. This 'residence time' typically relates to the time in which lake water may be retained within the lake prior to being discharged out of the lake system, typically either: • not to be returned to the lake system (e.g. to a downstream environment, or for reuse) • to flow or be pumped into a shallow, densely vegetated wetland environment (for a period adequate to limit the growth of algae and reduced nutrient levels). 'Polished' waters from the wetland can then be returned (e.g. pumped) to the lake system. Water by Design (2012a) suggests that control of cyanobacterial biomass via lake retention in SEQ will be most likely facilitated by constant flushing of the biomass from the lake system and that the following performance criteria is more appropriate locally: • *the exceedance criteria is set to 95% to limit the occurrences of extended lake retention to a single 20 day period per year* • a maximum (*sic*) residence time of 10-15 days. It should, however, be noted that there are no known constructed lakes within Queensland that would satisfy these criteria, although there are many lakes successfully operating (with minimal maintenance, and no known incidents of excessive algal growth). A more pragmatic approach to the lake is therefore recommended. It is anticipated that algal growth risks associated with extended residence times could be mitigated through recirculation of lake waters through a designated treatment plant to remove nutrients and algal cells and/ or through the upstream waterways (provided they were sufficiently vegetated to promote appropriate shading of waters and associated algal cell die-off).
Design Performance criteria	• Complete detailed modelling to determine appropriate turnover period. • A *Detailed Lake Design Report* is prepared during detailed design which documents the detailed residence time modelling methodology, results and design responses.
Construction, Establishment and Operational Performance criteria	Lake residence time is regulated in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* and standards current at the time including the guideline *Maintaining Vegetated Stormwater Assets* (Water by Design, 2012b) or equivalent.

4.12.3 Conceptual design verification

The residence time of the lake has been assessed using the water balance model for the proposed lake (described in Section 4.11 and Appendix E). The probability of exceedances of various residence times is given in Appendix E.

The analyses show that the residence times within the proposed lake would not satisfy Mackay City Council’s (2008) 20-day residence time target without some form of recirculation and/ or treatment of lake waters. To mitigate potential water quality problems associated with extended residence times, it is recommended that lake waters be actively recirculated and treated through a designated treatment plant and/ or through the waterways upstream of the lake.

As described in Table 4-11, it is anticipated that algal growth risks associated with extended residence times could be mitigated through recirculation of lake waters through a designated treatment plant and/ or the upstream waterways (provided they were sufficiently vegetated to promote appropriate shading of waters and associated algal cell die-off). In this arrangement, water from within the lake would be pumped to a treatment plant and/ or locations in upstream waterways – to augment the natural treatment processes of filtration, biological uptake and algal cell die-off (e.g. due to shading provided by vegetation), and subsequently ‘treat’ lake waters (and reduce risks of algal growth within the lake). A conceptual design of the potential recirculation system is illustrated in Figure 4-11.

Recirculation of the lake water through upstream waterways would also likely provide other benefits (e.g. improved amenity, aesthetic and ecological values in upstream waterways).

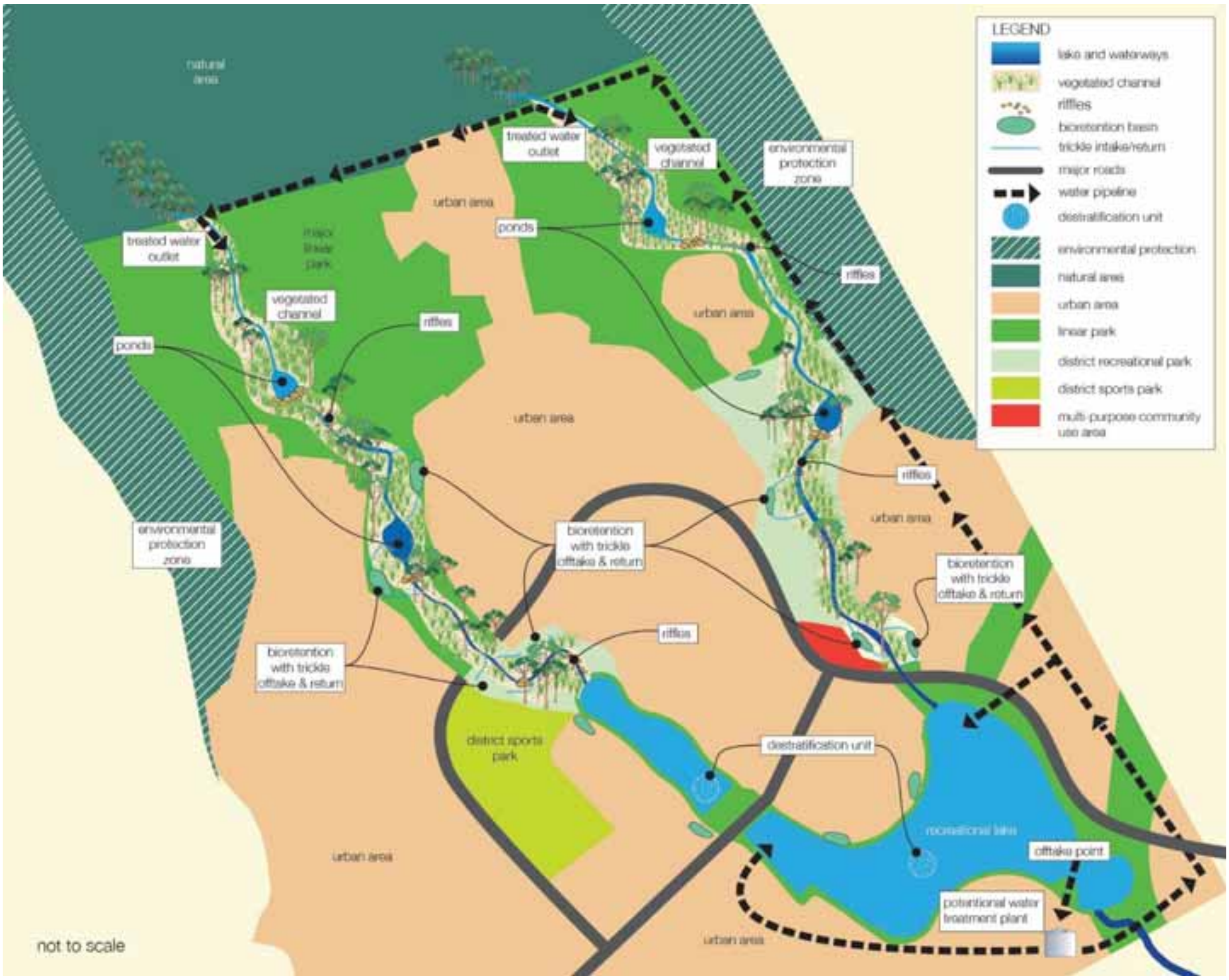

Figure 4-11 Illustrative Concept Design of Potential Recirculation of Lake Waters

4.13 Lake Mixing

In deep lakes (greater than 3m depth) and poorly mixed water lakes, thermal stratification can develop where a colder deoxygenated bottom layer creates reducing conditions which can release sediment-bound nutrients into the water column. This increase in nutrient concentrations can contribute to algal growth within lake systems while stagnant water can impact the ecology of the lake and downstream receiving environments including by creating unfavourable conditions for native species and favourable conditions for pest species (e.g. pest fish species, floating weeds, mosquitoes and midges).

Appropriate measures (refer Table 4-12) will be required to ensure that adequate mixing occurs.

In this case the low lake edge to lake area ratio also ensures that there are no aquatic ‘dead zones’ (i.e. water is well circulated through the lake). This means that there is less risk of cyanobacterial blooms, stagnant water and the accumulation of floating debris and floating weeds which mosquitoes use for egg-laying, breeding and refuge.

4.13.1 Risks

The key risk associated with inadequate lake mixing is the release of sediment bound nutrients and stagnant water which present the following risks:

- cyanobacterial blooms
- creation of favourable mosquito breeding conditions which in turn results in human health risks and limits lake recreation opportunities
- proliferation of other vector species (e.g. pest fish species and floating weeds)
- poor water quality impacting the health and ecology of the lake and downstream receiving environments.

4.13.2 Performance criteria

Recommended performance criteria for managing risks associated with physical hazards is provided in Table 4-12.

Table 4-12 Lake Mixing Performance Criteria

Lake Mixing	
Objective	To minimise the risks of thermal stratification, release of sediment bound nutrients, stagnant water and the consequential cyanobacterial blooms and proliferation of pest species.
Background	The performance criteria have been adapted from Mackay City Council (2008) and Webb (2013).
Design Performance criteria	**Bathymetry and hydrology** • There are no isolated coves or inlets to avoid hydraulic and wind mixing 'dead zones'. • A destratification unit is designed for the lake if appropriate. • Inlet and outlet structures are located at opposite ends of lake. • Short circuits and dead zones are avoided in the lake design including by designing the lake with as low an edge to area ratios as possible subject to site topography, mechanical mixing or underwater baffles. **Wind disturbance** • The lake is orientated to take advantage of prevalent winds subject to topography. • Adjacent building design does not overly limit prevalent winds. • Careful plant selection has been undertaken as part of the landscape design to ensure that it does not create wind barriers. • The base of the lake will be designed to promote even wind mixing where possible. **Ecology** • The bathymetry of the lake is designed such that water draws down evenly so isolated pools are avoided. (Refer to Table 4-4). **Lake Mixing Design Reporting** • A *Detailed Lake Design Report* is prepared during detailed design which documents how the lake meets the lake mixing design criteria identified in the *Flinders Precinct 1: Concept Lake Management Plan* or appropriate alternatives.
Operational Performance criteria	The lake mixing is regulated in accordance with the *Flinders Precinct 1: Concept Lake Management Plan* and standards current at the time including the guideline *Maintaining Vegetated Stormwater Assets* (Water by Design, 2012b) or equivalent.

4.14 Flooding

The management of flooding is being addressed concurrently to this report in the revised *'Flinders Precinct 1: Flood Impact Assessment'* (BMT WBM, 2017), hereafter referred to as the 'flooding report'. The flooding report reflects the design of the lake as presented in this concept management plan.

5 Lake Management

A Concept Lake Management Plan has been provided in Appendix B. As part of this plan, a Water Quality and Sediment Monitoring Program will be required. The Concept Water Quality and Sediment Monitoring Program is described in Appendix C and includes:

- Pre-development (baseline) water quality monitoring
- Construction phase water quality monitoring
- Operational phase water quality and sediment monitoring.

Similarly a Concept Lake Maintenance Plan for the proposed lake system is provided in Appendix D. In accordance with the TOR, the Concept Lake Management Plan, including the monitoring and maintenance plans will be fully documented in greater detail during the detailed design phase when further site-specific information is available.

The typical estimated annual management costs for the lake system are estimated to be between $391,000 and $522,000 per annum. It is noted that the costs will be refined as part of detailed design. Appendix F provides a detailed breakdown of the anticipated costs of managing the proposed lake system.

6 References

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Appendix A Terms of Reference

This appendix provides the Terms of Reference for the Concept Lake Management Plan as provided by EDQ.

From: Owen Haslam [mailto:Owen.Haslam@dsdip.qld.gov.au]
Sent: Tuesday, 22 July 2014 4:26 PM
To: Gavin Johnson
Cc: Ian McLean; stephen@harrisondg.com.au; MUS Records; Archie Venitis; Steve Conner
Subject: Lakeside at Flinders | Engineering TOR

Hi Gavin,

The engineering Terms of Reference (TOR) are provided below. Please let me know if your team has any queries.

Terms of Reference

Integrated Water Management Plan-
Flooding, Stormwater Management, Lake Reliability, and Lake Water Quality Elements

Flooding

To change the original approval, it will be necessary to update the Gilbert and Sutherland Report *Conceptual Flood Assessment, Flinders Grove, Undullah, Queensland* (March 2011) to reflect the proposed waterbody.

The embankment at the downstream end of the waterbody is likely to be substantial. A consideration of issues and risk associated with the embankment will be required, identifying the studies (for example Dam Failure Impact Assessment) that will be required as part of a subsequent IMP-OSS/application processes to confirm the number of Persons at Risk and embankment design criteria.

Lake Water Quality and Reliability

A Concept Lake Report will be required to define the operational parameters that will need to be satisfied as part of subsequent IMP-OSS/application processes. It is noted that sufficient work is required at this point to identify design and operational criteria which can be confidently included in the conditions of approval for the development. It is envisaged that detailed modelling and other investigations will be completed as part of subsequent IMP-OSS/application processes to confirm that the identified criteria can be achieved in the long term.

The Concept Lake Report will need to consider the following.

- *Lake Water Balance*
  A water balance will need to be completed to confirm the level of fluctuation that could occur over time due to natural processes. The water balance will need to consider a suitably long rainfall period (50 to 100 years or more if possible) in order that a range of climatic conditions are considered. It is expected that the water balance will need to consider options involving lining of the waterbody to reduce infiltration losses, additional losses due to recirculation systems, and the use of top up water.

  In the event of top up water being considered necessary, available sources for top up water and their reliability will need to be considered.

- *Amenity and Safety*
  Based on the fluctuation in level predicted for the waterbody in periods of dry weather, proposed measures to address safety issues (adults or children falling into the lake) will need to be considered.

- *Lake Water Quality- Overall*
  The lake will be a large body of water with significant depth. The potential exists for stratification and poor water quality at depth. Further, inflows to the lake (from the external catchment in particular) are expected to be highly turbid and to contain relatively high nutrient levels (even when treated to best practice standards). The lack of light penetration in the water column could promote algal growth and potentially blue-green algae outbreaks.

  As noted above, it is expected that the requirement to complete detailed water quality modelling will be included as a condition of approval. Sufficient investigations are required at this point to allow appropriate long term water quality objectives to be defined for the lake. The adopted water quality objectives will need to be achievable, and also provide for satisfactory lake operation (for example water quality objectives that will result in a high potential for blue-green algae outbreaks will not be supported).

  In defining water quality objectives, appropriate consideration will need to be given to the standard of treatment to be adopted for runoff from the site entering the waterbody (i.e. whether a standard higher than that identified under the State Planning Policy will be required in order to promote good water quality), and measures proposed to limit runoff from external catchments adversely impacting on water quality.

  The water quality objectives will need to include appropriate parameters (Chlorophyll 'a', nutrients, turbidity, dissolved oxygen etc) and also propose the level of human contact that can occur (expected to be secondary contact). In the event of top up water being considered for the waterbody, consideration will need to be given to potential water quality impacts associated with top up water.

- *Lake Water Quality- Poor Water Quality and Dry Periods*
  Initial consideration will need to be given to available options for corrective action in the event of poor water quality occurring and measures to be adopted in dry periods when there is little or no inflow to the waterbody.

- *Rate of Sedimentation*
  Due to the long residence time available within the lake system, it is expected that significant settlement will occur. Initial calculations in relation to the rate of sedimentation are required to confirm either that the need for cleanout will be minimal or the measures to be adopted to allow sediment to be removed from the lake.

- *Maintenance Costs*
  The maintenance costs associated with the lake will be significant (albeit lower than those associated with rehabilitation of the soils in the area). The likely maintenance activities associated with the operation of the lake will need to be identified. It is expected that the approval will be conditioned to require the completion of detailed maintenance costings as part of an IMP-OSS/application processes.

- *Water Quality Monitoring Program and Lake Management Plan*
  A draft water quality monitoring program for the lake will need to be proposed. Similarly, an initial Lake Management Plan indicating the intent for management and procedures to be adopted in the event of poor water quality/ algal blooms etc will need to be prepared. It is noted that both the program and the plan will be fully documented as part of a subsequent IMP-OSS/application processes.

Many thanks

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Please consider the environment before printing this email

Appendix B Concept Operational Lake Management Plan

B.1 Preamble

This appendix provides a Concept Operational Lake Management Plan which has been prepared in response to the TOR. It includes an indication of the intent for management and procedures to be adopted in the event of poor water quality/ algal blooms etc. Included in this plan is a Concept Water Quality and Sediment Monitoring Program (refer to Appendix C) and a Concept Lake Maintenance Plan (refer to Appendix D).

The Concept Lake Management Plan also describes some of the key objectives, ongoing tasks/ actions, performance indicators and corrective actions that will likely be required for the management of the proposed lake. These have been discretised into the following example categories:

- Recreation, amenity, aesthetics and lake ecology
- Public safety
- Water quality management.

This information is described in the following sub-sections. The plan will be more fully documented as part of a subsequent application processes.

B.2 Recreation, amenity, aesthetics and lake ecology

Objectives

To provide for aesthetically pleasing lake that augments the amenity of the site, provides the intended recreational opportunities and the protection of aquatic ecosystems by ensuring suitable water quality, bathymetry, shore design and proper function of lake system infrastructure. More specific performance criteria for each of these objectives are also provided in Section 4.

Tasks/ Actions

- *Infrastructure management*: Lake infrastructure (e.g. inlet/ outlet structures) will be inspected as part of the lake system maintenance plan (see Appendix D).
- *Water quality management*: Refer to Section B.4 below.
- *Macrophyte management*: On occasions, areas within the planted macrophyte zones of the lake systems may need to be harvested for aesthetic reasons. Harvesting does not need to be undertaken to improve water quality (i.e. nutrient uptake) as this has not been found to improve performance to any significant degree. Macrophyte management is outlined in the concept lake maintenance plan (see Appendix D).
- *Ecological surveys*: Six-monthly ecological surveys of the lake are undertaken by a suitably qualified consultant within the first few years of operation (i.e. post construction). These surveys will include the following assessments:

    - Benthic fauna using standard assessment schemes;
    - Weed Surveys – visual; and
    - Fish surveys – qualitative only, indicating potential presence or absence of key species.
- *Fauna Management*: If exotic fish species are identified within the lake, techniques approved by appropriate regulatory authorities (e.g. Department of Primary Industries and Fisheries) may need to be implemented to remove pest species, and the lake system restocked with appropriate native fish species (based on consultation with the Department of Primary Industries and Fisheries). Any introduced species such as ducks and geese will be managed through appropriate risk assessment and management in accordance with the Lake Management Plan and the *Waterbody Management Guideline* (Water by Design, 2013). If removal of pest birds species is required, this may be achieved through a one or a combination of various methods including for example:
    - reduction in food sources
    - habitat modification
    - signage to discourage the community from feeding wildlife
    - netting and other deterrents
    - water level variation to discourage breeding
    - physical removal or culling by a licenced contractor (with appropriate permits)
    - removing habitat.

Performance Indicators

- Relevant guideline levels for water quality constituents to be achieved in the receiving waterways and lake system are described in Appendix C.
- Exotic fish are managed so that populations are controlled at low levels.
- Other nuisance fauna (i.e. birds) are assessed and managed as soon as practical following detection.
- Performance indicators identified in Section 4 are met.

B.3 Public safety

Objective

To minimise any risk to the health and safety of the public. More specific performance criteria are provided in Table 4-1, Table 4-2, Table 4-3, Table 4-4 and Table 4-5.

Tasks/ Actions

Key recommended procedures for the operational phase of the site to minimise risks to public health and safety include the following:

- *Hazard management*: Lake infrastructure will be regularly inspected to minimise potential hazards. Physical hazards such as litter, debris and submerged macrophytes will be managed through ongoing maintenance of the lake. A conceptual maintenance plan for the lake is provided in Appendix D.
- *Water quality monitoring*: As described in Appendix C, water quality monitoring will be undertaken to identify any potential risks to public safety due to poor water quality.
- *Ecological monitoring*: As described in Section B.2, ecological surveys will be undertaken, which will identify any potential risks to public health and safety due to lake ecology.
- *Reporting*: Incidents should be recorded as part of the overall Workplace Health and Safety Program.

Performance Indicators

Health and safety risks are minimised and performance criteria are met including those identified in Table 4-1, Table 4-2, Table 4-3, Table 4-4and Table 4-5

Corrective Actions

Corrective actions will need to be specific to any incidents that may occur.

Where relevant, responses follow the recommended decision support fireworks identified in Table 4-1, Table 4-2, Table 4-3, Table 4-4 and Table 4-5.

B.4 Water quality management

Objectives

The main objectives associated with lake water quality management during the operational stage of the potential lake are as follows:

- Preventing environmental harm to lake system ecology and downstream receiving environments.
- Providing high quality, aesthetically pleasing surrounds.

Compliance with performance criteria identified in Table 4-2, Table 4-3,

- Table 4-4, Table 4-7, Table 4-8 and Table 4-9.
- Compliance with water quality criteria identified in Appendix C.

Ongoing Tasks/ Actions

Key tasks and actions associated with lakes water quality management during the operational stage are as follows:

- *Maintenance of stormwater management measures*: As described in Section 4.8, a wide range of stormwater management measures are proposed for the site. Bioretention systems will provide treatment to stormwater inflows (prior to discharging into the lake systems), and will require regular maintenance (in accordance with Water By Design (2012b))
- *Lake Maintenance*: Regular maintenance of the lake will be undertaken in accordance with the indicative maintenance plans for the lakes to be provided in the *Flinders Precinct 1: Concept Lake Management Plan*.
- *In-lake ecology*: Lake water quality can be seriously affected by the ecology that 'establishes' within the lakes system. Early attention will be given to this issue via active management to ensure the establishment of a viable and suitable lakes ecology, using the following techniques:
    - Stocking the lakes as early as possible with appropriate fish and crustacean species to enable them to establish before the potential entrance of more undesirable species. It should be noted that particular species of crustaceans that burrow into the ground may cause damage to the lake walls and should be avoided.
    - Development of an appropriate in-lake vegetation establishment program to provide habitat and feed for the lake fauna, and also to minimize the development of unsuitable or weed species in the lake.
    - Regular monitoring of lake ecology to provide early warning of colonization of pest species in the lakes and to give data that will relate to occasional manipulation of the lakes ecology (e.g. removal of any pest species, restocking).
- *Monitoring*: Monitoring of water quality will be undertaken in accordance with the proposed Water Quality and Sediment Monitoring Program (see Appendix C).

Performance Indicators

- Relevant guideline levels for water quality constituents to be achieved in the receiving waterways and potential lake system are described in Appendix C.
- Pre-treatment inflows comply with the performance objectives identified in Table 4-7.
- Controlled discharges do not result in downstream temperature changes of greater than 2° Celsius except in emergency situations.

Corrective Actions

In the event of lake water quality not meeting the design performance criteria and objectives described earlier, there are several courses of corrective action that are potentially available. The following list of corrective actions apply to poor water quality scenarios:

- Prior to the commencement of any corrective actions, further investigation into the likely source of poor water quality should be undertaken, especially that current maintenance practices are being properly implemented.
- Total nitrogen, total phosphorus, chlorophyll-*a* – Review and possibly improve catchment management practices. If stratification occurs, elevated nutrient and chlorophyll-*a* measurements may be due to anoxic sediments in the bottom depths of the lake system (or wetlands) and sediment removal may need to be considered.
- Total suspended solids, Secchi depth – ensure that erosion and sediment controls are in place and are consistent with relevant best practice guidelines. Improved catchment management practices should also be considered.
- Dose the lakes with proprietary products such as Phoslock (although it should be stressed that no dosing of proprietary products should be conducted without advice from a suitably qualified consultant).

Appendix C Concept Water Quality and Sediment Monitoring Program

This appendix provides a proposed Water Quality and Sediment Monitoring Program. This program should be considered preliminary only. A more detailed monitoring program for the lake and downstream receiving environment will be documented during detailed design.

The proposed monitoring program includes the following:

- Pre-development (baseline) water quality monitoring
- Construction phase water quality monitoring
- Operational phase water quality and sediment monitoring.

The following sections provide a general description of the proposed monitoring strategy. The detailed program (to be developed during detailed design stage) will include the following additional information for each of the monitoring types identified above:

- objectives
- monitoring sites
- methodology
- performance criteria
- timing schedule
- responsibilities
- reporting and review
- corrective actions.

Additionally, the detailed program will clearly explain how the program should be reflected in construction environmental management planning particularly the erosion and sediment plan/drawings for the construction phase.

C.1 Pre-Development (Baseline) Water Quality Monitoring

This component of the monitoring program will include ambient and event-based water quality monitoring of waterways on site and downstream receiving environments. The key objectives for conducting monitoring during the pre-development phase are to:

- characterise pre-development baseline water quality to:
    - quantify the pollutant export characteristics of the existing (pre-developed) catchment.
    - augment the development of an appropriate strategy to manage catchment pollutant loads (particularly from areas to remain undeveloped – e.g. external to the site).
    - assist in establishing water quality objectives for the lake.
    - assist in establishing downstream water quality objectives (with due consideration of objectives scheduled under the *Environmental Protection (Water) Policy* (2009)).
    - allow assessment of changes in downstream water quality following development including comparison to water quality objectives. This knowledge will then be used to inform responsive management so that impacts on receiving water quality is minimised in accordance with performance criteria.
- establish appropriate lake filling and top-up water quality criteria (e.g. for groundwater, diversion from Wyaralong Dam/Teviot Brook etc.).

In order to achieve these objectives, it will be necessary to define appropriate ambient and event mean concentrations for target pollutants and acceptable limits for physical parameters.

Sampling is likely to include a combination of both baseflow and stormflow monitoring of in-situ water quality using at least one of the following options:

- automatic samplers
- pre-calibrated hand held water quality instruments
- rising-stage samplers
- grab samples
- monitoring of groundwater wells.

Depending on the reliability of local rainfall gauging stations, rainfall monitoring may also be undertaken in order to determine pre-development mean concentrations.

A range of physio-chemical water quality indicators will be analysed in the laboratory or by using the pre-calibrated hand held water quality instrument. Surface water quality parameters during the baseline monitoring program are to be measured in accordance with Table C-1.

Table C-1 Proposed Surface Water Quality Monitoring Parameters

Physical Parameters	Solids & Nutrients	Metals (total and filtered)	Other
Oxidation reduction potential (ORP)	Total suspended solids	Aluminum	Total thermotolerant coliforms
Salinity	Total phosphorus	Arsenic	Total hydrocarbons
Conductivity	Total nitrogen	Barium	
	Nitrite + nitrate (as N)	Beryllium	
	Ammonia-nitrogen	Boron	
	Ortho-phosphorus	Cadmium	
		Chromium	
		Cobalt	
		Copper	
		Iron	
		Lead	
		Manganese	
		Mercury	
		Nickel	
		Selenium	
		Silicon	
		Silver	
		Strontium	
		Vanadium	
		Zinc	

C.2 Construction Phase Water Quality Monitoring

The construction phase water quality monitoring component will include monitoring:

- water quality of sediment basins and basin discharges
- lake water quality and sediment accumulation (depth/extent)
- downstream receiving environment water quality.

The aims of the monitoring during the construction/operational phase of the project include:

- to assess the effectiveness of management strategies for protecting the lake and receiving environments
- ensure that any non-compliance with respect to water quality is identified
- inform timely, responsive management practices when non-compliance is detected.

Sampling may include a combination of monitoring techniques using at least one of the following options:

- automatic samplers
- pre-calibrated hand held water quality instruments
- rising-stage samplers
- grab samples.

Additionally, as turbidity will be the key pollutant of concern during the construction phase, telemetered sensors may be placed downstream of areas being developed. Should these turbidity sensors detect turbidity levels in site runoff which exceeds predefined threshold levels, alarm signals will be sent to construction personnel so that they can investigate the cause of the elevated turbidity levels and undertake appropriate corrective actions. Examples of telemetered water quality monitoring infrastructure is provided in Figure C-1.

Figure C-1 Photos of Telemetered Water Quality Monitoring Infrastructure

Erosion and sediment control objectives relevant to the construction phase monitoring program are provided in Table 4-7.

C.3 Operational Phase Water Quality and Sediment Monitoring

The operational phase water quality monitoring component will include monitoring:

- water quality and sediment quality of the lake
- lake sediment accumulation depth and extent
- downstream receiving environment water quality.

Both the aims and likely sampling techniques identified for the construction phase (refer to Section above) are also applicable to the operational phase, with the likely exception of the telemetered monitoring. Additionally, the operational phase monitoring program will need to be undertaken in order to:

- revise the preliminary water quality objectives for the lake (refer to Table C-2), i.e.to ensure that the objectives are achievable in the long term and reflect the potential for the quality of water used for topping up the lake may influence water quality, while protecting downstream receiving ecological values.
- establish appropriate discharge water quality criteria from the lake to receiving environments which ensure protection of downstream ecological values.

Table C-2 provides a summary of the preliminary water quality parameters, frequency and locations for water quality monitoring within the proposed lake system. Six-monthly consolidated lake water quality monitoring reports are proposed to be prepared and submitted to Council for review. Any corrective action undertaken will also be reported immediately to Council.

Table C-2 Summary of Recommended Operational Phase Lake Water Quality Monitoring Plan

Parameter	Unit	Water Quality Objective*	Monitoring Frequency	Monitoring Locations
Water Quality Monitoring				
Physical Monitoring				
Temperature	°C	No objective for the lake although controlled discharges do not result in downstream temperature changes of greater than 2° Celsius except in emergency situations.	Monthly	Specific locations to be confirmed during detailed design Recorded 0.3m from surface and every 0.5m from surface til lake bottom.
Salinity	ppt	-		
Conductivity	mS/cm	-		
Dissolved Oxygen	mg/L	-		
Dissolved Oxygen	% Sat.	>50		
pH	-	6.5 – 8.5		
Turbidity (NTU)	NTU	<20		
Chemical and Biological Analyses				
Total Suspended Solids	mg/L	-	Monthly	Specific locations to be confirmed during detailed design Recorded 0.3m from surface and 1m from lake bottom.
Total Nitrogen	mg/L	<0.75		
Oxidised Nitrogen	mg/L			
Ammonia Nitrogen	mg/L			
Total Phosphorus	mg/L	<0.07		
Filterable Reactive Phosphorus	mg/L			
Chlorophyll-a	µg/L	<30		
Faecal Coliforms	org./ 100mL	<1000 (& 80th %ile <4000)		
Enterococci^	org./ 100mL	<230 (& Max. <700)		
Cyanobacteria	Level 1 guideline:[4] • ≥10 µg/L total microcystins or • ≥50 000 cells/mL toxic *Microcystis aeruginosa* or biovolume equivalent of ≥4 mm^3/L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or[5] Level 2 guideline • ≥10 mm^3/L for total biovolume of all cyanobacterial material where known toxins are not present or • cyanobacterial scums are consistently present[6].		Monthly	Specific locations to be confirmed during detailed design

[4] In practical terms the biovolume definition component of the Level 1 guideline (i.e. total cyanobacterial biovolume of known toxigenic cyanobacteria >4 mm^3/L) may be used to initially trigger the action mode (red level) before toxicity or toxin analysis is available. If this is the case and the subsequent toxin analysis is negative, the mode may revert to alert mode (amber level) in the biovolume range >0.4 - < 10 mm^3/L. If cell numbers continue to increase, the Level 2 guideline definition applies if either the total biovolume of all cyanobacterial material exceeds 10 mm^3/L or cyanobacterial scums are consistently present.

[5] This applies where high cell densities or scums of 'nontoxic' cyanobacteria are present, i.e. where the cyanobacterial population has been tested and shown not to contain known toxins (microcystin, nodularin, cylindrospermopsin or saxitoxins).

[6] This refers to the situation where scums occur at the recreation site each day when conditions are calm, particularly in the morning. Note that it is not likely that scums are always present and visible when there is a high population, as the cells may mix down with wind and turbulence and then reform later when conditions become stable.

<table>
<tr><th>Parameter</th><th>Unit</th><th>Water Quality Objective*</th><th>Monitoring Frequency</th><th>Monitoring Locations</th></tr>
<tr><td colspan="5">Heavy Metals & Pesticides</td></tr>
<tr><td>Cadmium</td><td rowspan="5">µg/L</td><td><2</td><td rowspan="6">Six-monthly</td><td rowspan="6">Specific locations to be confirmed during detailed design

Recorded 0.3m from surface and 1m from lake bottom.</td></tr>
<tr><td>Copper</td><td><5</td></tr>
<tr><td>Nickel</td><td><150</td></tr>
<tr><td>Lead</td><td><5</td></tr>
<tr><td>Zinc</td><td><50</td></tr>
<tr><td>Organochlorine and Organophosphorus pesticides</td><td colspan="2">Below detectable limits</td></tr>
<tr><td colspan="5">Sediment Quality Monitoring</td></tr>
<tr><td>Cadmium</td><td rowspan="5">mg/kg (dry weight)</td><td><10</td><td rowspan="5">Annually</td><td rowspan="5">Specific locations to be confirmed during detailed design</td></tr>
<tr><td>Copper</td><td><270</td></tr>
<tr><td>Nickel</td><td><220</td></tr>
<tr><td>Lead</td><td><60</td></tr>
<tr><td>Zinc</td><td><410</td></tr>
</table>

*: Objectives are median values unless otherwise stated. These objectives are based on the recommended values for ‘freshwater lakes/ reservoirs’ in South East Queensland, as given in DERM (2009) and ANZECC (2000) and operational data from various lakes across South East Queensland (in order to ensure more realistic objectives).

Appendix D Concept Lake Maintenance Plan

This appendix provides an indicative maintenance plan for the proposed lake system. The maintenance requirements for possible pre-treatment systems, recirculation and water quality treatment infrastructure (yet to be designed) has not been included at this stage. The plan will be fully documented during the detailed design stage in accordance with the TOR.

Table D-1 Schedule of Maintenance Timing

Purpose of Visit	Frequency	J	F	M	A	M	J	J	A	S	O	N	D
Routine inspection	26/year	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN
Routine clean up of litter	26/year	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN
Sediment accumulation monitoring	1/ 5 years					✓							
Clean out of sediment	1/ 20 years						✓						

'FN': Fortnightly

The above schedule is a guideline only. Inspection and maintenance frequencies should be adjusted according to site and weather conditions.

Table D-2 Schedule of Maintenance Activities

INSPECTION	
1.	**ROUTINE INSPECTION**
1.1	Routine inspection should be carried out on a regular bi-weekly basis. The purpose of the inspection is to check the condition of the lake system and associated infrastructure, and can be combined with the weekly litter and debris clean up.
1.2	Routine inspection involves visually checking lake edges, shallow areas and embayments for litter or other debris accumulation. Associated lake infrastructure such as the rock walls, signage and boardwalks should also be inspected for signs of damage, vandalism or deterioration.
1.3	The amount of submerged macrophytes (e.g. water weeds such as hydrilla) should be noted if growth is excessive so that harvesting can be arranged. Also, any accumulation of floating macrophytes (e.g. duckweed and salvinia) should be noted.
1.4	Any domestic fauna found to be on or around the lake, such as ducks and geese should be noted for risk assessment and management.
1.5	The recirculation system should be checked to ensure it is operating correctly and no blockages have occurred.
1.6	The destratification unit should be checked to ensure it is operating correctly and no blockages have occurred.
1.7	Complete the attached Maintenance Form and forward to relevant maintenance coordinator.

ROUTINE MAINTENANCE	
2	**Purpose**
2.1	Routine maintenance of the lake areas involves weed control and the collection of any litter and minor remedial works if required.
3	**Weed Management**
3.1	If weeds have been observed during routine inspection, these weeds should be removed from the wetland. Common weed species that have been associated with constructed wetlands and suggested removal techniques are given below:

Species	Typical locations	Suggested Removal Technique
Typha domegensis (Cumbungi)	Planted aquatic areas	Cut stems to below water level (remove all cut plant material)
Duckweed	Open water zones	Physical removal (e.g. netting)
Salvinia molesta (Salvinia)	Open water zones	Biological control (weevil), Chemical, Physical removal, refer DNRM Pest Fact Sheet
Eichhornia cassipes (Water hyacinth)	Planted aquatic areas	Biological control, Chemical, Physical removal, refer to natural resources department pest fact sheets
Brachiaria mutica (Paragrass)	Wetland edges, planted aquatic areas	Physical removal in planted aquatic areas. Herbicide (glyphosate) in wetland edges
Myriphyllum aquaticum (Parrot's feather)	Planted aquatic areas	Physical removal, see natural resources department pest fact sheets
Rumex spp. (Curled dock)	Planted aquatic areas	Physical removal
Baccharis halimifolia (Groundsel)	Wetland edges and adjacent areas	Physical removal of seedlings. Adults cut stump treatment with herbicide (glyphosate)

3.2	Where physical removal has been specified, the aim is to remove the weed including the roots when the weeds are less than 3 months old, otherwise infestation can rapidly occur and may be difficult to control. Perennial weeds such as *Typha* can be drowned if cut below the water level in late autumn.
3.3	Herbicides should not be used where they may contaminate water in the lake system (and wetland areas).
3.4	The weeds should be disposed of offsite at an appropriate waste management facility.
3.5	Replant wetland species as necessary in areas that have been extensively weeded.

3.6	*In general, the planted wetland species should not be harvested unless encroachment into open water zones is excessive. Harvesting wetland plants has little, if any, benefit for treatment performance.*
4	**Litter Management**
4.1	A small motorised boat or punt should be used to perform the clean-up. Pool scoops or simple manual removal are the best options for litter and debris removal. The boat or punt should have a reasonably shallow draft to allow access into the inshore areas of the lake.
4.1	Minor infestations of floating macrophytes such as duckweed and *Salvinia* can be manually removed from the lake using pool scoops. These weeds must be regularly removed to prevent excessive growth.
4.2	Contact with sharp objects, including hypodermic needles, is a risk when removing litter. All workers must be made aware of this risk, wear appropriate protective gear and use caution.
4.3	The collected litter and debris should be loaded into the back of a tip-truck. If the load includes loose material that is able to be blown off or fall from the truck, the load should be covered prior to leaving the Lake.
4.4	Tidy the site of any debris prior to leaving.
4.5	Proceed to landfill for disposal of trash.
5	**Remedial Works**
5.1	Routine inspection may detect minor damage to the lake after storms that should be repaired. This damage should be repaired as part of the routine maintenance of the lake.
SEDIMENT ACCUMULATION MONITORING	
6.1	On an annual basis, the amount of sediment accumulation needs to be monitored. The most accurate process for doing this is by undertaking a survey of bathymetry of the Lake and comparing it to previous bathymetry measurements.
CLEANOUT OF SEDIMENT	
7.1	The cleanout of sediment from the lake system will be a major operation that will require specific technical input. Sediment removal should only be performed if absolutely necessary due to possible negative impacts on Lake water quality, aesthetics and ecology.

Table D-3 Lake Maintenance Checklist

LAKE MAINTENANCE CHECKLIST			
Asset I.D.			
Inspection Frequency:	1 to 6 monthly	**Date of Visit:**	
Location:			
Description:			
Site Visit by:			
INSPECTION ITEMS	**Y**	**N**	**ACTION REQUIRED (DETAILS)**
Litter within lake?			
Sediment accumulation at inflow points?			
Revetment walls in satisfactory condition?			
Boardwalks and pathways in satisfactory condition?			
Signage around lake present and in satisfactory condition?			
Damage/vandalism to structures present?			
Is recirculation system operating correctly?			
Is destratification unit operating correctly?			
Terrestrial vegetation condition satisfactory (density, weeds etc.)? (Specify areas for future harvesting/ weed control)			
Aquatic vegetation condition satisfactory (density, weeds etc.)?			
Replanting required?			
Comments:			

Appendix E Water Balance Modelling Methodology and Results

As outlined in Section 4.11 and 4.12, a customised spreadsheet-based water balance model of the potential lake has been developed to provide an understanding of anticipated 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.

E.1 Modelling Methodology

The following scenarios have been modelled for the proposed lake:

(1) With existing catchment conditions, with no top-up water or recirculation of lake waters

(2) With existing catchment conditions, with additional 'top-up' water and recirculation of lake waters

(3) With developed catchment conditions, with no recirculation of lake waters and no top up

(4) With developed catchment conditions, with recirculation of lake waters, top up (when required) and irrigation of parkland.

Table E-1 provides a summary of the water balance model. Table E-2 provides a summary of the catchment model that has been utilised to calculate flows from the catchment upstream of the lake.

Figure E-2 and Figure E-3 illustrate the assumed land usage and catchment extent for the existing and developed site respectively.

Table E-1 Summary of Water Balance Model for Proposed Lake

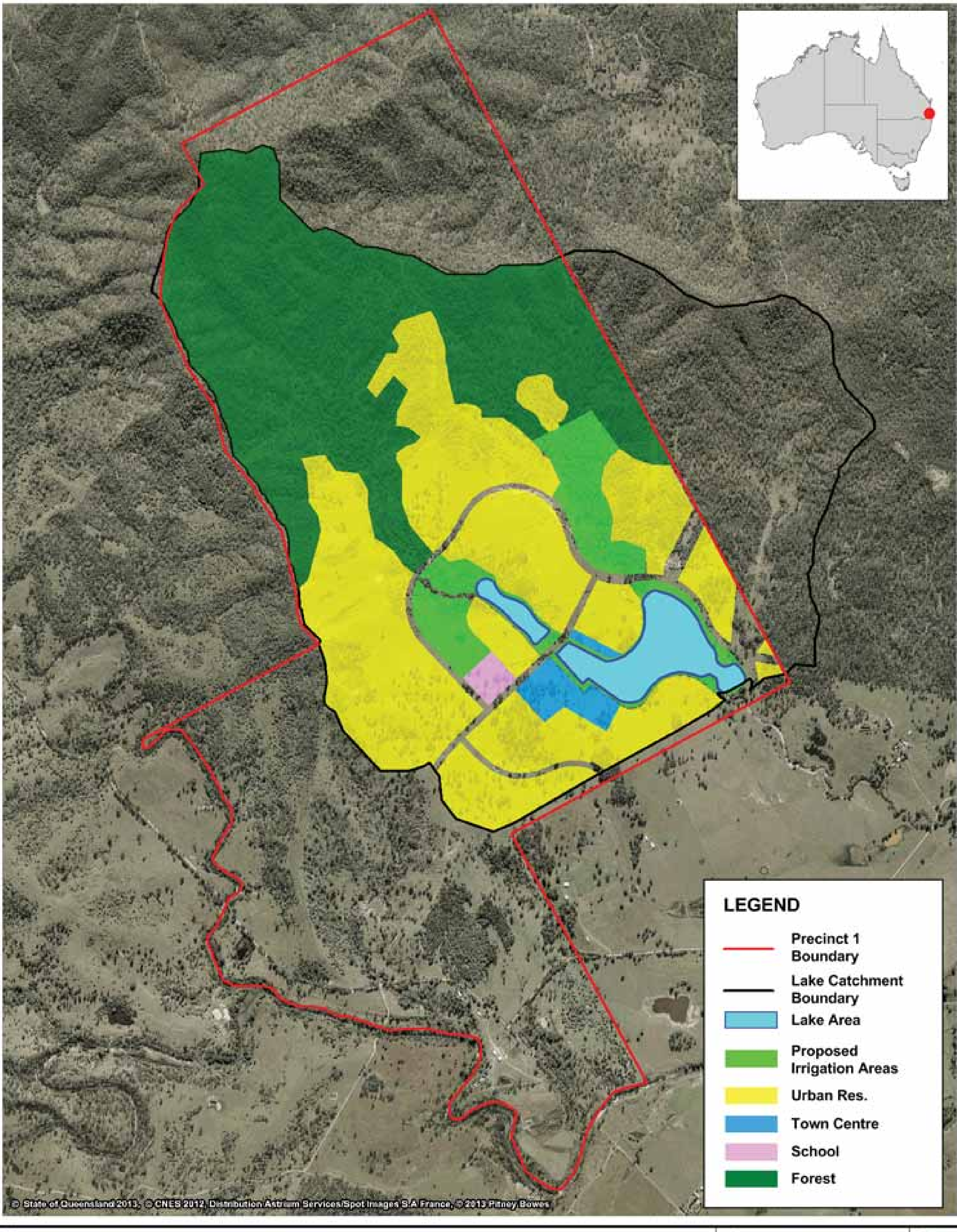
Parameter	Comments
Waterbodies	Upper lake and lower lake within the site. Water balance modelling also undertaken for the western branch and eastern branch (proposed pool/ riffle system located upstream of these water bodies).
Modelling period	64-year period of SILO rainfall data (for the site of the proposed lake) – from 1st January 1950 to 31st December 2014.
Modelling time step	Daily.
Bathymetry	Bathymetry (i.e. elevation, area, volume) of upper and lower lakes from digital elevation model of proposed design. Bathymetry of western and eastern branch based on preliminary design of pool-riffle.
Initial volume of waterbodies	The lake was assumed to be full (100% initial volume), except for the lake filling assessment (where all waterbodies were assumed to be empty (0% volume).
Inputs	
Direct rainfall	Direct rainfall input a function of daily rainfall and waterbody area (dependent on daily volume and bathymetry). Sensitivity analyses undertaken with other daily rainfall data sources (e.g. data from nearby Bureau of Meteorology Station).
Surface flows	Calculated by catchment model (see Table E-2).
Groundwater flows	Assumed to be zero.
'Top-up' from	This is assumed to be 20 litres/ second (1728m^3/day, discharged to the

Parameter	Comments
external sources	lower lake) for Scenario 2 and 4 only. This top-up is only utilised if the water level within the lower lake is less than 150mm below the overflow level. For the lake filling assessments, this top-up continued until 100% capacity of the lower lake was achieved.
Outputs	
Evaporation	SILO daily potential evapotranspiration. Sensitivity analyses undertaken with other potential evaporation sources – including monthly averages from Water By Design (2010).
Seepage	0.8mm/day, cited by Gilbert and Sutherland (2015: *Pers.Comm*).
Water extraction	Assumed to be zero except for Scenario 4 where irrigation occurs.
Overflow	At the end of each modelling time step, any volume in excess of the volume at the waterbody spillway weir level is assumed to overflow (before the commencement of the next modelling timestep). Western branch overflows to upper lake. Upper lake and eastern branch overflow to lower lake. Lower lake overflows to downstream waterway.
Irrigation	For scenario four, waters from both lakes are utilised for irrigation depending on the proximity of the lake to the irrigated area. The total irrigated area is approximately 26 ha. This equates to a total irrigation requirement of 618 m^3/day (with 164 m^3/day from the upper lake and 455 m^3/day from the lower lake). Irrigation is assumed to not occur when: • rainfall exceeds 10 mm/day • rainfall exceeds 50 mm in the previous seven days • water levels drop below 150 mm of the full supply level of each lake The approximate areas assumed to be irrigated are shown in Figure E-1.
Recirculation	
Recirculation	For modelled scenarios with recirculation, waters retained in the lower lake are proposed to be treated via a water treatment plant. Most of the treated water will then be returned to the upper and lower lake and a lesser portion will be discharged at the upstream ends of both the western and eastern branches. Objectives of recirculation include reduced ‘residence time’ (or increased turnover) of lake waters (to augment appropriate lake water quality and reduce algal growth), and increase amenity/ ecology of western and eastern branches by augmenting a ‘babbling brook’ type waterway system upstream of the lakes. Maximum rate of extraction of lower lake waters (for recirculation) equal to the volume of both lakes divided by twenty days – equal to 45.8 ML/day (or 530 litres/ second). Recirculation assumed to not occur on any day when daily rainfall exceeds 5mm. Distribution of recirculated lake waters is assumed to be as follows: • Upper lake: 53% of recirculated water • Lower lake: 40% of recirculated water • Western branch: 3% of recirculated water • Eastern branch: 4% of recirculated water

It should be highlighted that the water balance modelling should be considered preliminary and approximate only. The modelling includes key assumptions that require further investigation, particularly the assumed values for seepage.

Table E-2 Summary of Catchment Model (Utilised for Calculating Surface Flows) for Proposed Lake

Parameter	Comments
Catchment	Contributing catchment to proposed lake within Precinct 1, Flinders
Modelling period	64-year period of SILO rainfall data (for the site of the proposed lake) – from 1st January 1950 to 31st December 2009
Modelling time step	Daily
Catchment area	557 hectares
Existing Catchment	
Land usage	Undeveloped. See Figure E-2.
Surface flows	Calculated by BMT WBM utilising MUSIC software, with rainfall runoff properties from Water By Design (2010).
Developed Catchment	
Land usage	See Figure E-3 for the proposed development layout.
Surface flows	Calculated by BMT WBM utilising MUSIC software, with rainfall runoff properties from Water By Design (2010).



Title:

Proposed Irrigation Areas

Figure: E-1

Rev: A

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0 0.5 1km

Approx. Scale

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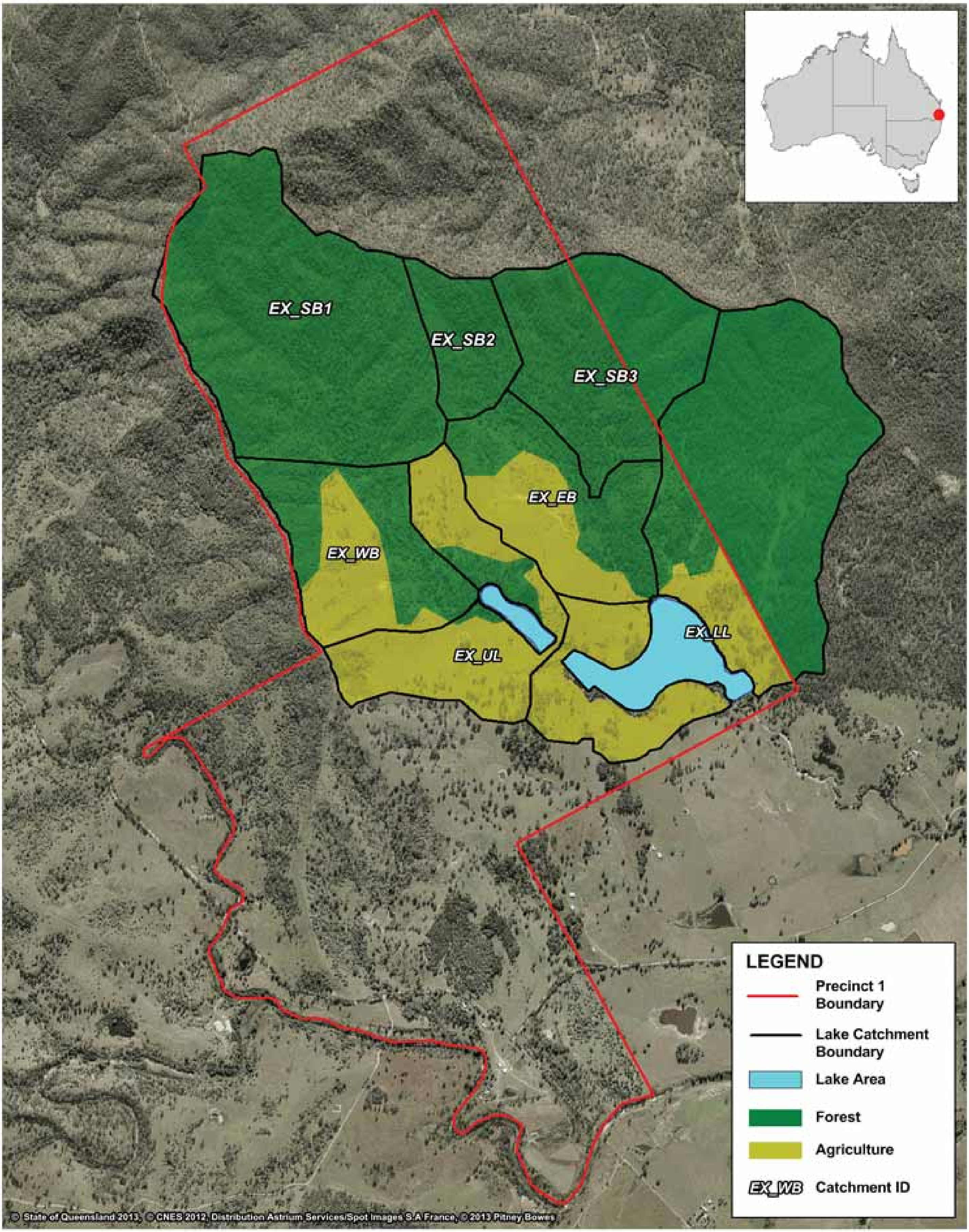

Title:

Assumed land usage and catchment extent for existing site with proposed lake system

Figure: E-2

Rev: A

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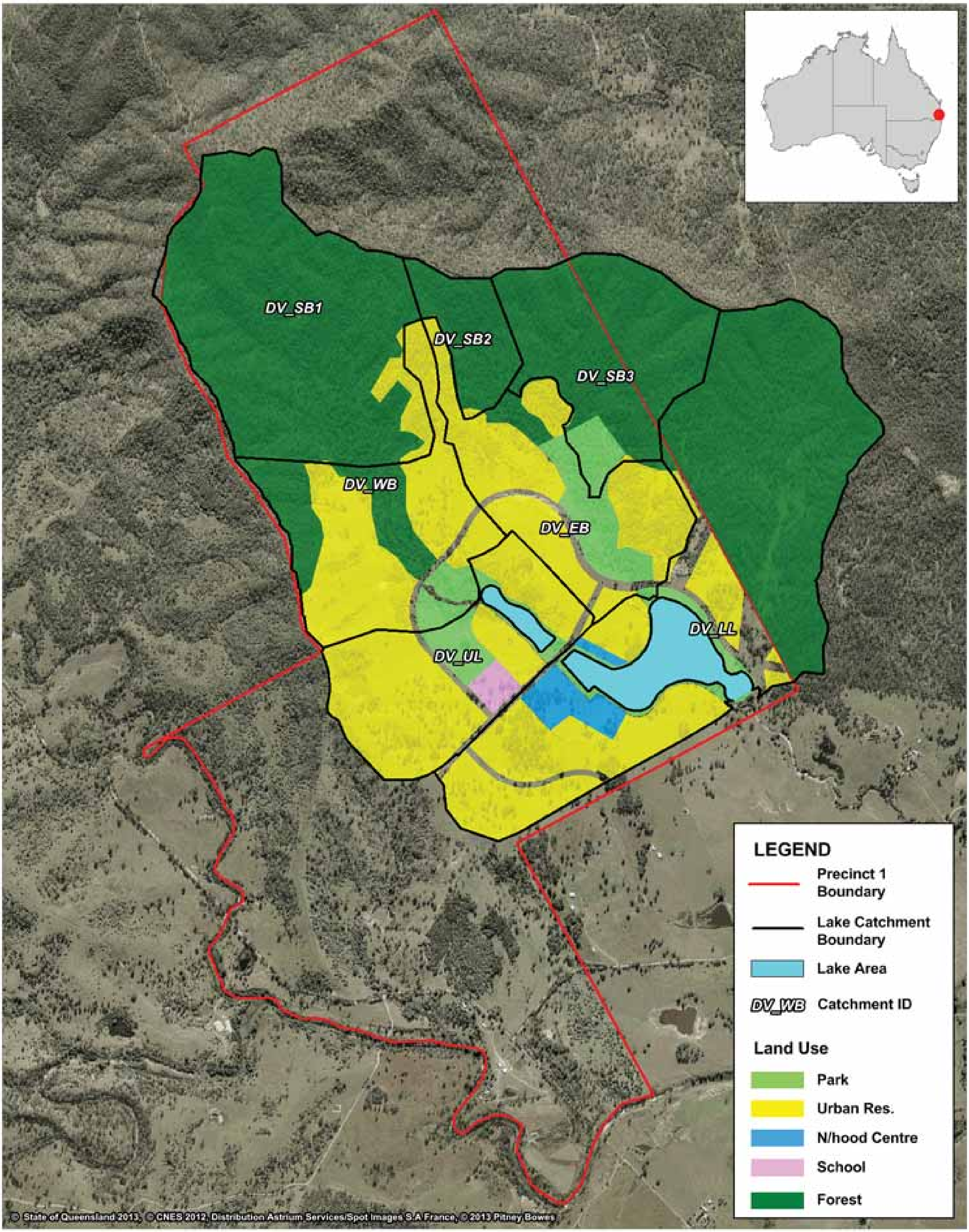

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Assumed land usage and catchment extent for developed site with proposed lake system

Figure: E-3

Rev: A

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For the purposes of this assessment, this water balance model has been utilised to assess the following (for the 64-year climatic period):

- Variation in water levels within the lake
- Assess the water balance of the site (e.g. quantity and distribution of water flowing in and out of lake)
- Lake residence (or 'turnover') time
- Lake filling time.

For the lake filling time analyses, the water balance model was used to assess the time potentially required for the proposed lake to fill during the initial stages of the project. This was done using the following methodology:

- Existing catchment conditions assumed.
- The lake was assumed to be empty on 1st June for every ten year increment (i.e. lake was assumed to be zero on 1st June 1950, 1960, 1970, 1980, 1990, 2000 and 2010).
- The number of days taken for the lake to reach 100% capacity was calculated.
- The upper lake is filled first and then overtops to fill the lower lake.

E.2 Results

Water balance model results are presented in the following sections – for both the upper and lower lake.

The following figures are presented for the proposed lakes:

- Graphs of predicted water level variation. These graphs show how the water levels within the lake would vary over the 60-year period of historical climate data.
- Predicted probability of exceedances of water levels and volumes. These graphs show how likely/probable various water levels and volumes would be exceeded (using the historical climate data).
- Distribution of inflows and outflows, showing the percentage distribution of flows (e.g. direct rainfall, runoff) and outflows (e.g. evaporation, overflow) for the lakes (using the climate data).
- Predicted probability of exceedances of lake residence (or 'turnover' time). These graphs show how likely/probable various residence times would be exceeded (using the climate data). Comparisons are also made to the residence times recommended by Mackay City Council (2008), given in Table 4-11.

E.2.1 Existing Catchment Conditions, with no top-up water or recirculation of lake waters

E.2.1.1 Upper Lake

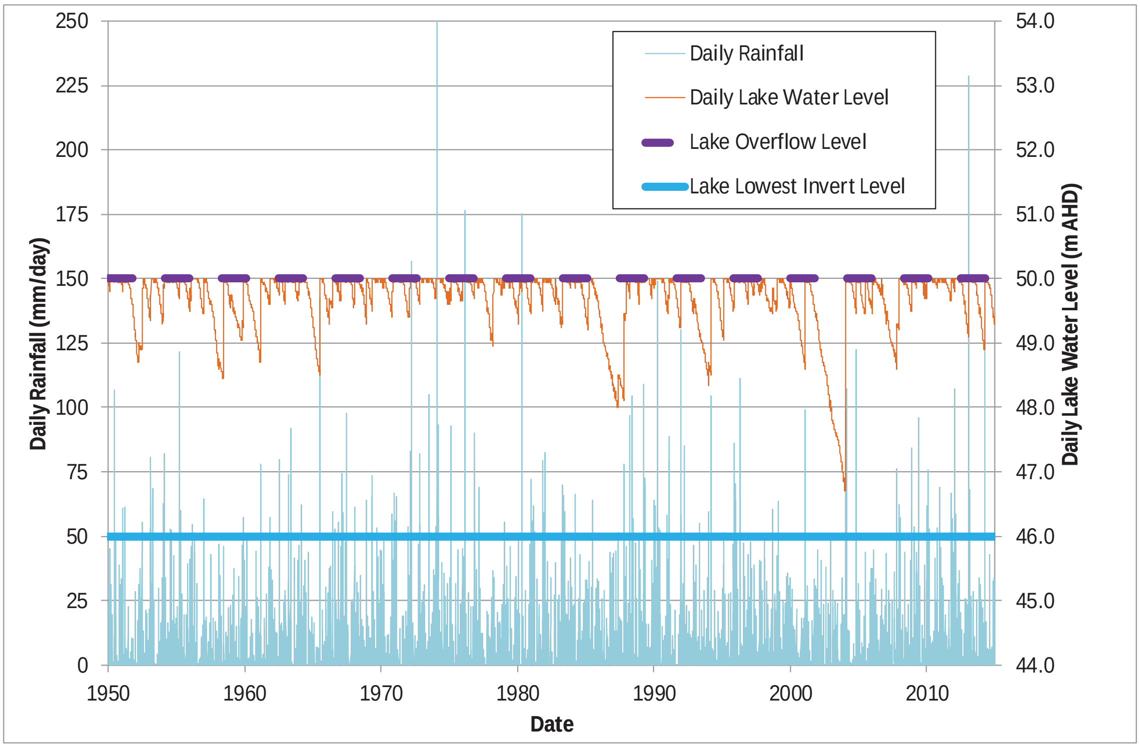

Figure E-4 Predicted Water Level Variation in Upper Lake for Existing Catchment Conditions

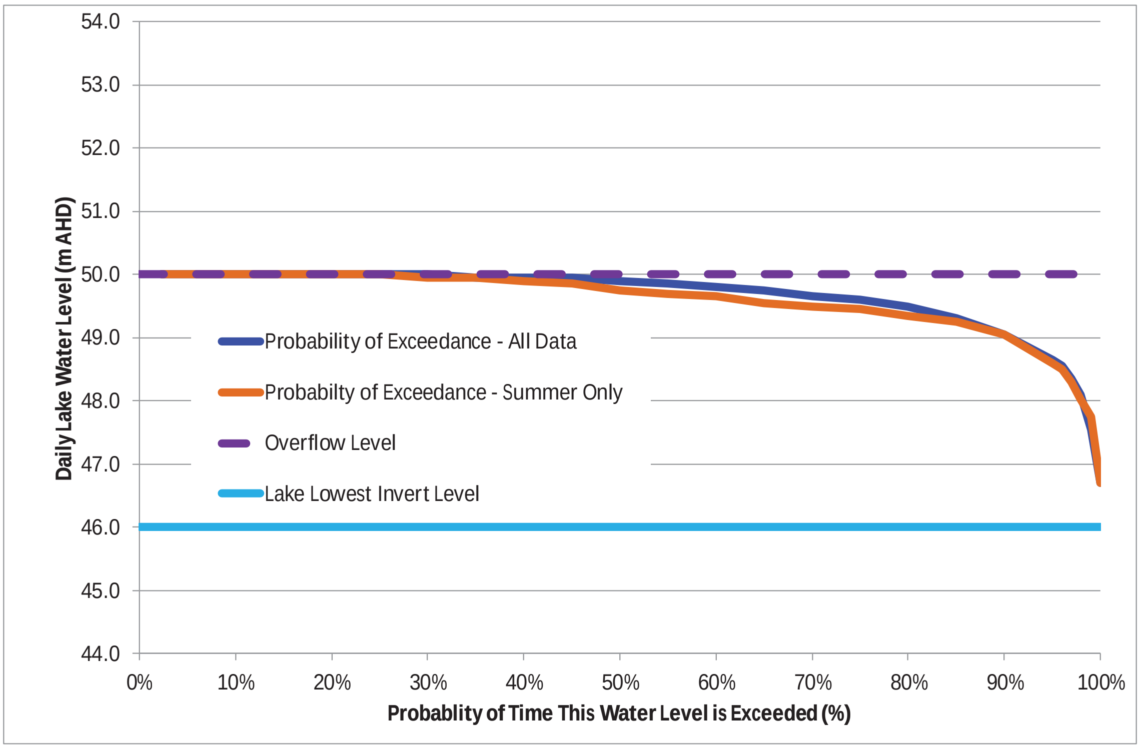

Figure E-5 Predicted Probability of Exceedance of Water Levels for Existing Catchment Conditions (1950 to 2014) for the Upper Lake

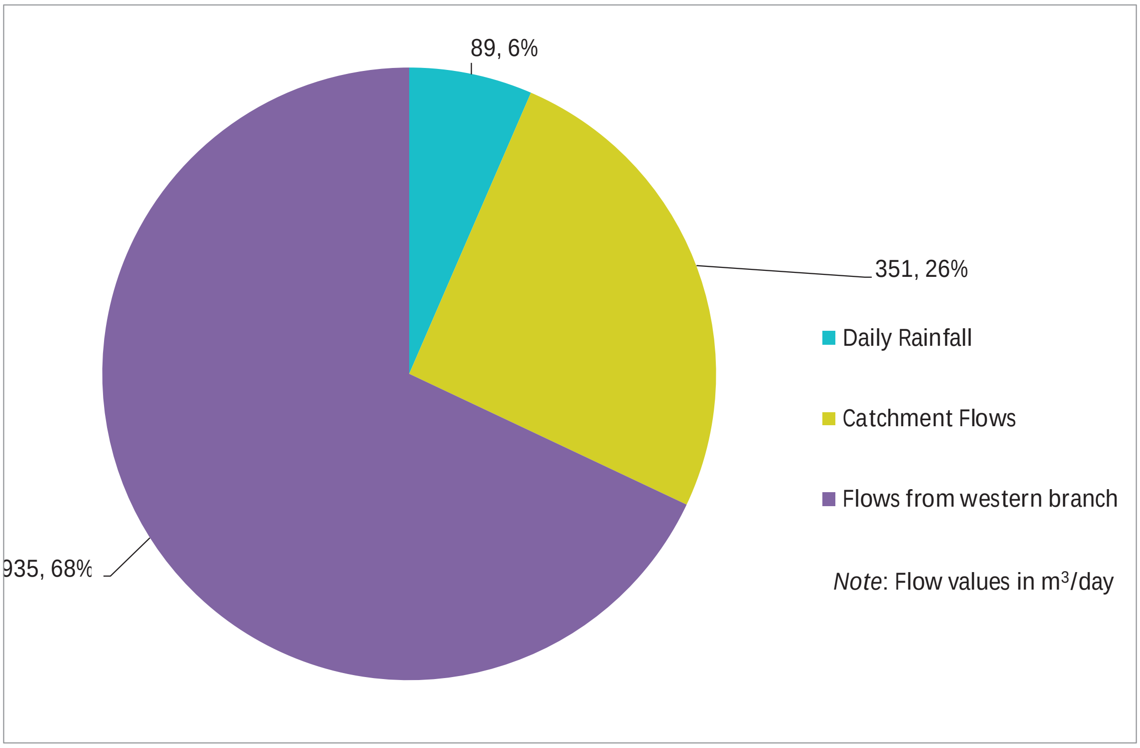

Figure E-6 Predicted Distribution of Inflows to Upper Lake for Existing Catchment Conditions (1950 to 2014)

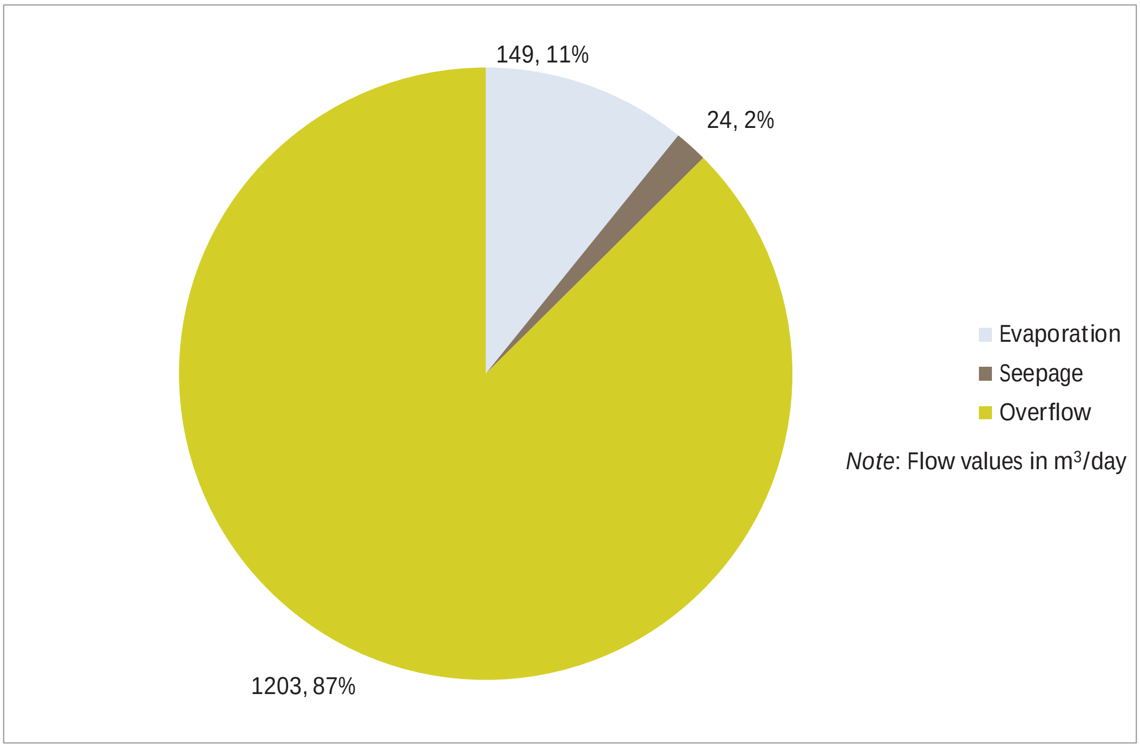

Figure E-7 Predicted Distribution of Outflows from Upper Lake for Existing Catchment Conditions (1950 to 2014)

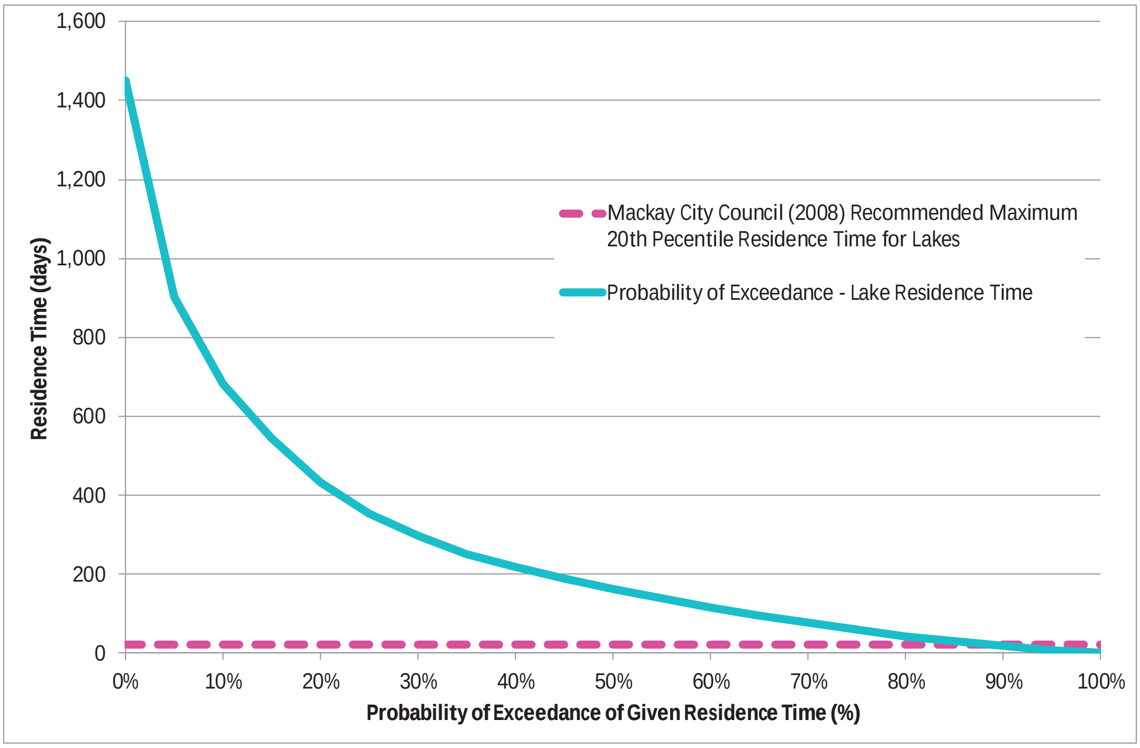

Figure E-8 Predicted Probability of Exceedance of Residence Time for Existing Catchment Conditions (1950 to 2014) for the Upper Lake

E.2.1.2 Lower Lake

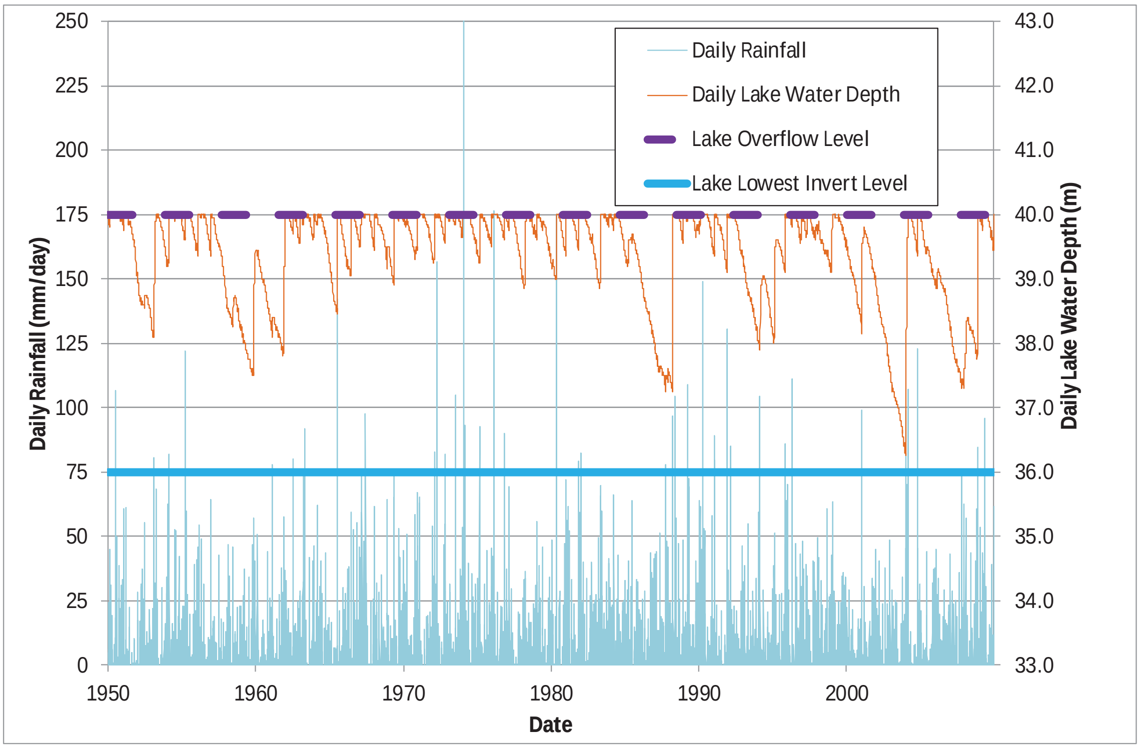

Figure E-9 Predicted Water Level Variation in Lower Lake for Existing Catchment Conditions

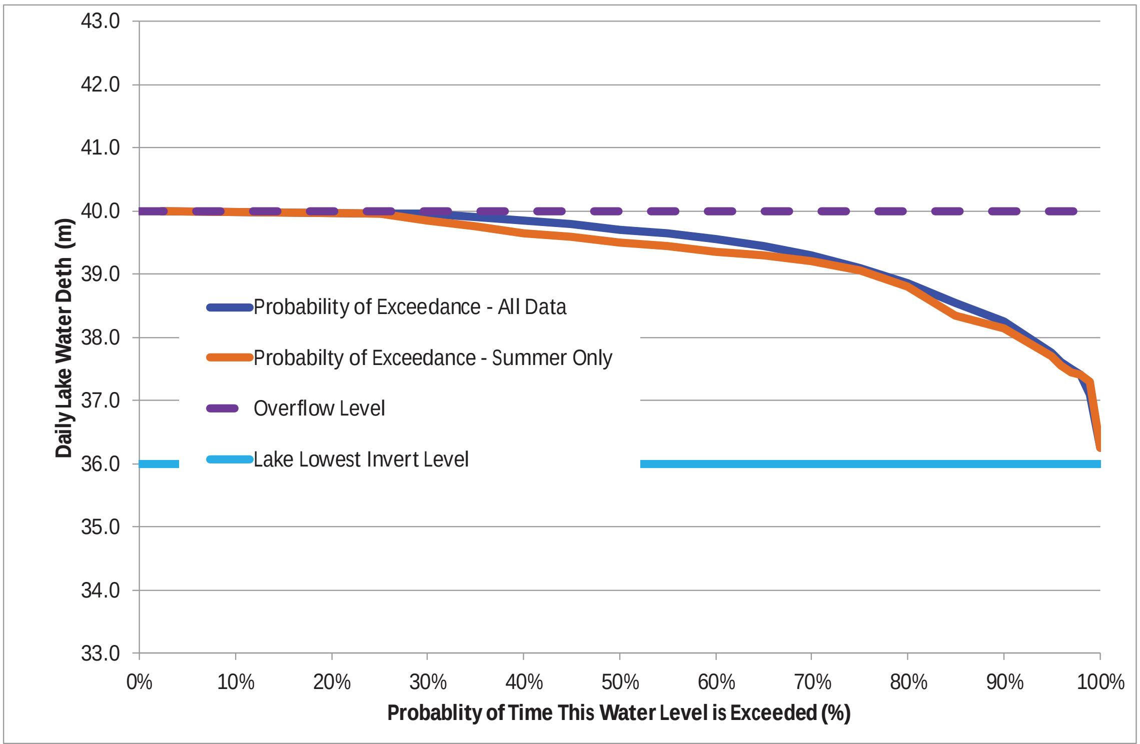

Figure E-10 Predicted Probability of Exceedance of Water Levels for Existing Catchment Conditions (1950 to 2009) for Lower Lake

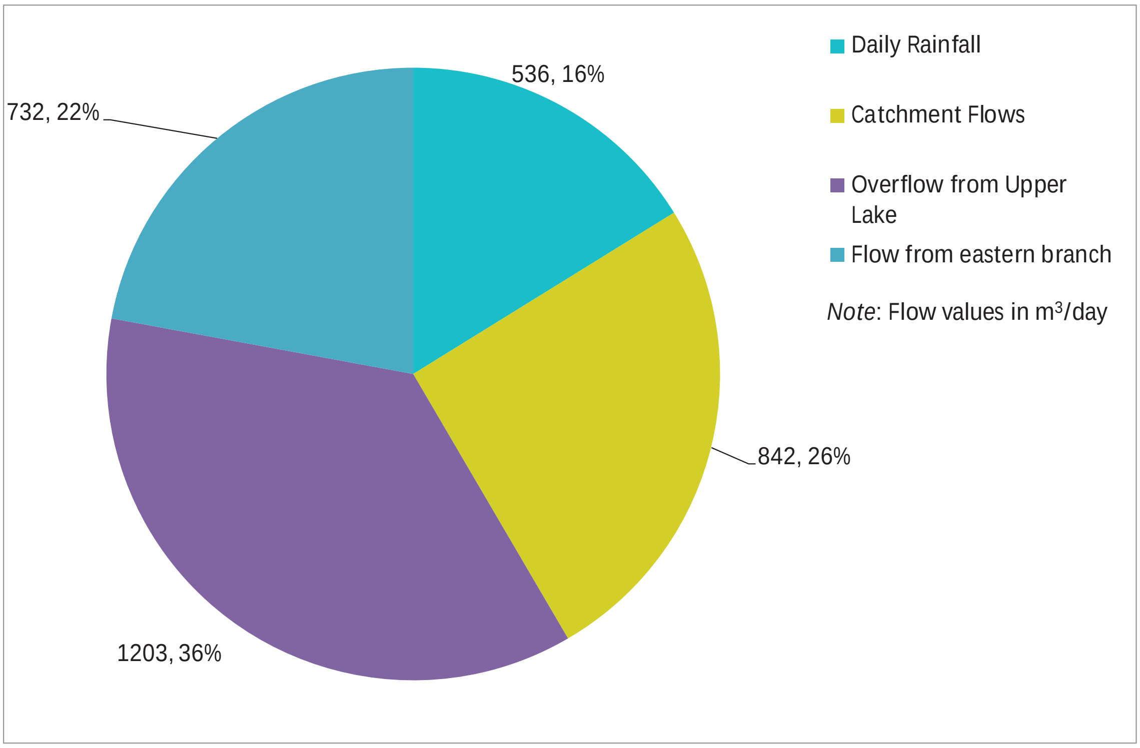

Figure E-11 Predicted Distribution of Inflows to Lower Lake for Existing Catchment Conditions (1950 to 2009)

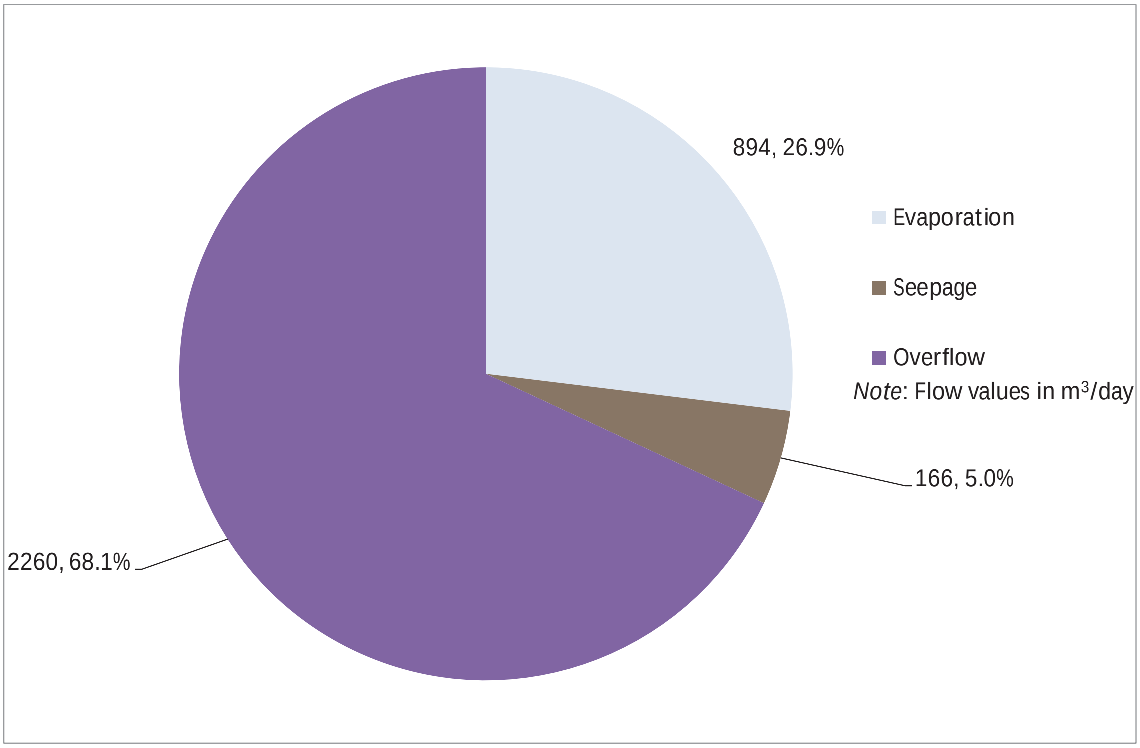

Figure E-12 Predicted Distribution of Outflows from Lower Lake for Existing Catchment Conditions (1950 to 2014)

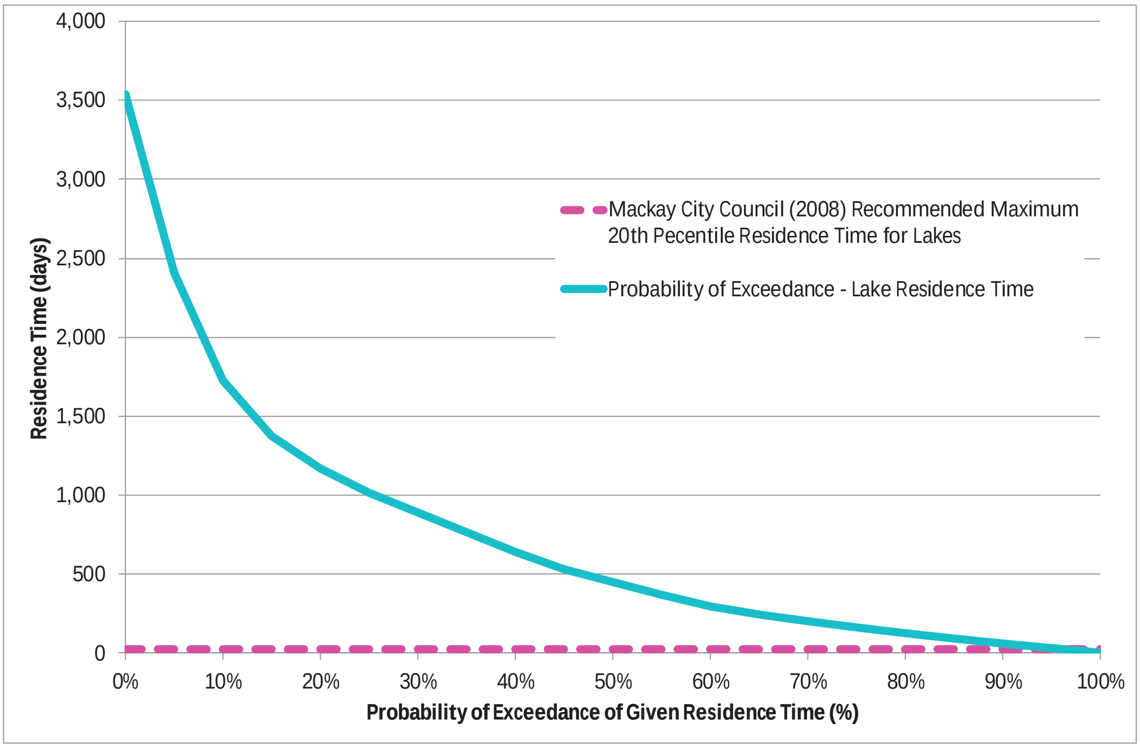

Figure E-13 Predicted Probability of Exceedance of Residence Time for Existing Catchment Conditions (1950 to 2014) in Lower Lake

E.2.2 Existing Catchment Conditions, with additional top-up water and recirculation of lake waters

E.2.2.1 Upper Lake

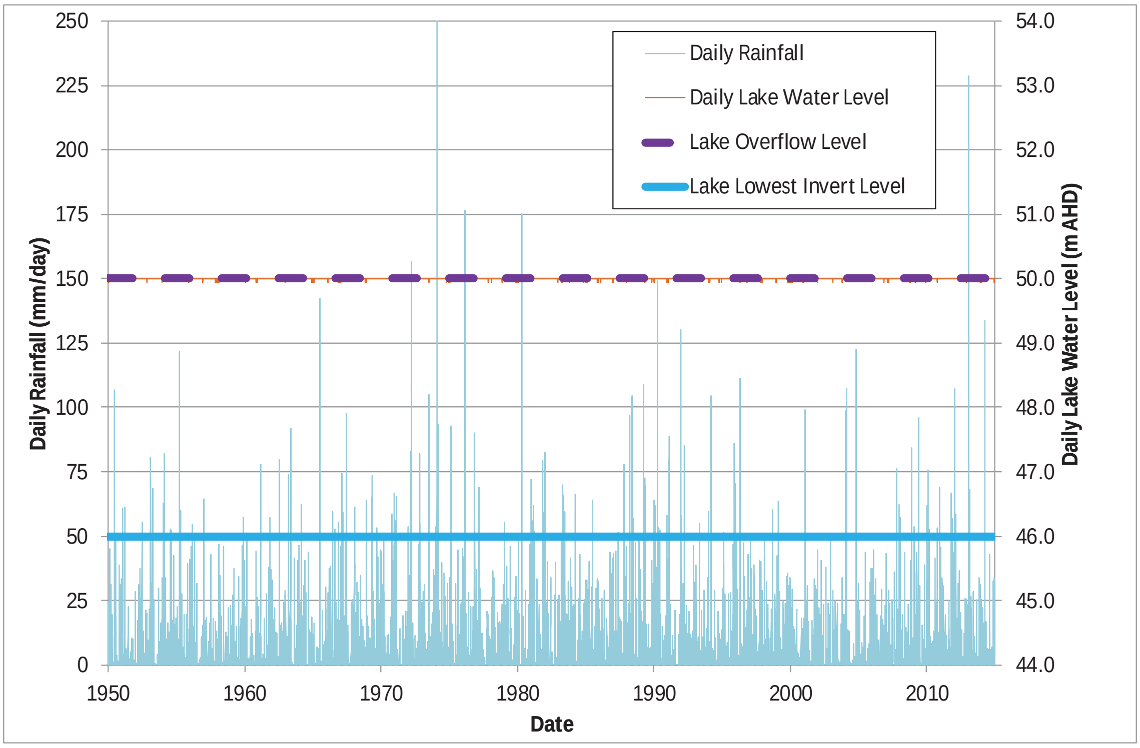

Figure E-14 Predicted Water Level Variation in Upper Lake for Existing Catchment Conditions

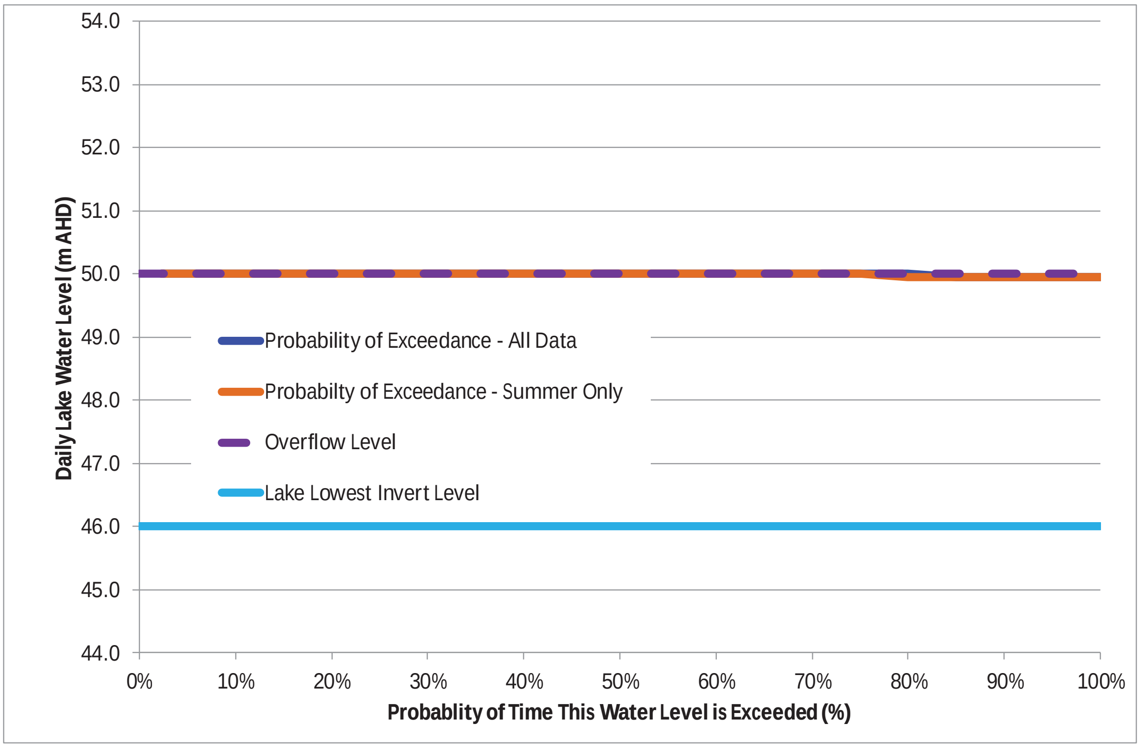

Figure E-15 Predicted Probability of Exceedance of Water Levels for Existing Catchment Conditions (1950 to 2014) for the Upper Lake

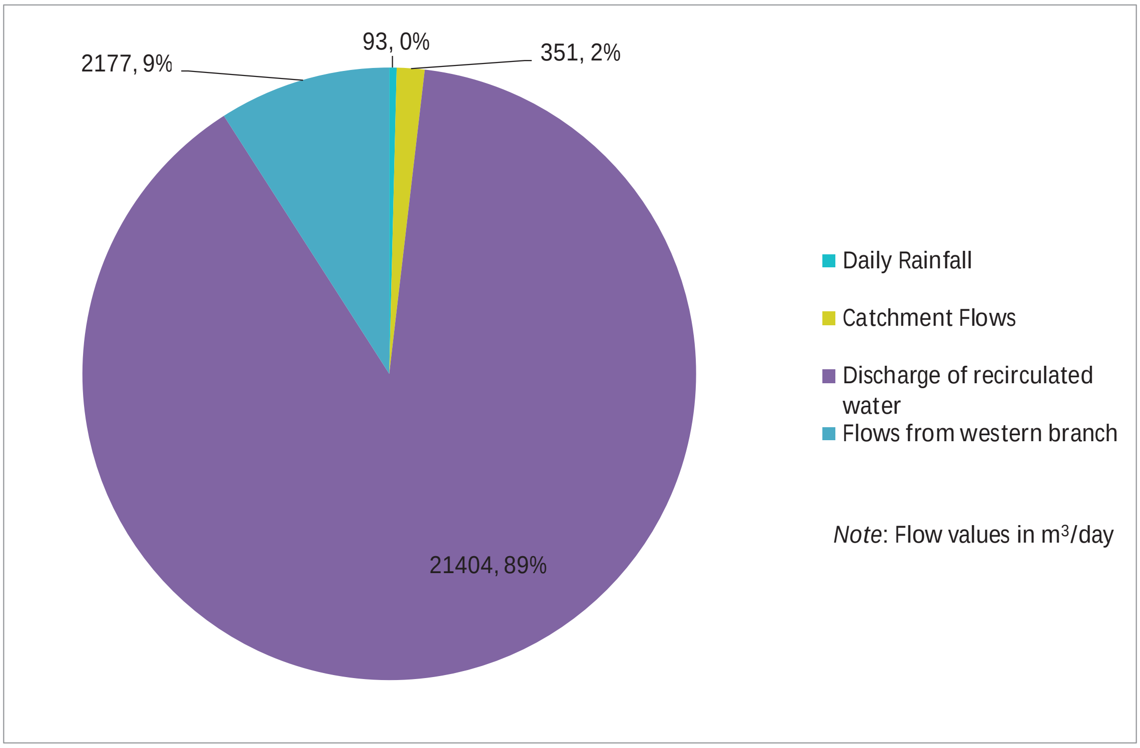

Figure E-16 Predicted Distribution of Inflows to Upper Lake for Existing Catchment Conditions (1950 to 2014)

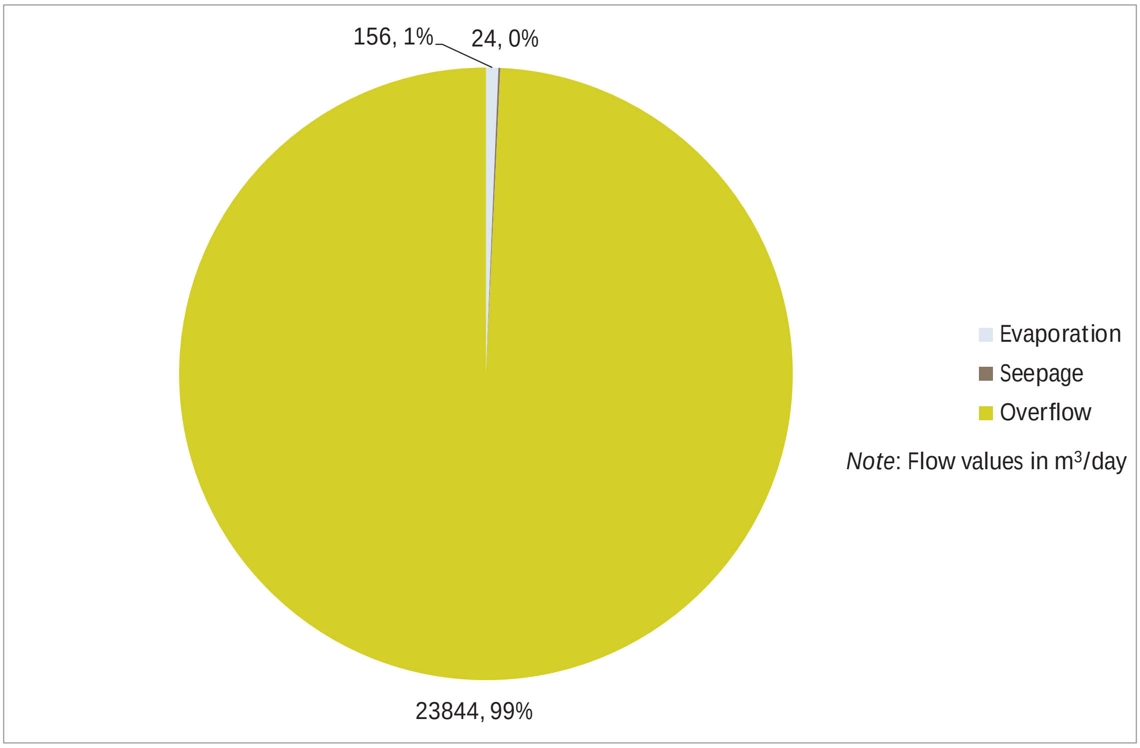

Figure E-17 Predicted Distribution of Outflows from Upper Lake for Existing Catchment Conditions (1950 to 2014)

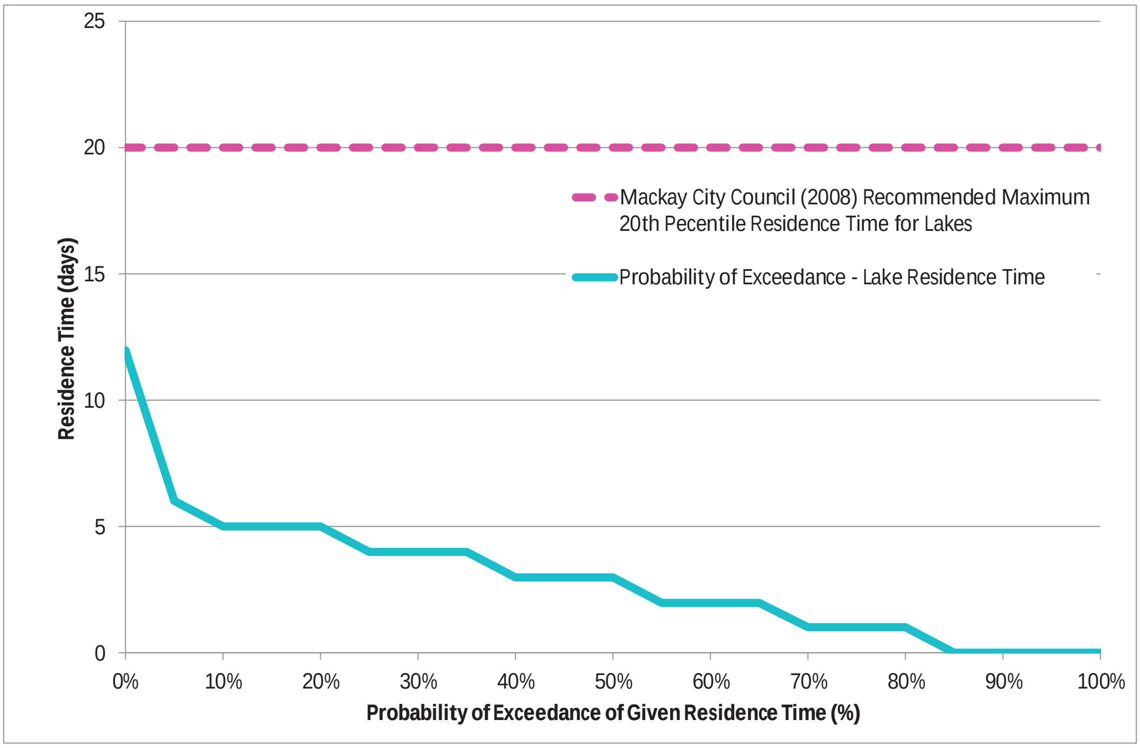

Figure E-18 Predicted Probability of Exceedance of Residence Time for Existing Catchment Conditions (1950 to 2014) for the Upper Lake

E.2.2.2 Lower Lake

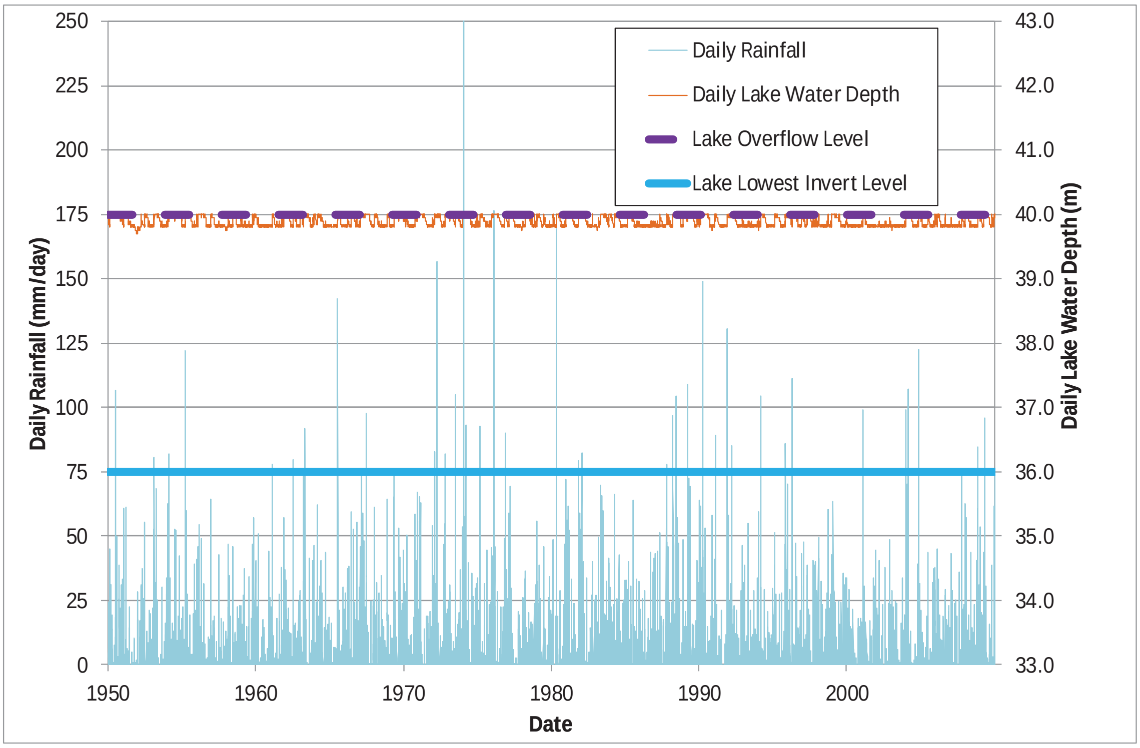

Figure E-19 Predicted Water Level Variation in Lower Lake for Existing Catchment Conditions

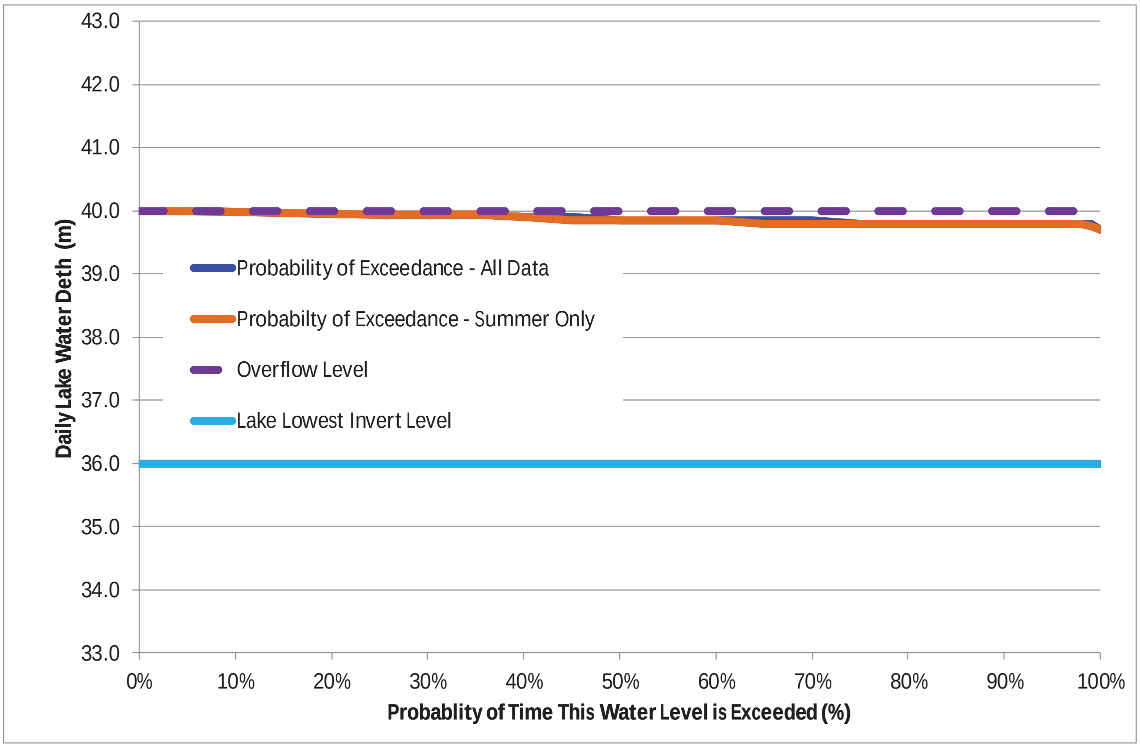

Figure E-20 Predicted Probability of Exceedance of Water Levels for Existing Catchment Conditions (1950 to 2009) for Lower Lake

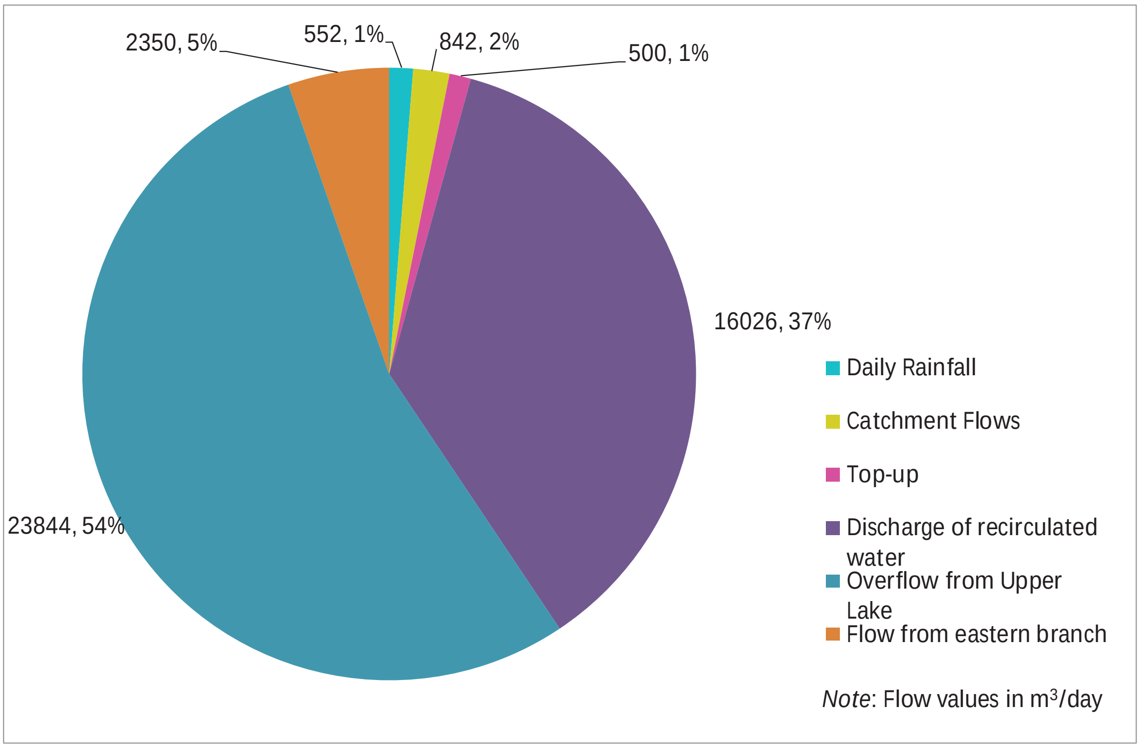

Figure E-21 Predicted Distribution of Inflows to Lower Lake for Existing Catchment Conditions (1950 to 2009)

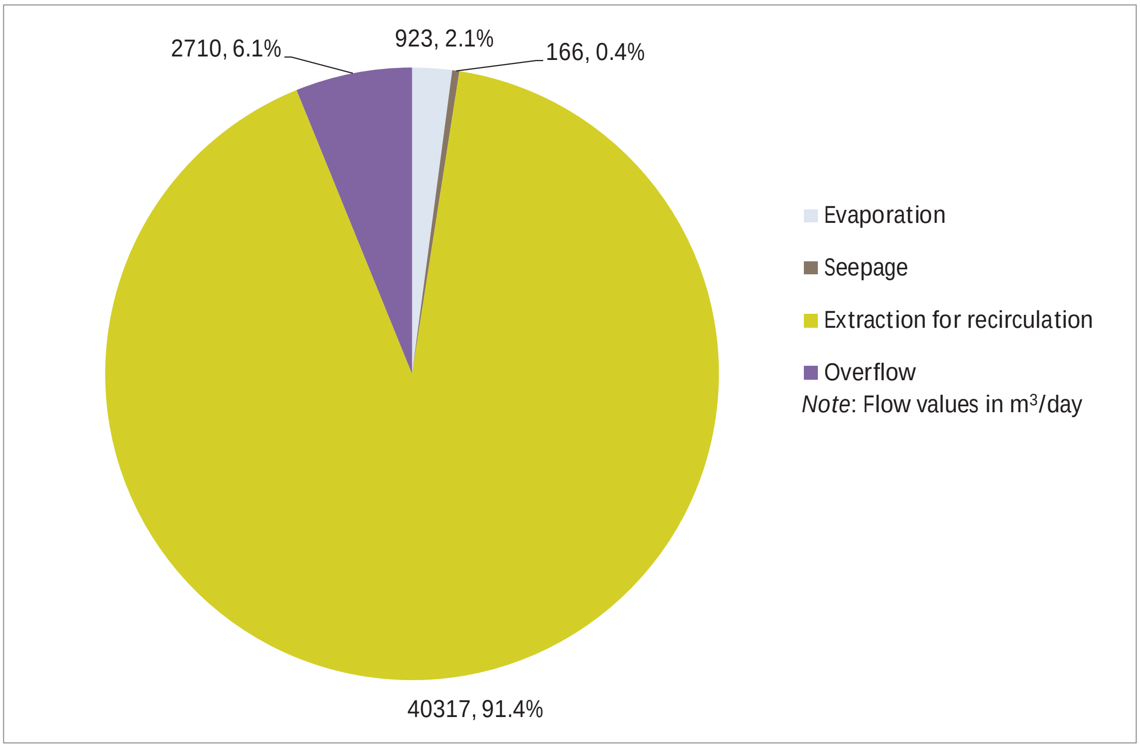

Figure E-22 Predicted Distribution of Outflows from Lower Lake for Existing Catchment Conditions (1950 to 2014)

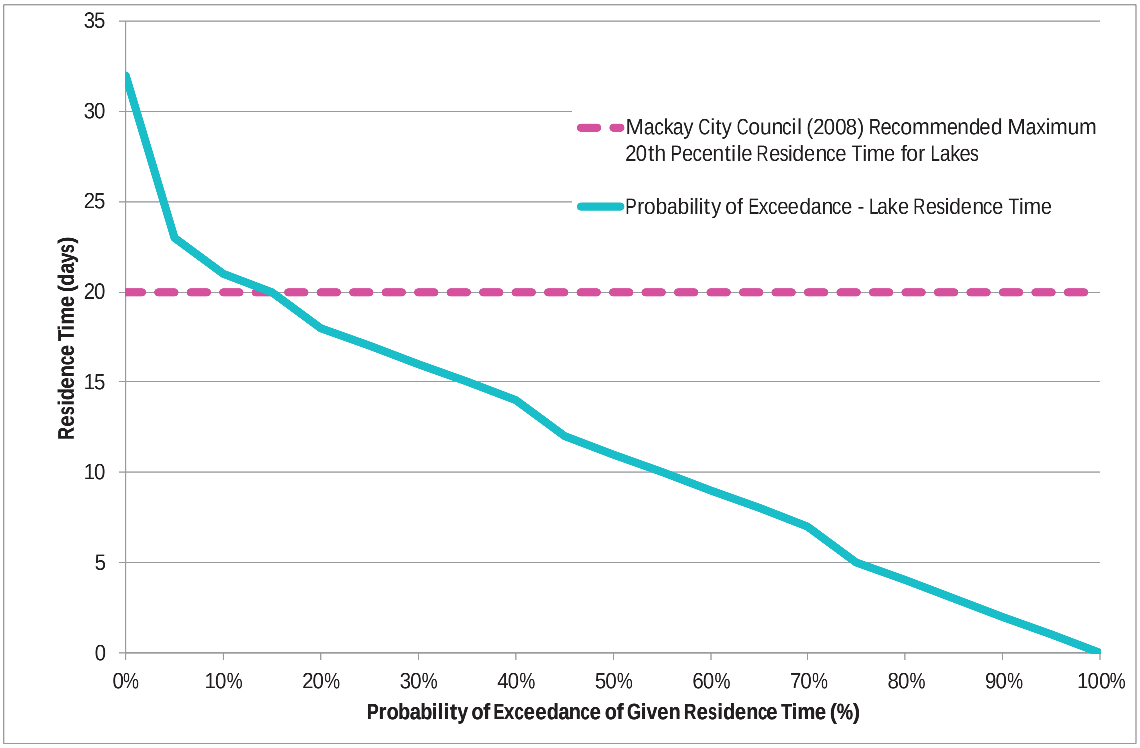

Figure E-23 Predicted Probability of Exceedance of Residence Time for Existing Catchment Conditions (1950 to 2014) in Lower Lake

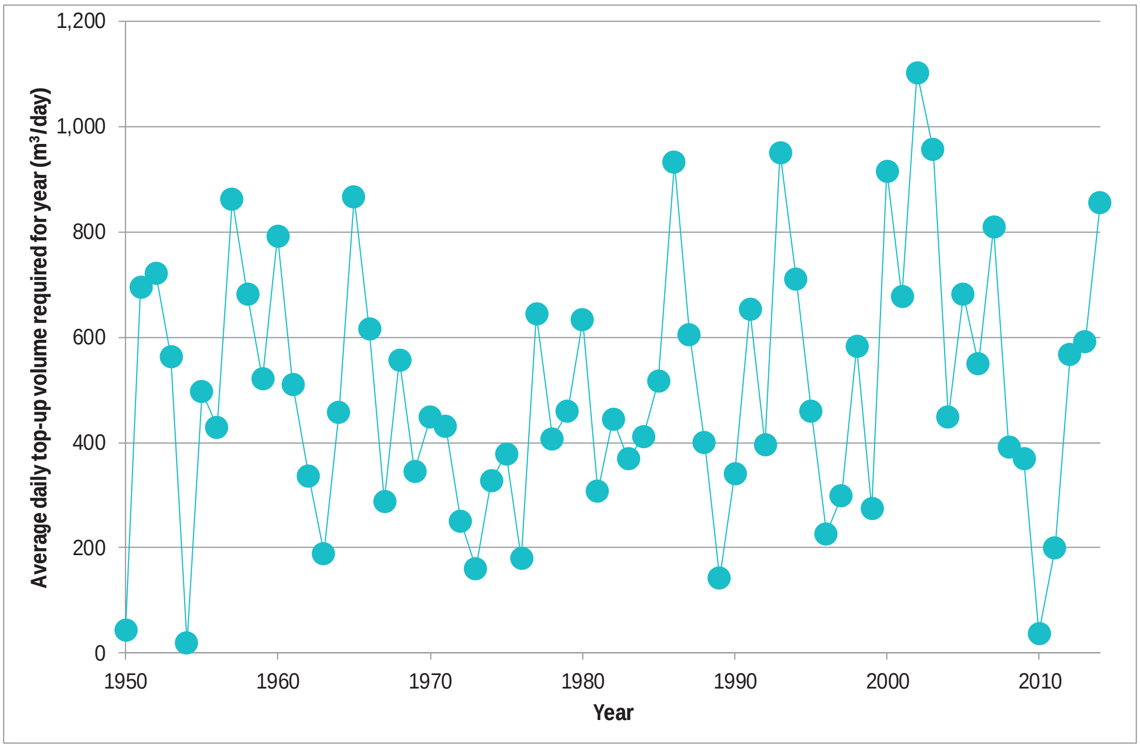

Figure E-24 Predicted Average Top-up Volume by Year Required for Existing Catchment Conditions (1950 to 2014)

E.2.3 Developed Catchment Conditions, with no recirculation and no top up

E.2.3.1 Upper Lake

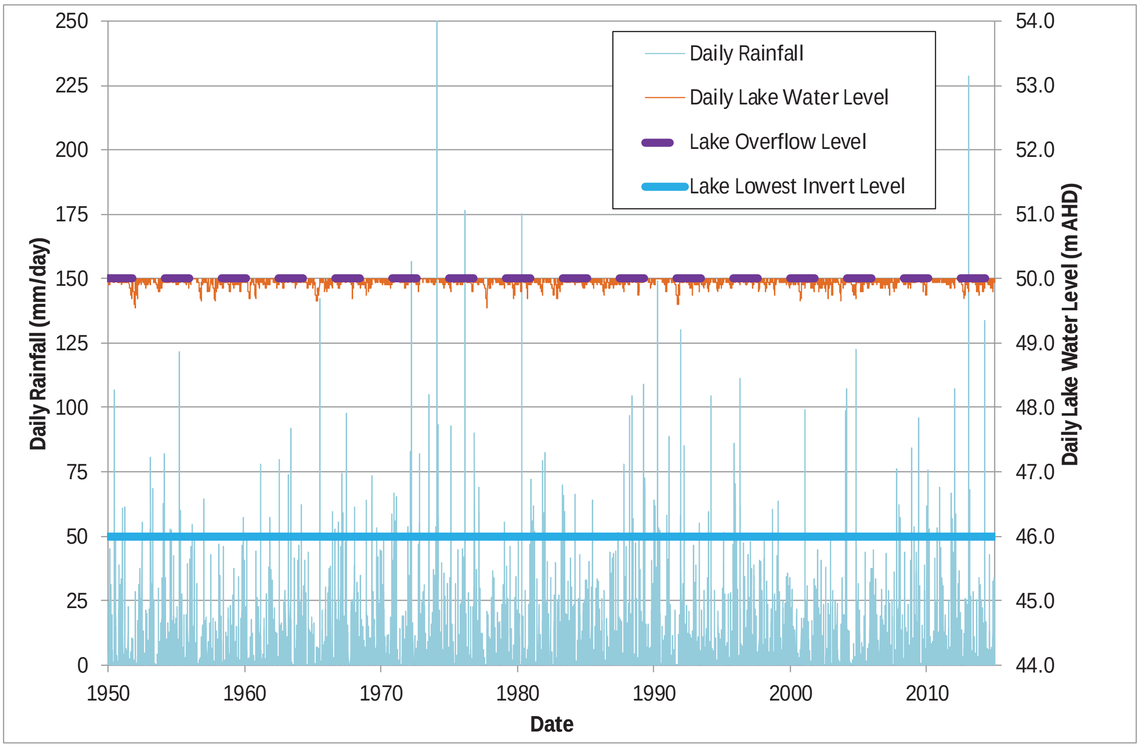

Figure E-25 Predicted Water Level Variation in Upper Lake for Developed Catchment Conditions

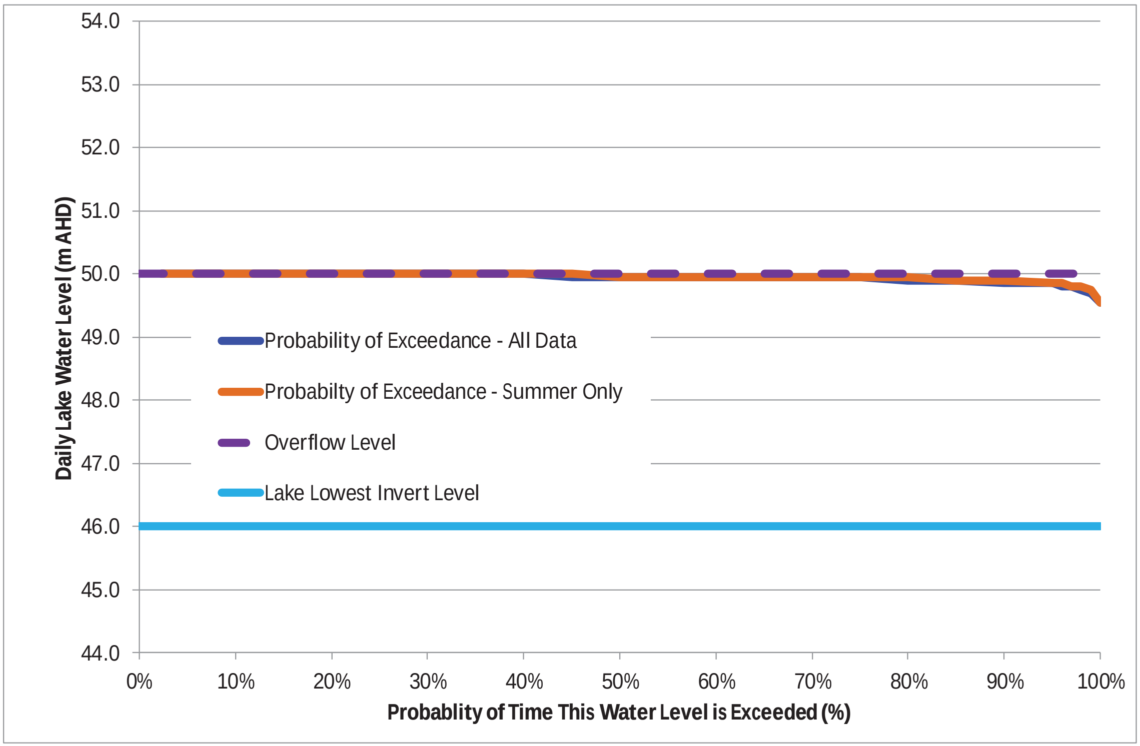

Figure E-26 Predicted Probability of Exceedance of Water Levels for Developed Catchment Conditions (1950 to 2009) for Upper Lake

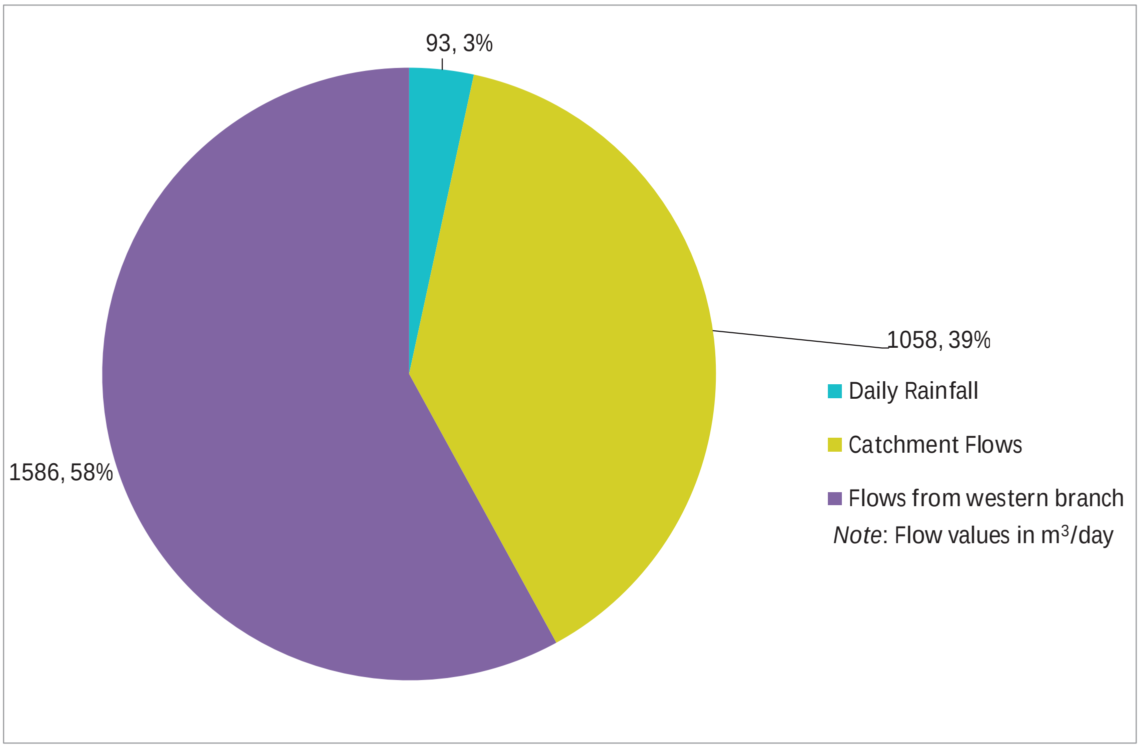

Figure E-27 Predicted Distribution of Inflows to Upper Lake for Developed Catchment Conditions (1950 to 2009)

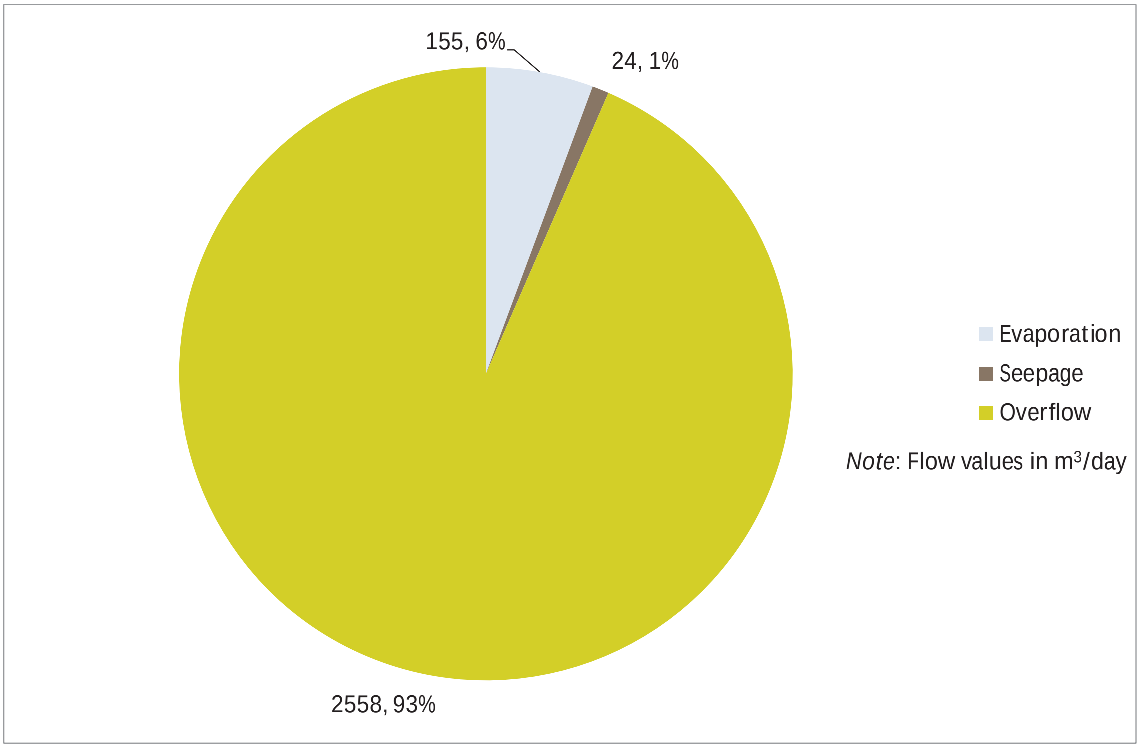

Figure E-28 Predicted Distribution of Outflows from Upper Lake for Developed Catchment Conditions (1950 to 2009)

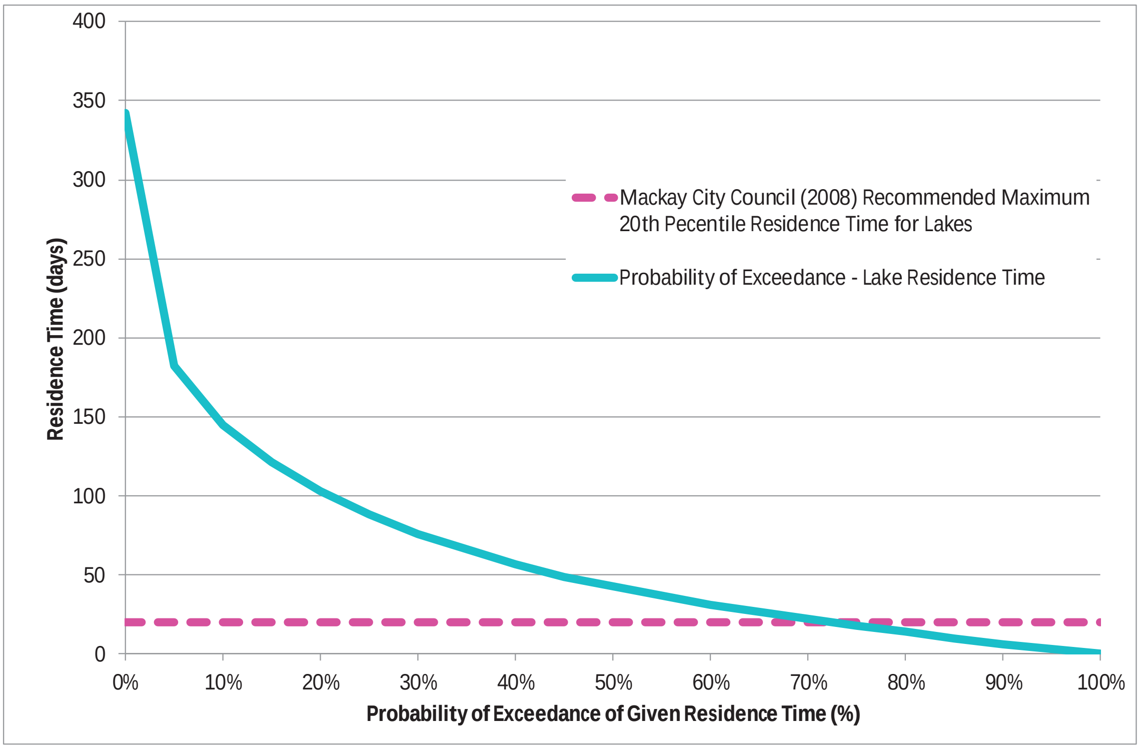

Figure E-29 Predicted Probability of Exceedance of Residence Time for Developed Catchment Conditions (1950 to 2009) for Upper Lake

E.2.3.2 Lower Lake

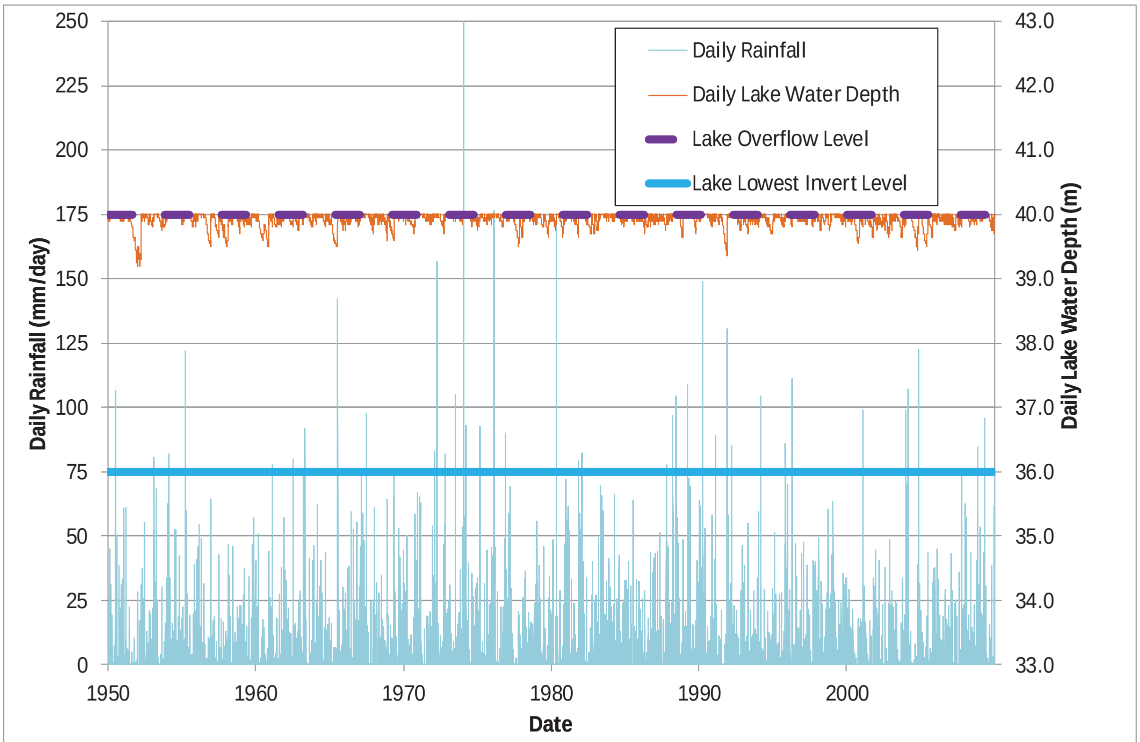

Figure E-30 Predicted Water Level Variation in Lower Lake for Developed Catchment Conditions

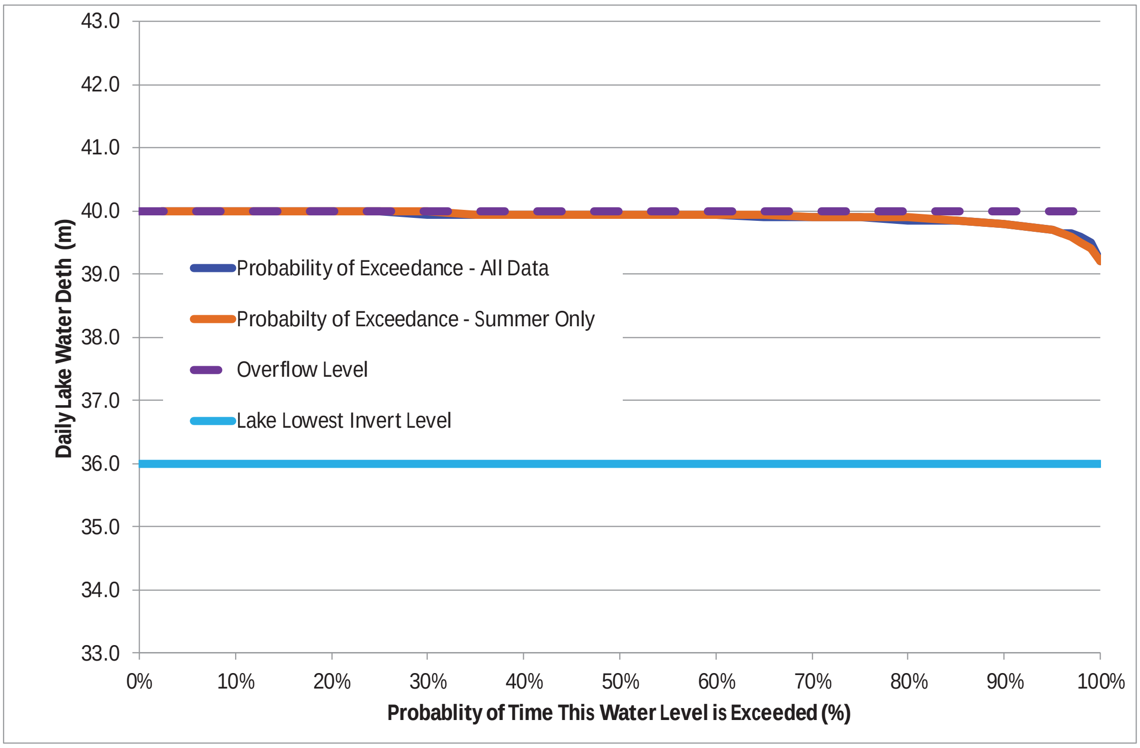

Figure E-31 Predicted Probability of Exceedance of Water Levels for Developed Catchment Conditions (1950 to 2009) for Lower Lake

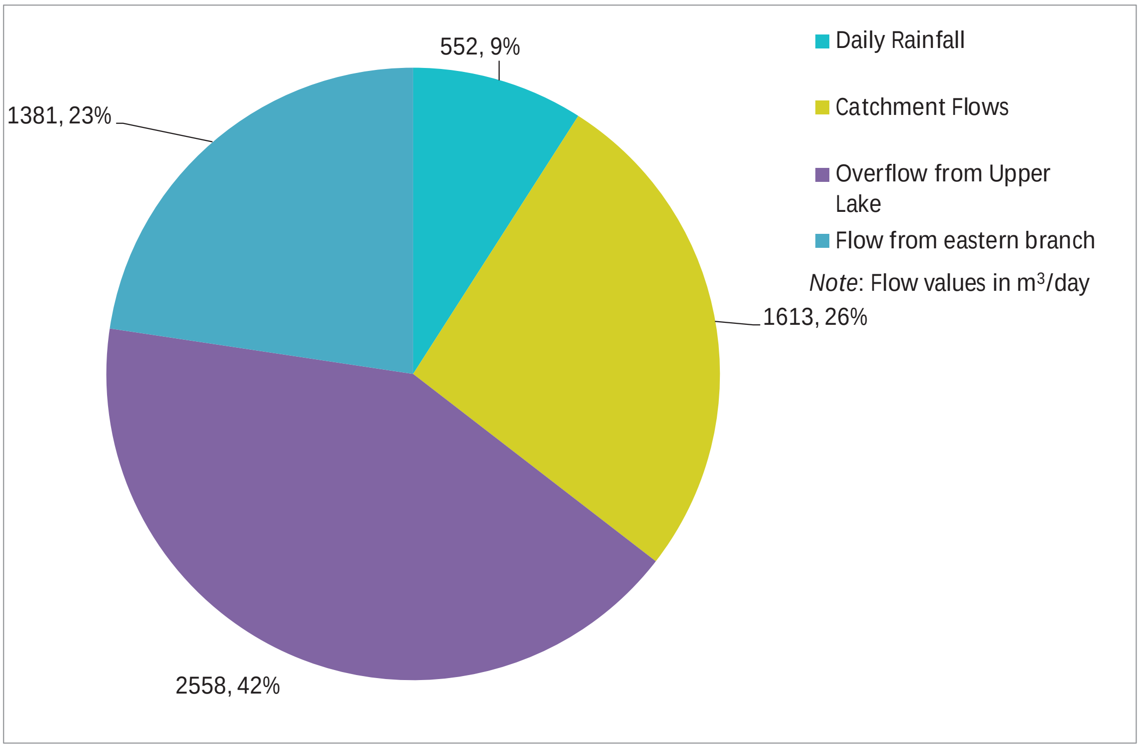

Figure E-32 Predicted Distribution of Inflows to Lower Lake for Developed Catchment Conditions (1950 to 2009)

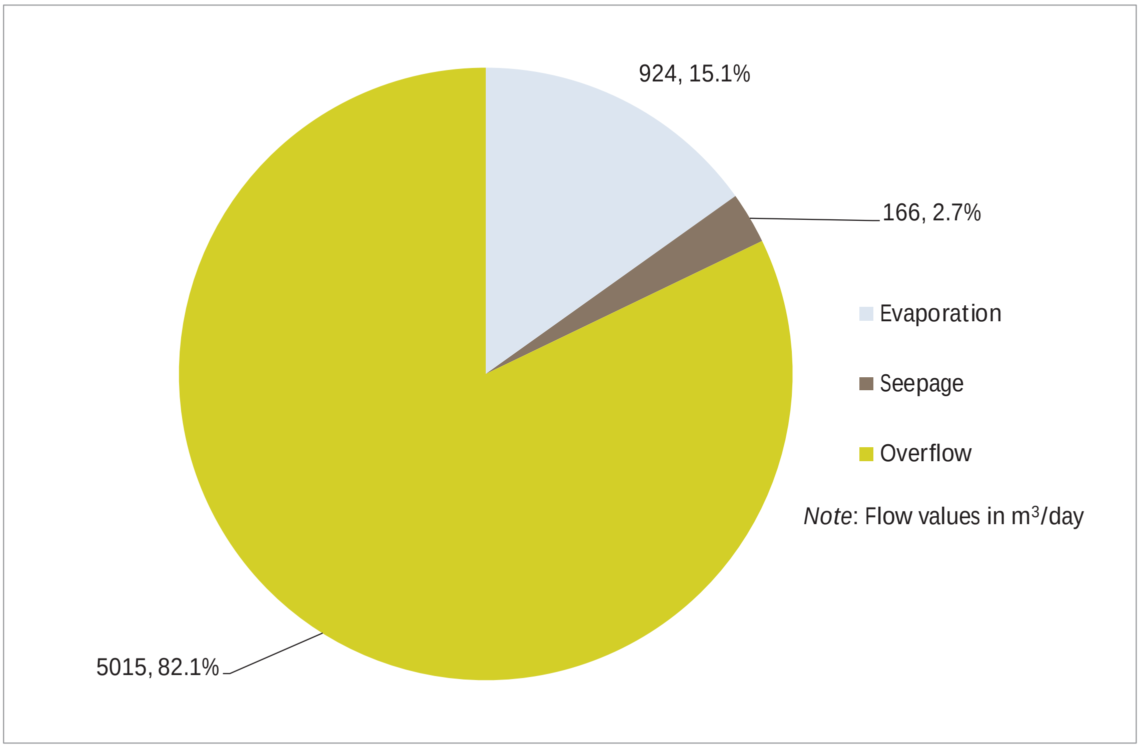

Figure E-33 Predicted Distribution of Outflows from Lower Lake for Developed Catchment Conditions (1950 to 2009)

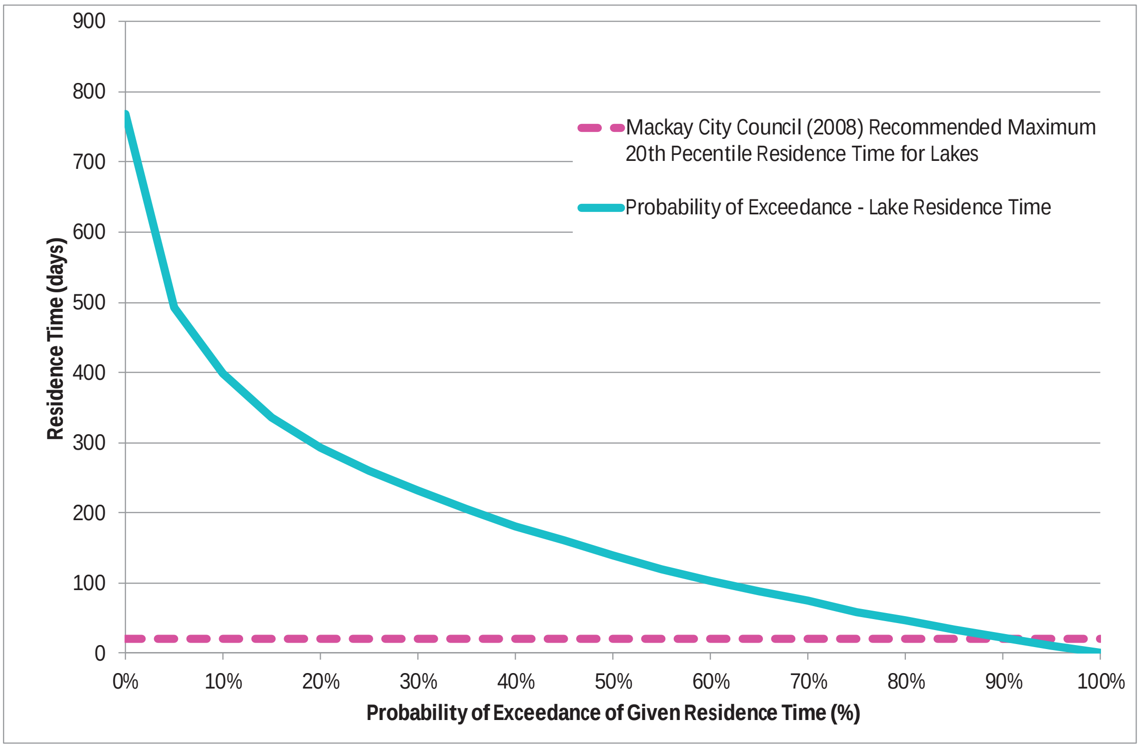

Figure E-34 Predicted Probability of Exceedance of Residence Time for Developed Catchment Conditions (1950 to 2009) for Lower Lake

E.2.4 Developed Catchment Conditions, with top up, recirculation and irrigation

E.2.4.1 Upper Lake

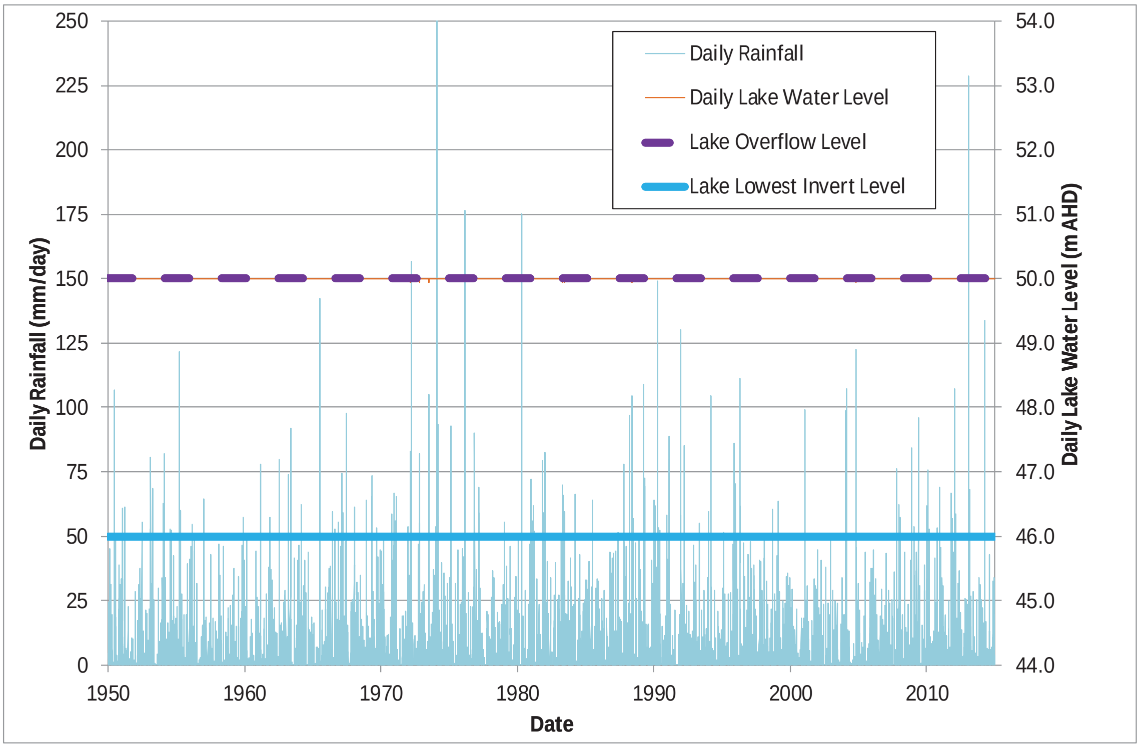

Figure E-35 Predicted Water Level Variation in Upper Lake for Developed Catchment Conditions

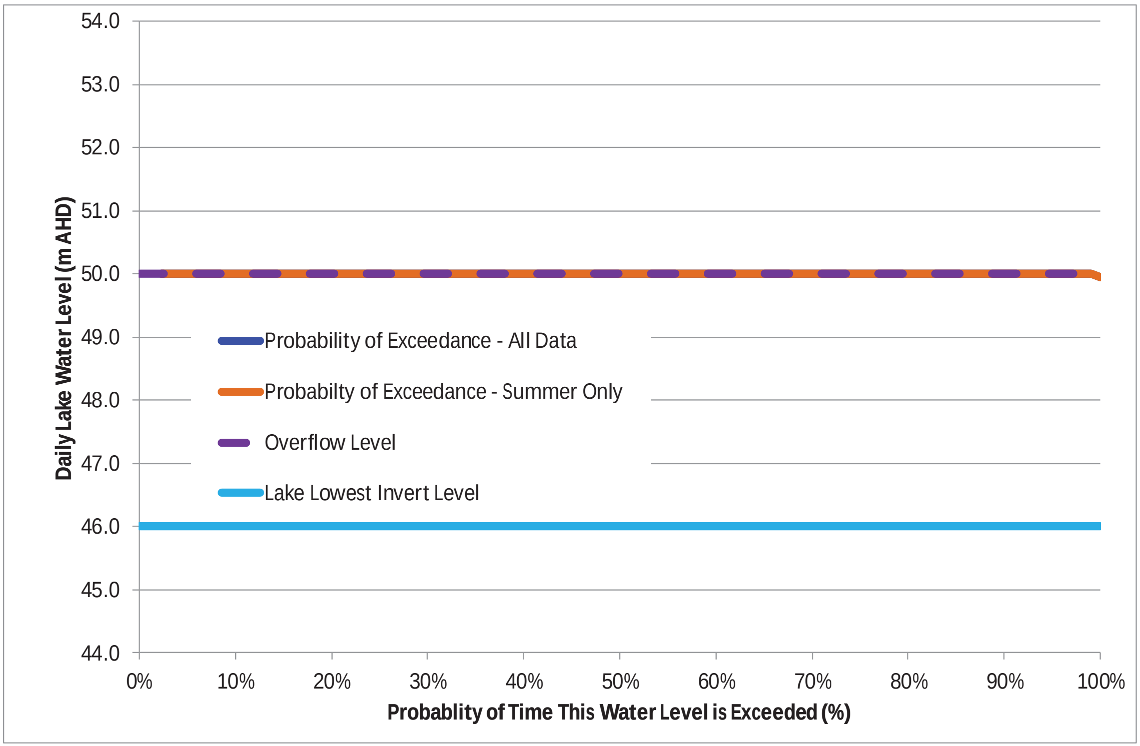

Figure E-36 Predicted Probability of Exceedance of Water Levels for Developed Catchment Conditions (1950 to 2009) for Upper Lake

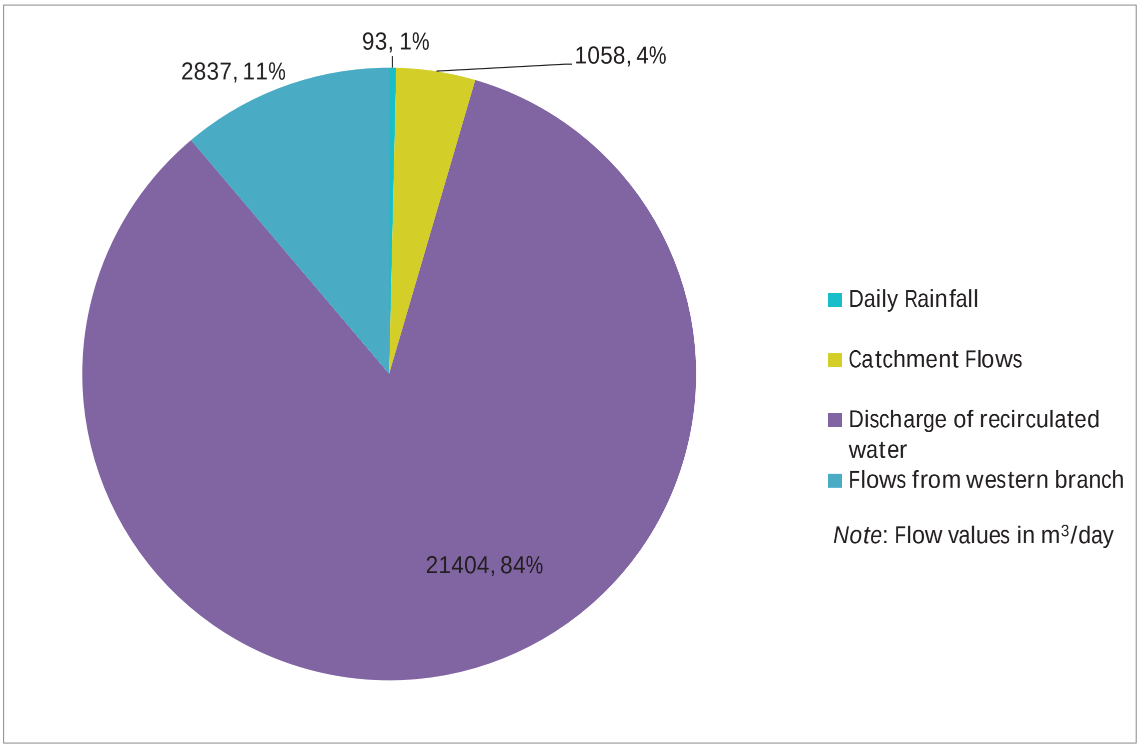

Figure E-37 Predicted Distribution of Inflows to Upper Lake for Developed Catchment Conditions (1950 to 2009)

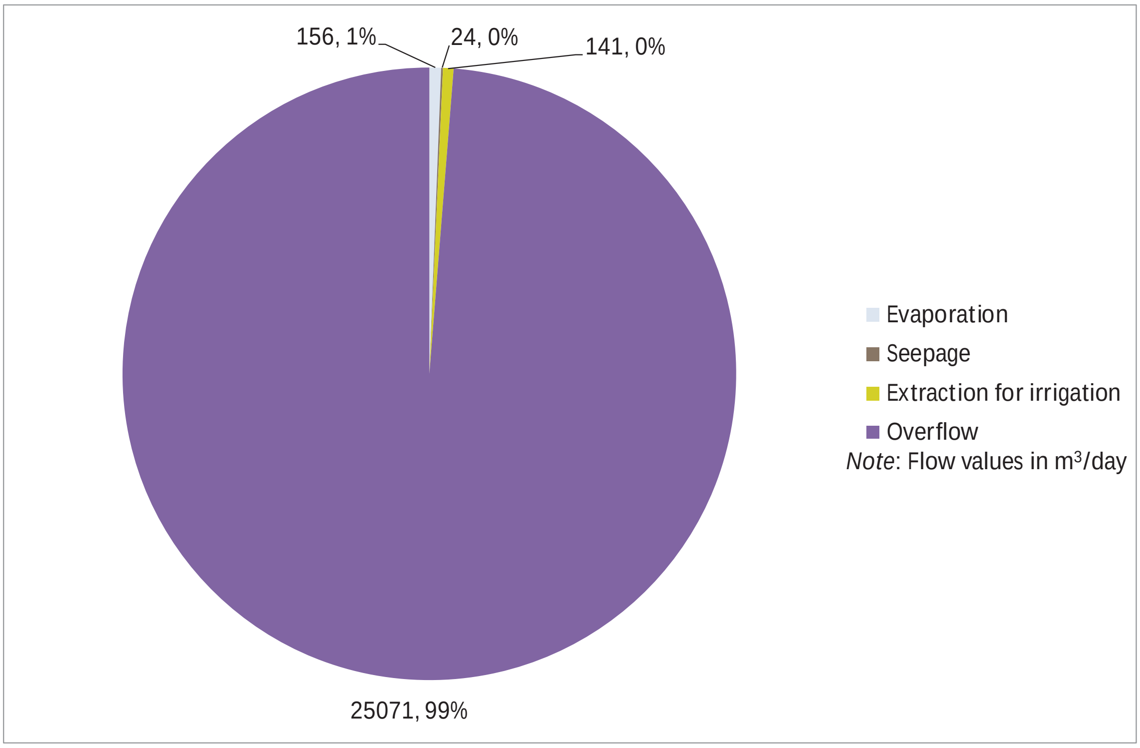

Figure E-38 Predicted Distribution of Outflows from Upper Lake for Developed Catchment Conditions (1950 to 2009)

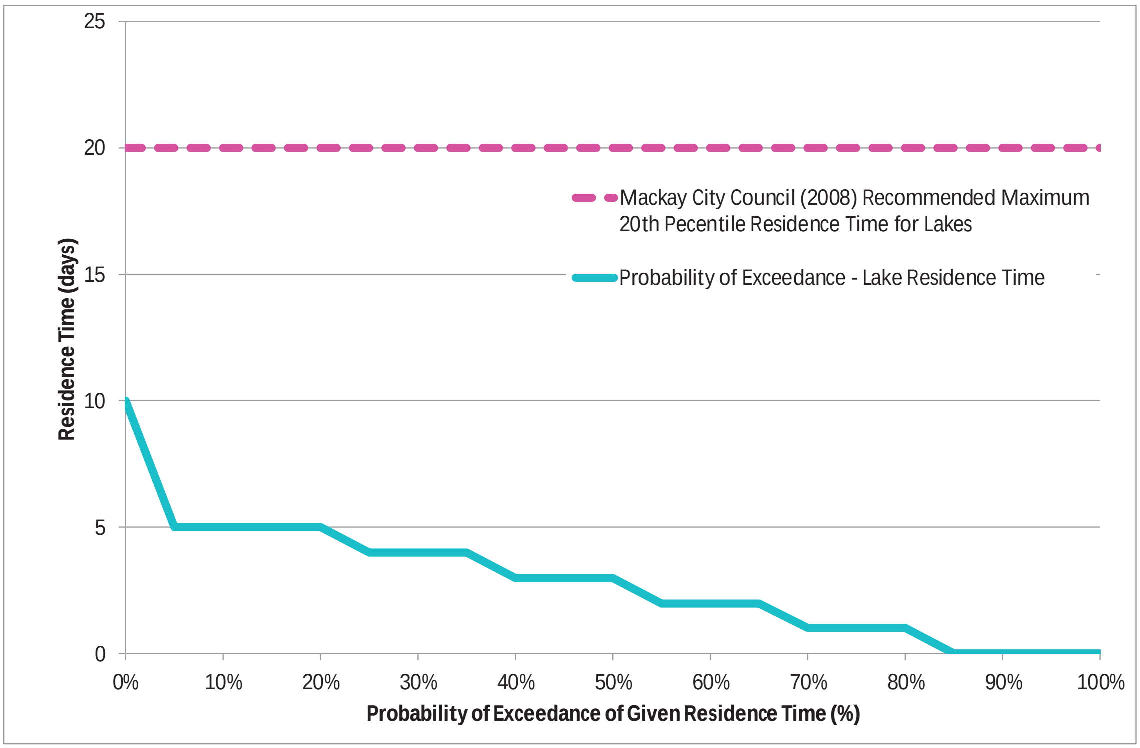

Figure E-39 Predicted Probability of Exceedance of Residence Time for Developed Catchment Conditions (1950 to 2009) for Upper Lake

E.2.4.2 Lower Lake

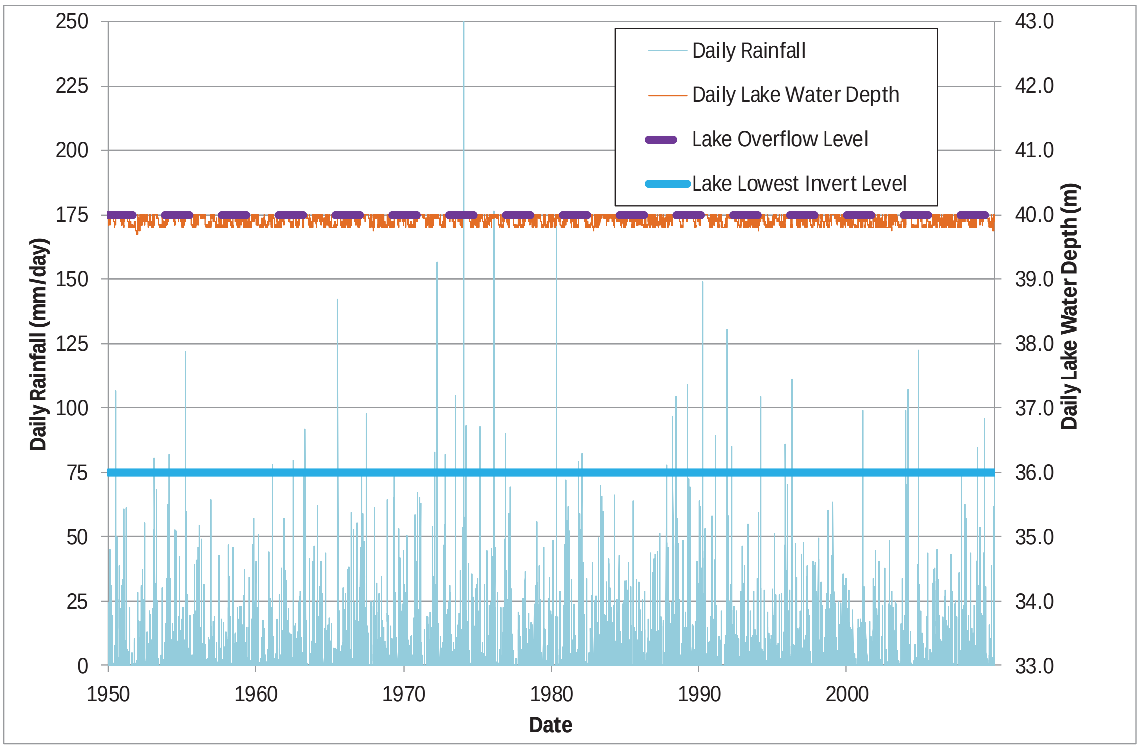

Figure E-40 Predicted Water Level Variation in Lower Lake for Developed Catchment Conditions

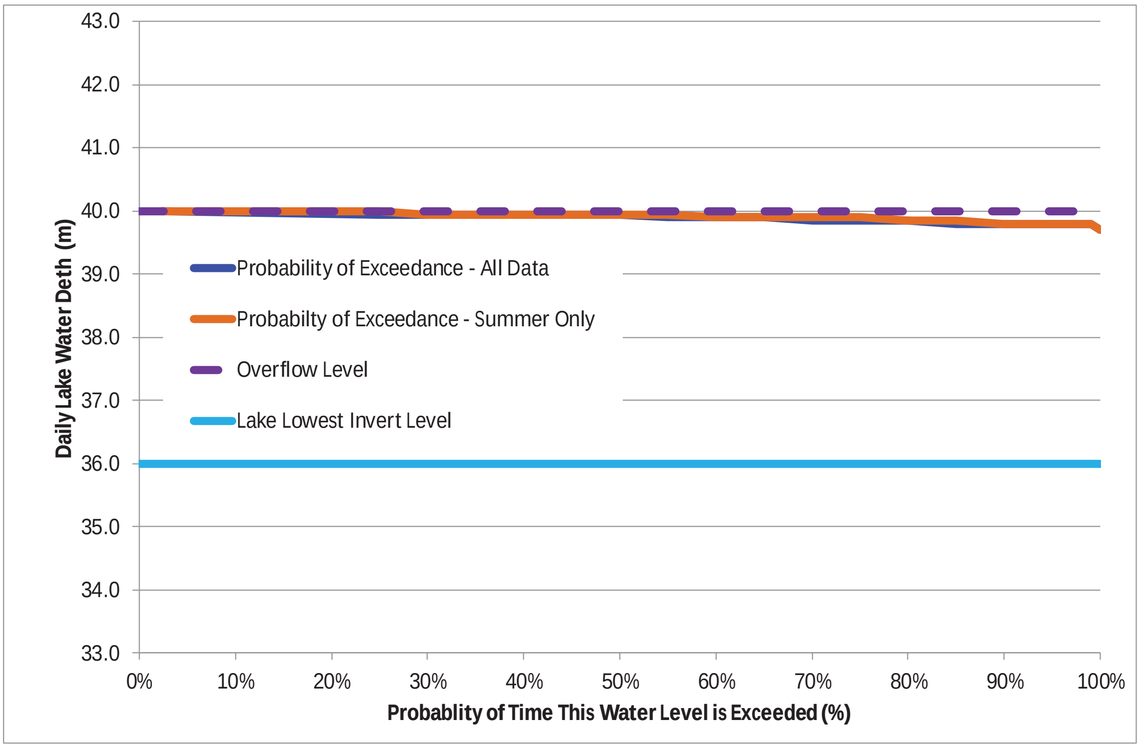

Figure E-41 Predicted Probability of Exceedance of Water Levels for Developed Catchment Conditions (1950 to 2009) for Lower Lake

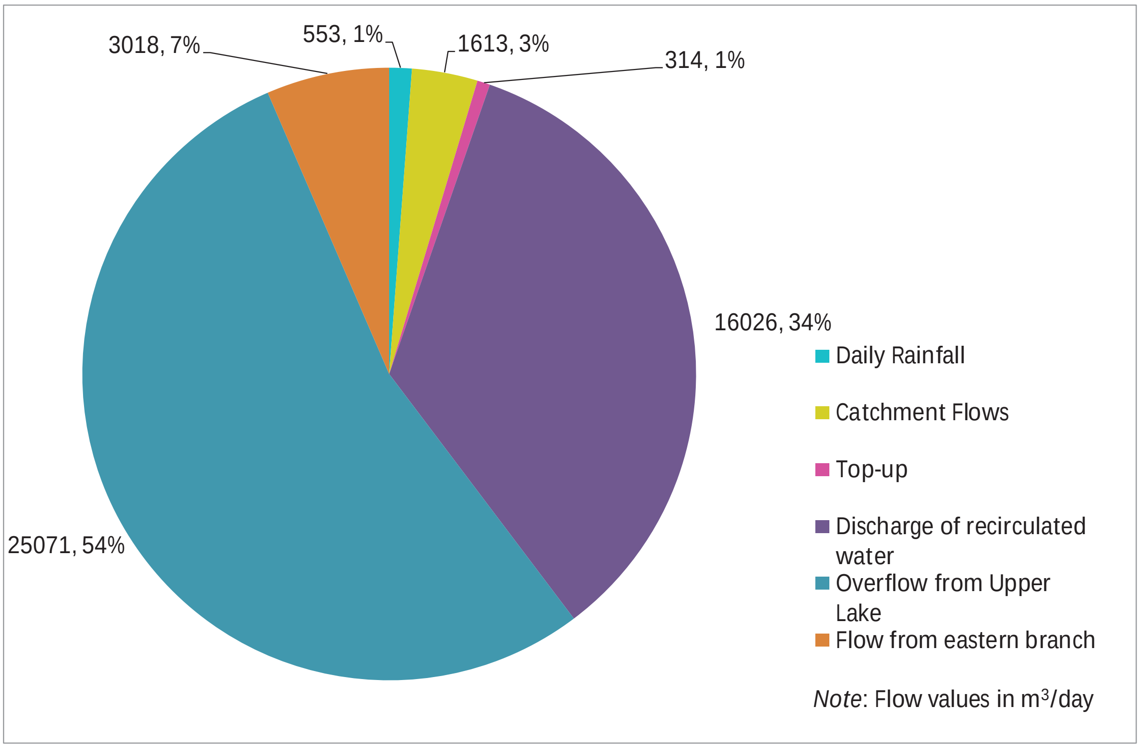

Figure E-42 Predicted Distribution of Inflows to Lower Lake for Developed Catchment Conditions (1950 to 2009)

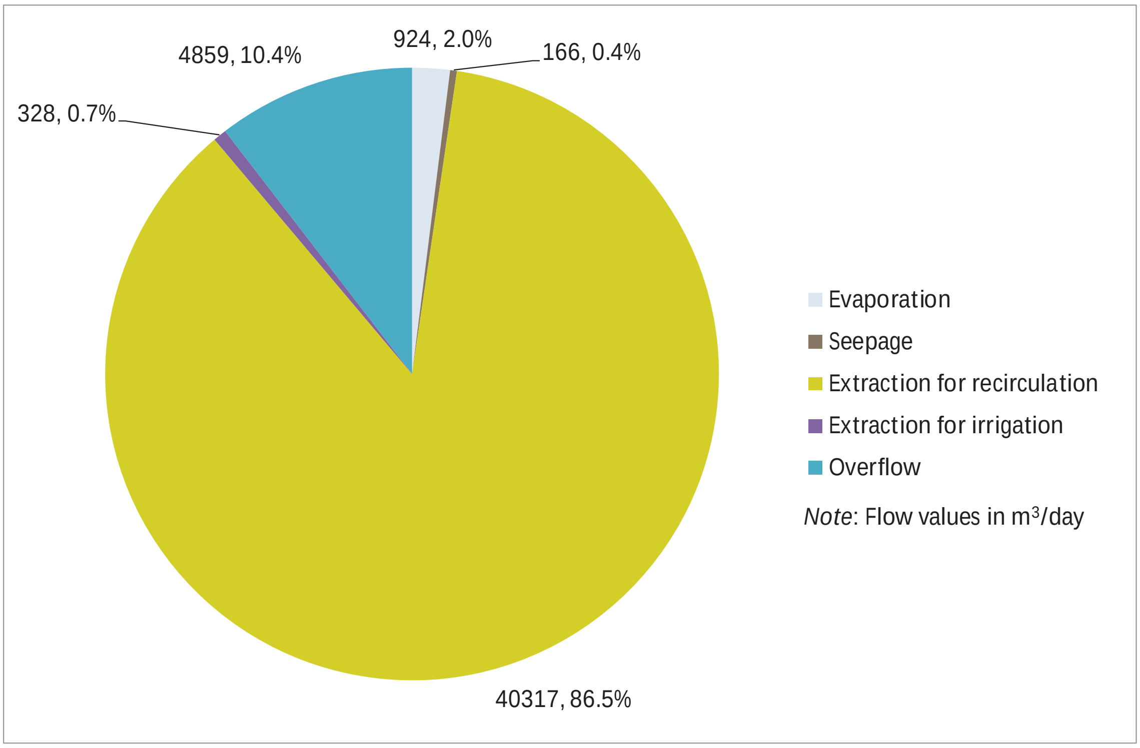

Figure E-43 Predicted Distribution of Outflows from Lower Lake for Developed Catchment Conditions (1950 to 2009)

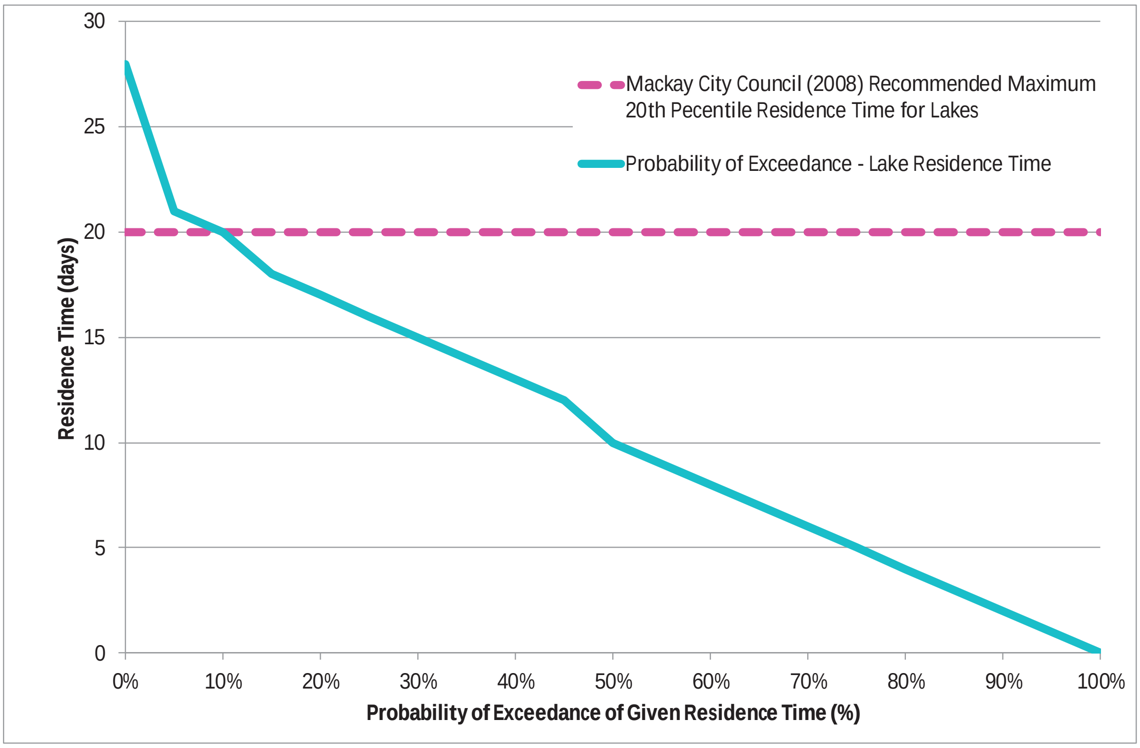

Figure E-44 Predicted Probability of Exceedance of Residence Time for Developed Catchment Conditions (1950 to 2009) for Lower Lake

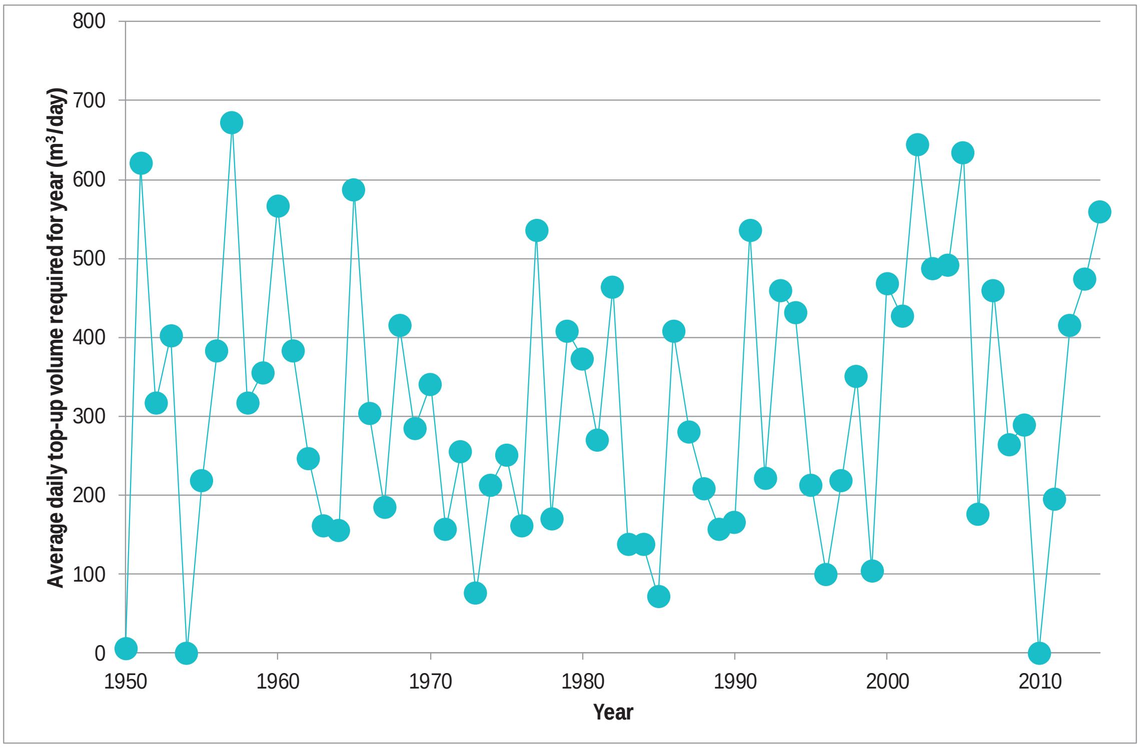

Figure E-45 Predicted Average Top-up Volume by Year Required for Developed Catchment Conditions (1950 to 2014)

E.2.5 Dam Filling Time Results

The results of the dam filling time results are presented in the figures below and Table E-3.

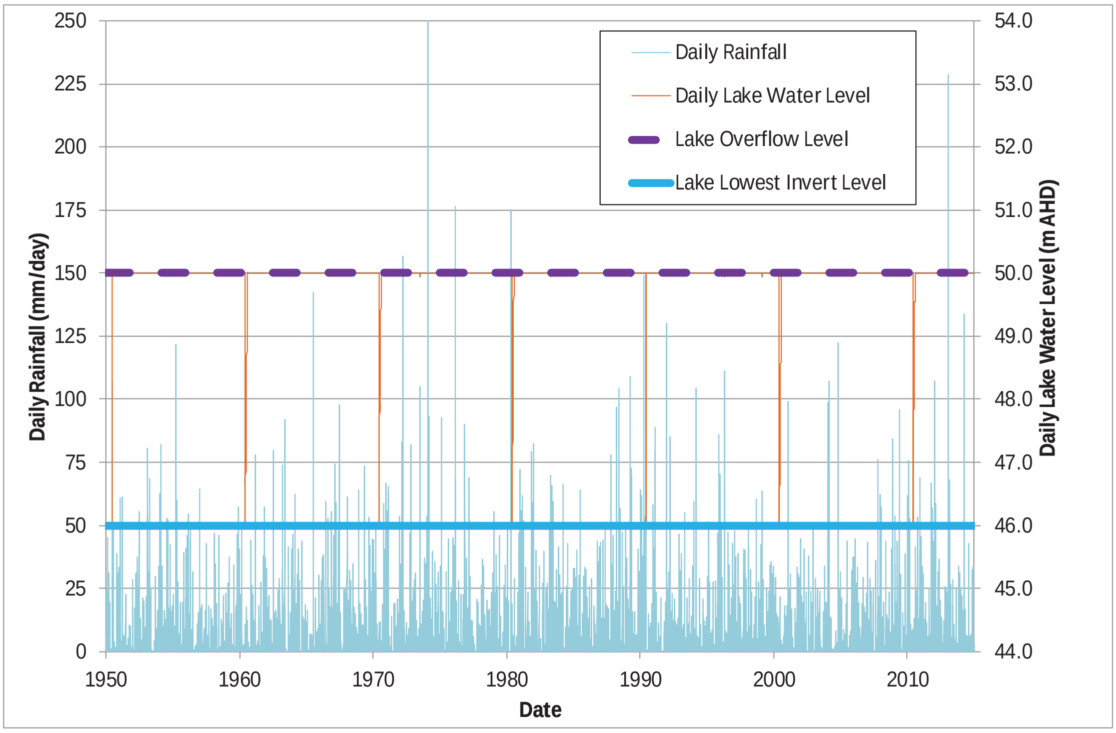

Figure E-46 Graph Showing Results of Upper Lake Filling Time Results (Lake Volume Assumed to be Zero Every Ten Years)

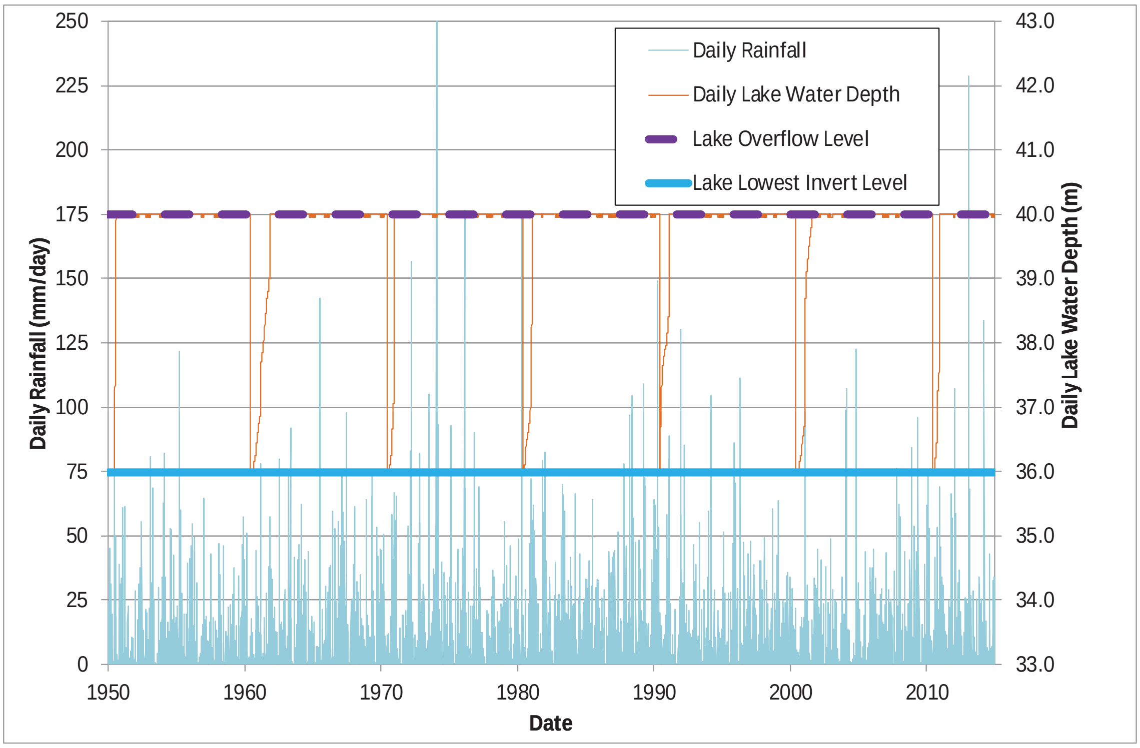

Figure E-47 Graph Showing Results of Lower Lake Filling Time Results (Lake Volume Assumed to be Zero Every Ten Years)

Table E-3 Summary of Lake Filling Time Results

Start Year	Number of Days to Fill to 100% Lake Capacity	
	Upper Lake	Lower Lake
1950	23	39
1960	70	470
1970	71	122
1980	50	204
1990	24	230
2000	70	388
2010	66	144
Average	**53**	**228**

The results show the number of days to fill the upper and lower lake, noting that the upper lake is filled first before overtopping to the lower lake. The results show that both lakes can fill to 100% that both lake will fill to 100% capacity within an average of less than one year (and commence overflowing to the downstream environment). The maximum duration to fill to 100% capacity during the ten-year periods assessed was approximately 1.5 years (during the 1960's). In one of the seven periods assessed, the lake was predicted to fill to 100% capacity in approximately two months.

E.2.6 Summary of Results

Based on the modelling results presented in the previous sub-sections, in summary:

- For existing catchment conditions, with no top-up water or recirculation of lake waters:
  - Predicted water levels for the proposed lower lake are more than 1m below the overflow level for approximately 20% of the time.
  - There was one period within the 64-year period modelled where the lake water level was more than 3m below the overflow level – this was during the 'millennium drought'.
  - Water level variation is predicted to not achieve the performance criteria given in Table 4-10.
  - The majority of water inputs are from catchment flows.
  - Approximately 68% of water outputs from the lower lake are from overflow.
  - Recommended values for lake residence time (given by Mackay City Council (2008)) are significantly exceeded for the lower lake.
- For existing catchment conditions with top-up water and recirculation of lake waters:
  - The available top-up water can maintain predicted water levels for the proposed upper and lower lake at acceptable levels.
  - Recommended values for lake residence time (given by Mackay City Council (2008)) are achieved in the upper and lower lake.
  - The predicted required annual average top-up water significantly varies, with a maximum of 1103m^3/day (top-up operating 233 days in 2002), minimum of 19m^3/day (operating 4 days in 1954) and average of 500m^3/day
  - Based on the five climatic periods assessed, the upper and lower lakes will fill to 100% capacity within an average of less than one year (and commence overflowing to the downstream environment).
- For the development catchment conditions:
  - Water level variation is predicted to achieve the performance criteria given in Table 4-10.
  - In the absence of recirculation, recommended values for lake residence time (given by Mackay City Council (2008)) are significantly exceeded for the lower lake.
  - With recirculation, recommended values for lake residence time are achieved.

E.2.7 Discussion

Catchment flows will be heavily influenced by the imperviousness and hydraulic efficiency of the catchment – with increased imperviousness (e.g. associated with roads, buildings) and hydraulic efficiency (e.g. associated with stormwater conveyance infrastructure) contributing to an increased frequency and volume of flows to the lake. In the absence of the proposed development (and associated imperviousness and high hydraulic efficiency) and any top-up water, catchment flows are low (relative to the developed catchment) and total predicted water inflows to the lake are not anticipated to be sufficient to prevent unacceptable water level variation in the lake.

Subsequently, prior to the proposed development of the contributing catchment (to the proposed lake), additional (albeit temporary) sources of water (of appropriate quality) are anticipated to be required to prevent unacceptable water level variation.

The assumed 20 litres/ second (1728m^3/day) of available top-up water is predicted to be sufficient to fill the lake to maximum capacity within a reasonable period of time (in less than one year, on average) and maintain appropriately high water levels within the proposed waterbodies.

To mitigate potential water quality problems associated with extended residence times, it is recommended that lake waters be actively recirculated and treated through a designated treatment plant and/ or through the waterways upstream of the lake. It is further recommended that these gully areas be configured to promote shading and treatment of the recirculated lake waters. This is described further in Section 4.12.3.

Appendix F Lake operation and management cost analyses

The management and maintenance cost to maintain the quality of water within the proposed lake is important to understand. Section 4 outlines a range of tasks and actions required as part of the ongoing management of the proposed lakes.

This appendix provides an assessment of the likely required management actions and associated estimated costs to maintain the proposed lake. These costs are also compared against those required to maintain an equivalent open space area (in the absence of the lake).

F.1 Methodology

Key tasks in this assessment include the following:

- Determine lake management and maintenance requirements to meet the operational performance criteria given in Section 4.
- Review existing lake maintenance cost data including:
  - Available literature.
  - Monitoring and maintenance data from an established urban lake in south east Queensland.
- Apply existing maintenance and monitoring cost data to estimate potential costs of the proposed lake in Precinct 1 of the Flinders development.
- Provide an ‘equivalent area’ cost of maintaining open space (if applied instead of the lake).

F.1.1 Assumptions

The following assumptions were made when calculating the maintenance costs for the proposed lake at Flinders, Precinct 1:

- Water and sediment quality monitoring assumes:
  - Physical water quality parameters monitored monthly at approximately 14 sites across the lake. Parameters to be monitored at regular intervals throughout the water column and include temperature, conductivity, salinity, pH, dissolved oxygen and turbidity.
  - Chemical parameters monitored monthly at four (4) of the sites at both surface and lake bottom (parameters include total suspended solids, total nitrogen, total phosphorus and nutrient speciation, chlorophyll-a, faecal coliforms, enterococci and blue-green algae).
  - Pesticides and trace metals to be assessed twice a year at four (4) sites in the lake, including both surface and sub-surface samples.
  - Sediments to be assessed for nutrients and heavy metals once a year at four (4) sites throughout the lake.
- Lake sediment accumulation assessment is undertaken every 10 years.
- Routine fortnightly inspection of potential physical hazards, lake infrastructure, weed growth, mosquito larvae and removal of debris and litter from the lake and edges will be undertaken by on-site staff. The time was estimated to be 16 hours per fortnight at an hourly rate of $100/hr.

- Aquatic ecological survey includes a benthic fauna survey, fish survey (qualitative), and flora survey (every 5 years).

F.2 Results

F.2.1 Lake Management and Maintenance Requirements

Section 4 outlines the potential lake management and maintenance requirements to meet the operational performance criteria. Key maintenance requirements include:

- Routine fortnightly inspection of all infrastructure, weed growth, mosquito larvae and removal of debris and litter from the lake and edges. To be undertaken by on-site staff.
- Vegetation management.
- Destratification system to ensure thermal stratification of the lake does not develop.
- Lake water 'top up' to maintain lake water levels.
- Water quality and sediment monitoring program.
- Ecological surveys.
- Sediment accumulation monitoring.
- A water treatment system (WTS) is likely to be required to mitigate potential water quality problems associated with extended residence times. It is also proposed that the water from the WTS will be pumped for possible further treatment through the waterways upstream of the lake.

F.2.2 Review of Existing Operational Maintenance Cost Data

A review of the existing literature highlighted that there is limited lake maintenance costs available in south east Queensland, particularly for lakes that have been designed and constructed to current best practice standards. Available data includes:

- Bayley et al (2007) *A Review of Water Quality and Maintenance Costs of Constructed Water Bodies in Urban Areas of South East Queensland*.
  - This report provides a summary of maintenance costs gathered from 20 urban waterbodies within south east Queensland during 2005/06. It should be noted the majority of these lakes were designed before current best practice standards and would, therefore, likely have inflated operational costs compared to a lake designed to the standards specified for Flinders Lake.
- Six (6) years of maintenance data from an established lake in south east Queensland.
- Estimated costs based on BMT WBM experience of lake monitoring and management.
- McCann et al. (2014) *Urban Lakes, The Good News*.
  - This paper provided estimates of maintenance costs for open space land uses.

Table F-1 provides a summary of the tasks associated with the operation, maintenance and maintenance of Flinders Lake.

Table F-1 Typical Lake Operation, Maintenance and Monitoring Elements

Item	Details
Routine inspection	Inspection frequency of the order of two days inspection every fortnight.
Vegetation management	Management tasks include macrophyte harvesting and terrestrial weed management.
Destratification	Associated with destratification units will be operational costs (electricity), pump maintenance and line maintenance.
Lake water 'top up'	In the early phase of development and for prolonged periods of dry weather, top up water will be required. The top up water will be obtained via pumping under licence from Woollaman Creek.
Water quality and sediment monitoring	Water quality sampling is expected to occur monthly at 14 sites, with physical parameters sampled at all sites and chemical parameters sampled at 2 sites. Annual sediment sampling to occur at 2 sites. In addition, data interpretation and reporting will be required in relation to collected data.
Ecological surveys	As per the Lake Management Plan, surveys will include benthic fauna, qualitative fish surveys (presence or absence of key species) and flora surveys at five (5) sites. Surveys will be completed from a boat, with laboratory analysis of samples undertaken.
Sediment accumulation monitoring	Sediment accumulation monitoring will be undertaken using core sampling and visual inspection of the samples along with a bathymetric survey. The bathymetric survey is proposed to be via a single beam dual frequency (50 and 200 kHz) echo sounder or other suitable device on a survey vessel or a drogue boat.
Water Treatment Plant operation	A treatment plant and associated pump system is to be provided to maintain water quality and achieve adequate lake turnover.
Management of animal pests	Periodic activity will be required to minimise pests in and around the lakes.
Edge treatment	The lake edge will require routine maintenance over time.
Desilting	Desilting of lake will be required on an infrequent basis.
Other general operational matters	In addition to the above tasks, there will be other minor maintenance activities associated with the operation of the lakes, such as the removal of litter.

Table F-2 provides a summary of typical lake operational and maintenance costs based on experience of lake monitoring and management. It is noted that the costs will be refined as part of detailed design.

F.2.3 Cost of Maintaining an Equivalent Park Area

The cost of maintaining an equivalent park area if a lake was not to be incorporated into the Flinders development was estimated referencing the following two sources of data:

- McCann et al. (2014) *Urban Lakes, The Good News*.
  - This conference paper provided estimates of maintenance costs for open space land uses.
- Water by Design (2010) *A Business Case for Best Practice Urban Stormwater Management: Case Study Report.*
  - This report provided an estimate of the cost to maintain a turfed area.

The costs estimated for maintaining equivalent open space areas are listed in Table F-2.

Table F-2 Summary of Typical Maintenance and Monitoring Costs for Flinders Lake and Equivalent Open Space Area

Asset	Unit costs ($/m^2/yr)* ($2017)	Estimated Average Annual Maintenance Cost
Lake Monitoring and Maintenance		
Expected maintenance cost	$1.50 - $2.00	$391,000 - $522,000
Equivalent Area		
Typical lake (from McCann et al. 2014)	$1.19	$310,600
Turf (Water by Design, 2010)	$1.24	$324,200
Local / district park (from McCann et al. 2014)	$1.07	$279,500
High profile park (from McCann et al. 2014)	$2.09	$545,400

* Adjusted for inflation

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Appendix G Review of other freshwater lakes in South East Queensland

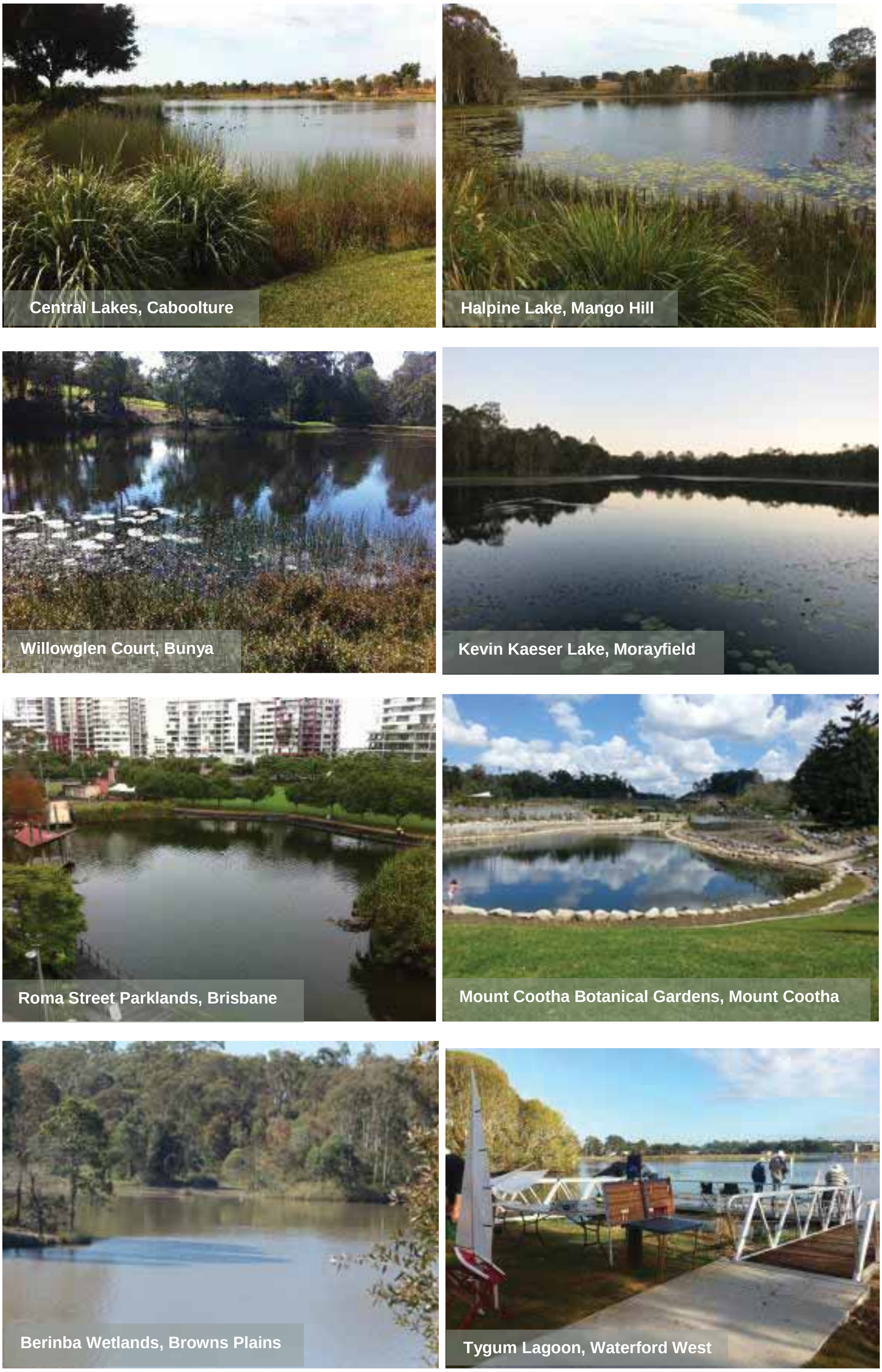
This appendix provides a review of the other freshwater lakes in South East Queensland, including a review of operational costs and common issues – and how these issues will be addressed in the design of the proposed lake system.

G.1 Background

Constructed waterbodies (lakes) are a popular feature of urban development in South East Queensland (SEQ). SEQ now has a large number of freshwater "urban lakes" (lakes in urban environments), which were designed and built as part of urban development.

Figure G-1 provides example photos of freshwater lakes in SEQ.

Figure G-1 Example photos of Freshwater Lakes in South East Queensland



Central Lakes, Caboolture
Halpine Lake, Mango Hill
Willowglen Court, Bunya
Kevin Kaeser Lake, Morayfield
Roma Street Parklands, Brisbane
Mount Cootha Botanical Gardens, Mount Cootha
Berinba Wetlands, Browns Plains
Tygum Lagoon, Waterford West

Figure G-1 Example photos of Freshwater Lakes in South East Queensland (Cont'd)

G.2 Operational Issues

Urban freshwater lakes are subject to a large number of stressors that ultimately impact on their health and management requirements. Stormwater runoff from urban catchments, for example, can be a significant source of pollutant (e.g. nutrient and sediment) loads, contributing to poor water quality in urban lakes.

Common water quality issues for urban lakes within SEQ include the following (Bayley et al, 2007):

- Excessive algal growth
- Cyanobacterial blooms
- Eutrophication (excessive water plant growth due to high nutrient levels)
- High turbidity levels
- General non-point source pollution.

These poor water quality issues are commonly due to a combination of the following factors:

- Poor water quality inflows (often due to a lack of treatment of incoming stormwater flows)
- High organic carbon loads – often due to decomposing plant matter (from within the lake and upstream catchment)
- Long residence times (or lack of lake 'flushing')
- Stratification.

The subtropical climate of SEQ also has characteristics that increase the risk of water quality issues within urban lakes, such as (Bayley et al, 2007):

- High temperatures that increase the productivity of algae, macrophytes and cyanobacteria.
- High inflow variability, with high intensity storms and extended periods of limited inflow. processes.

The appropriate design of urban lakes is vital to augmenting their values, whilst minimising management requirements. In recent years, various documents have been provided to assist in the design of urban lakes, including:

- Brisbane City Council's (2000) "*Urban Management Division Subdivision and Development Guidelines: Part C Water Quality Management Guidelines*"
- Melbourne Water's (2005) "*Constructed shallow lake systems – design guidelines for developers*"
- Melbourne Water's (2005) "*WSUD Engineering Procedures: Stormwater*"
- Mackay City Council's (2008) "*Engineering design guidelines – constructed lakes*"
- Townsville City Council's (2010) "*Townsville constructed lake guideline*".

The vast majority of existing urban lakes within SEQ have, however, been poorly designed, with limited pre-treatment of stormwater flows, excessive depth (typically greater than 4m), and long 'residence' times. Subsequently, the vast majority of existing urban lakes within SEQ would not comply with the recommendations outlined in the aforementioned documents. It is anticipated that this poor design has significantly contributed to poor long-term health outcomes of several urban lakes and increased management requirements.

G.3 Operational costs and revenue

A summary of the maintenance costs associated with lakes (and equivalent open space areas in SEQ) has been presented in Appendix F. The data presented suggest that maintenance costs for lakes are comparable with or cheaper than other types of open space.

Case studies also show that lakes have a strongly positive influence on land values. For example, Luttik (2000) shows increases in value of up to 28% for houses proximate to lakes with this value decreasing with distance away from lakes and other natural features. This increase in value was demonstrated for houses up to one kilometre away from a lake, with the increase in value obviously reducing with distance.

Given that Council rates are linked to land valuations and there can be a demonstrable relationship between proximity of environmental features (e.g. lakes) and land values, the integration of a sustainable lake system can subsequently influence Council rates revenue. When considering these increased rates, economic analyses by McCann et al (2014) have shown that lakes can provide a positive net present value where an equivalent open space area would cost Council (with maintenance costs and lower rates revenues).

G.4 Discussion

Maintenance cost data from freshwater urban lakes and open space areas within SEQ provided in Appendix F suggests maintenance costs for freshwater urban lakes are comparable with or cheaper than other types of open space. There are also considerable additional benefits derived – social, environmental and economic which equal or exceed parkland.

Amenity value of lakes is considerable and they are focal points of urban landscapes with passive and active recreation common. Communities form strong links/affiliation with lakes and recognise the contribution made to lifestyle and urban character. There are several urban freshwater lakes in SEQ that are demonstrably a valuable asset for new and existing urban areas and contribute to amenity, ecology, property values, while maintenance costs are similar or lower than adjoining parkland or open space.

However, there are exceptions to this, with several notable examples of lakes in SEQ that pose a significant maintenance challenge to Councils. As outlined above, however, these poorly functioning lakes (and associated excessive maintenance requirements) are invariably linked to a lack of stormwater treatment, long residence times and stratification.

As described in Section 4, these contributing factors to the poor function of freshwater have been carefully considered and various mitigation measures subsequently integrated into the design of the proposed lake. In summary, key design issues and how these have been integrated into the proposed lake include the following:

- **Poor water quality inflows:** As described in Table 4-7, stormwater quality treatment systems will be integrated in the upstream catchment to achieve best practice targets (for developed areas), and potential pollutant loads from undeveloped areas and areas external to the site will also be appropriately managed.
- **High organic carbon loads:** Aforementioned stormwater quality treatment systems will significantly reduce the discharge of organic loads into the lake. As described in Section 4.10, floating plants will also be avoided within the potential lake systems and submerged plants and/or emergent plants encouraged to minimise the accumulation of organic carbon and the release of nutrients from lake sediments.
- **Long residence times:** As described in Table 4-11, complete detailed modelling will be undertaken to determine an appropriate turnover period. As further described in Appendix E, preliminary water balance modelling predicts that recommend values for residence time will be achieved.
- **Stratification:** As described in Table 4-12, a number of design elements will be incorporated into the lake system to minimise stratification and augment mixing, including the integration of a destratification unit, appropriate hydraulic design (e.g. avoiding short-circuiting, appropriate bathymetry)

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