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Lagoons Catchment Management Plan

Water Quality Monitoring Program

Mackay Regional Botanic Gardens

12 May 2014

Revision: 0

Reference: 240114

Document control record

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1 Introduction

1.1 Background

The Kaliguil Lagoon and Eulamere Lagoon ("the Lagoons") form the central feature of the Mackay Regional Botanic Gardens (MRBG) Figure 1. These lagoons are showing clear signs of water quality decline as evidenced by:

- Accelerated / prolific aquatic plant growth and algal blooms;
- Review of existing water quality data collected via the *Pioneer Catchment Healthy Waterways Program.*

This situation is problematic for at least four reasons:

- Aesthetic impacts for MRBG users;
- Reduced biodiversity within the Lagoons (a known water bird and fish habitat);
- Discharge of contaminated waters into the Pioneer River;
- Increased sedimentation which is likely to be increasing flood risk to the MRBG's displays and infrastructure.

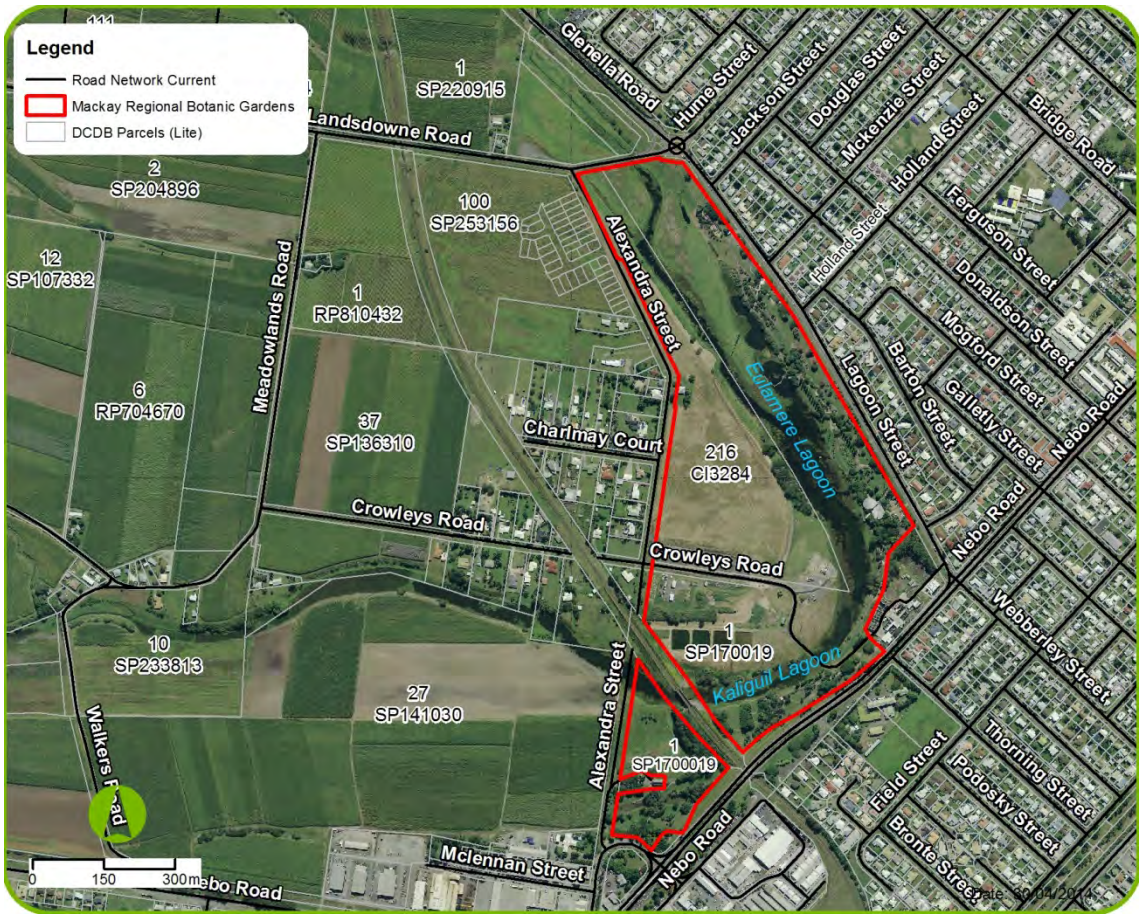


Figure 1: The Mackay Regional Botanic Gardens and associated Lagoons

1.2 The Site

For the purposes of this Water Quality Monitoring Program (WQMP), the Site is the whole of the catchment incorporating the Lagoons, i.e., the *Lagoons Catchment* as delineated in Figure 2.

Consistent with the principles of Total Water Cycle Management (Water by Design, 2010), the management of the water quality of the Lagoons necessarily requires understanding and managing water quality from a whole of catchment perspective. Hence, for the purposes of this Water Quality Monitoring Plan (WQMP), the entire catchment within which the Lagoons are located is considered to be 'the Site' (see Figure 2), otherwise referred to as the Lagoons Catchment.

1.3 Purpose

Collection and assessment of water quality data is essential for system understanding and hence successful catchment management. The purpose of this document is to present a detailed water quality monitoring program for the Lagoons and their catchment (Lagoons Catchment) that is designed to establish both a robust data set and an equally robust means of assessing and interpreting this data. Such information is pivotal to the long term management of the Lagoons as it will provide an important means of:

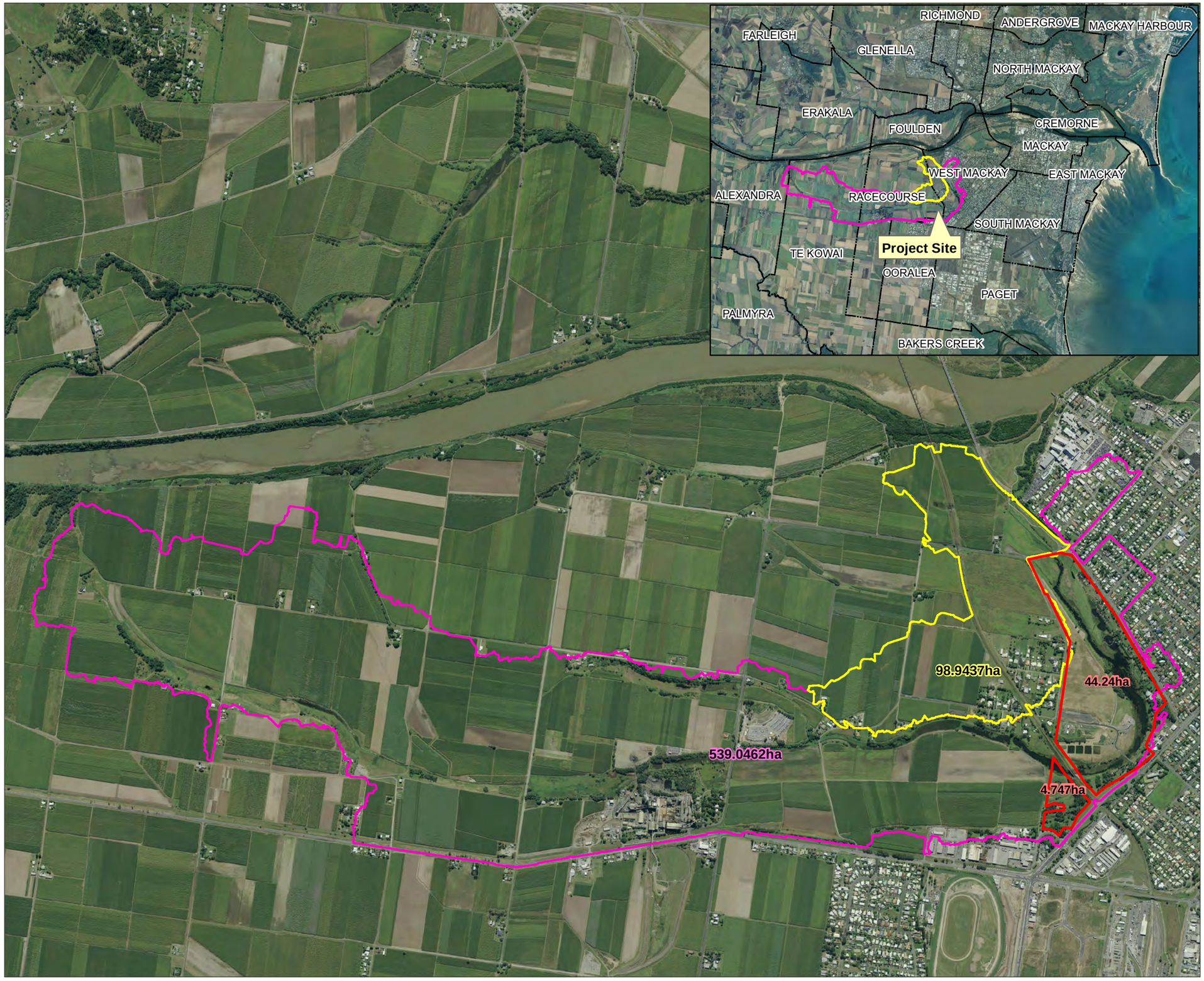
- Defining the water quality status of the Lagoons Catchment relative to published guidelines and regional water quality;
- Assisting with the identification of pollutant sources as a precursor to water quality improvement planning;
- Establishing a baseline and assessing the effectiveness of water quality mitigation measures;
- Assessing the impacts of significant changes in landuse within the Lagoons Catchment;
- Providing quantitative evidence to support changes in landuse practices and the implementation of water quality improvement infrastructure.

This WQMP is to be incorporated into the *Lagoons Catchment Management Plan – Draft for Public Comment*.

1.4 Scope

The scope of this document is to:

- Establish a comprehensive list of potential contaminants/pollutants;
- Identify sampling locations;
- Establish a monitoring and analytical regime;
- Institute water quality indicator targets;
- Outline water monitoring and sampling protocols (including costs);
- Provide an outline on how to use and interpret water quality data (Appendix D).



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Mackay Regional Botanic Gardens

Lagoon Catchment

Sub Catchment A

Sub Catchment B

Source: Sub Cathment A and Sub Catchment B have been generated off the 2009 LiDAR surface.

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Job No: 240114

Coordinate System: GDA 1994 MGA Zone 55

MRGB Lagoons Catchment Water Quality Monitoring Program

Figure 2: The Site ("Lagoons Catchment")

1.5 Statement of Limitations

Aurecon performed the services in a manner consistent with the normal level of care and expertise exercised by members of the environmental profession. No warranties express or implied, are made.

The outcome of this report is limited to information supplied for the activities associated with the scope of works only. It is intended that this plan provides a water quality monitoring program to facilitate the ongoing management of the Lagoons (Figure 1) and their Catchment (Figure 2).

Aurecon uses best judgement and makes recommendations based solely on the results obtained.

We note that this report has been prepared for the Mackay Regional Botanic Gardens (MRGB) for its own use, and is based on information provided by them or third parties. Aurecon takes no responsibility and disclaims all liability whatsoever for any loss or damage that MRGB may suffer as a result of using or relying on any such information or recommendations contained in this report, except to the extent Aurecon expressly indicates in this report that it has verified the information to its satisfaction. This report does not provide a complete assessment of the environmental status of the Site, and it is limited to the scope defined herein. Should further information become available regarding the conditions at the Site, including previously unknown anthropogenic structures that are likely to impact on the Lagoons water quality (e.g. stormwater drainage and commercial and / or industrial discharges), Aurecon reserves the right to review the report in the context of the additional information.

The findings, observations and conclusions expressed by Aurecon are not, and should not be considered as, an opinion concerning the commercial feasibility of the property or asset. The report may contain various remarks about and observations on legal documents and arrangements such as contracts, supply arrangements, leases, licences, permits and authorities. A consulting engineer can make remarks and observations about the technical aspects and implications of those documents and general remarks and observations of a non-legal nature about the context of those documents. However, as a consulting engineer Aurecon is not qualified, cannot express and should not be taken as in any way expressing any opinion or conclusion about the legal status, validity, enforceability, effect, completeness or effectiveness of those arrangements or documents or whether what is provided for is effectively provided for. They are matters for legal advice.

2 Derivation of Potential Contaminants

2.1 General

Whilst current technology allows for the analysis of countless contaminants in water, the cost and logistics of doing so is prohibitive. To address this, the first steps in developing a water quality monitoring plan for a given catchment is to identify which contaminants are most likely to be present.

The purpose of this chapter is to establish a list of water quality indicators that are likely to present within the Lagoons Catchment by investigating current and historic landuses that are / have occurred within the Lagoons Catchment.

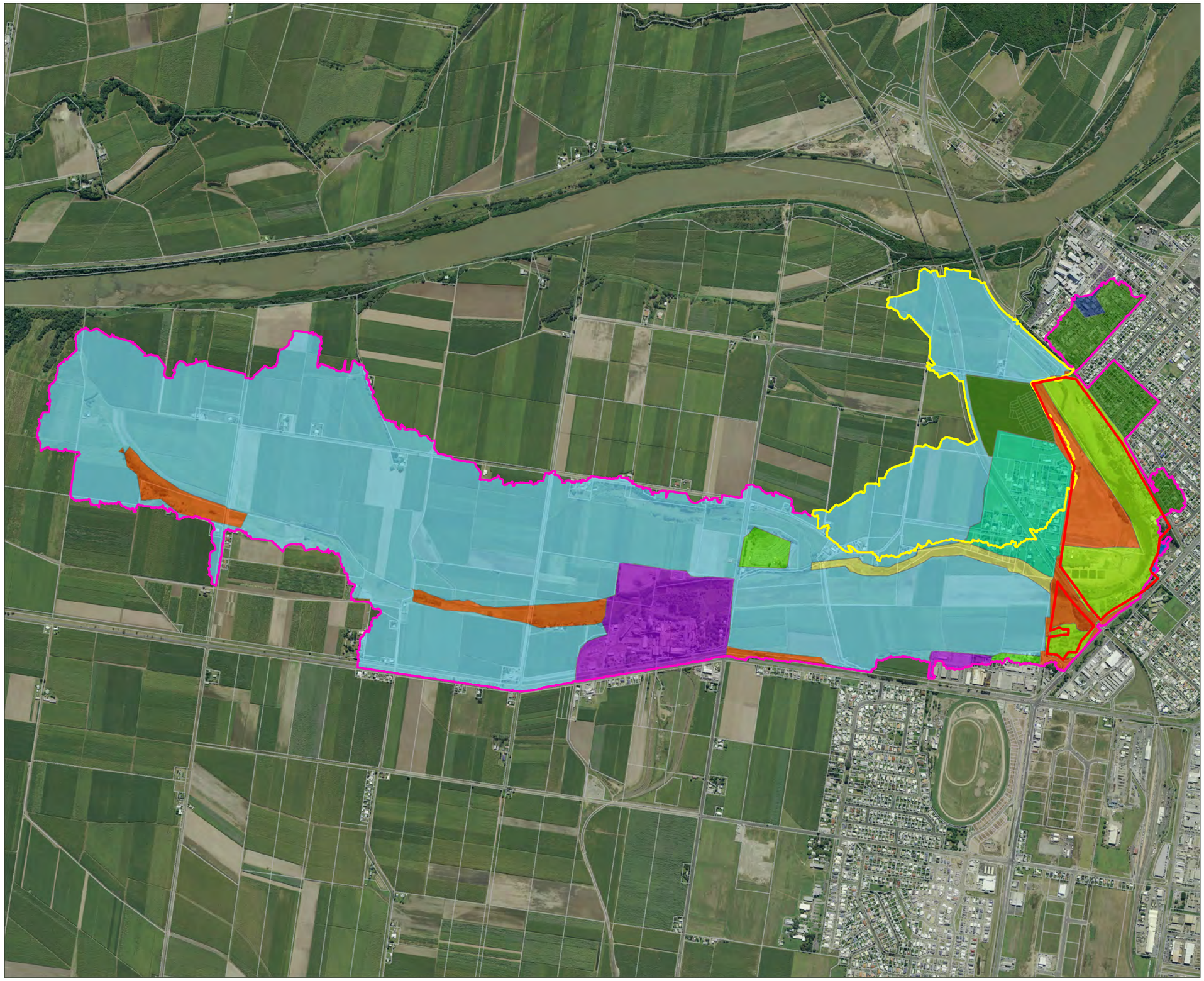
2.2 Potential Pollutants – Lagoons Catchment

Anthropogenic (human) landuse practices can dramatically affect the hydrology and chemistry of surface waters within a catchment. The more diverse the types of landuses are, the more extensive the types of potential pollutants can be expected. Likewise, as landuse intensity increases the potential concentrations of these pollutants can be expected to rise.

Based on the Lagoons Catchment Analysis (Aurecon, 2013) and additional field work undertaken during the preparation of this plan, the following landuses have been identified within the Lagoons Catchment:

- Agriculture (predominately irrigated sugar);
- Commercial and industrial (including water filtration plant, metal fabrication and treatment, mobile equipment depots, rural supply bulk storage and sugar refining);
- Recreation and culture (e.g., the Mackay Regional Botanic Gardens);
- Residential (low and medium density).

The distribution of these land uses throughout the Lagoons Catchment is illustrated in Figure 3 and the relative proportion of each by area is provided in Figure 4.



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Mackay Regional Botanic Gardens

Lagoon Catchment

- Sub Catchment A
- Sub Catchment B

Landuse

- Commercial services
- Irrigated sugar
- Manufacturing and industrial
- Other minimal use
- Public services
- Recreation and culture
- Research facilities
- Reservoir/dam
- Residential
- Residual native cover
- Rural residential

Source: Landuse (1999) - Department of Science, Information Technology, Innovation and the Arts

Landuse	Area ha
Commercial services	5.48
Irrigated sugar	452.72
Manufacturing and industrial	36.63
Other minimal use	39.63
Public services	1.38
Recreation and culture	35
Research facilities	0.15
Reservoir/dam	0.47
Residential	31.93
Residual native cover	7.61
Rural residential	26.98

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Coordinate System: GDA 1994 MGA Zone 55

MRGB Lagoons Catchment Water Quality Monitoring Program

Figure 3: Landuse distribution within the Lagoons Catchment

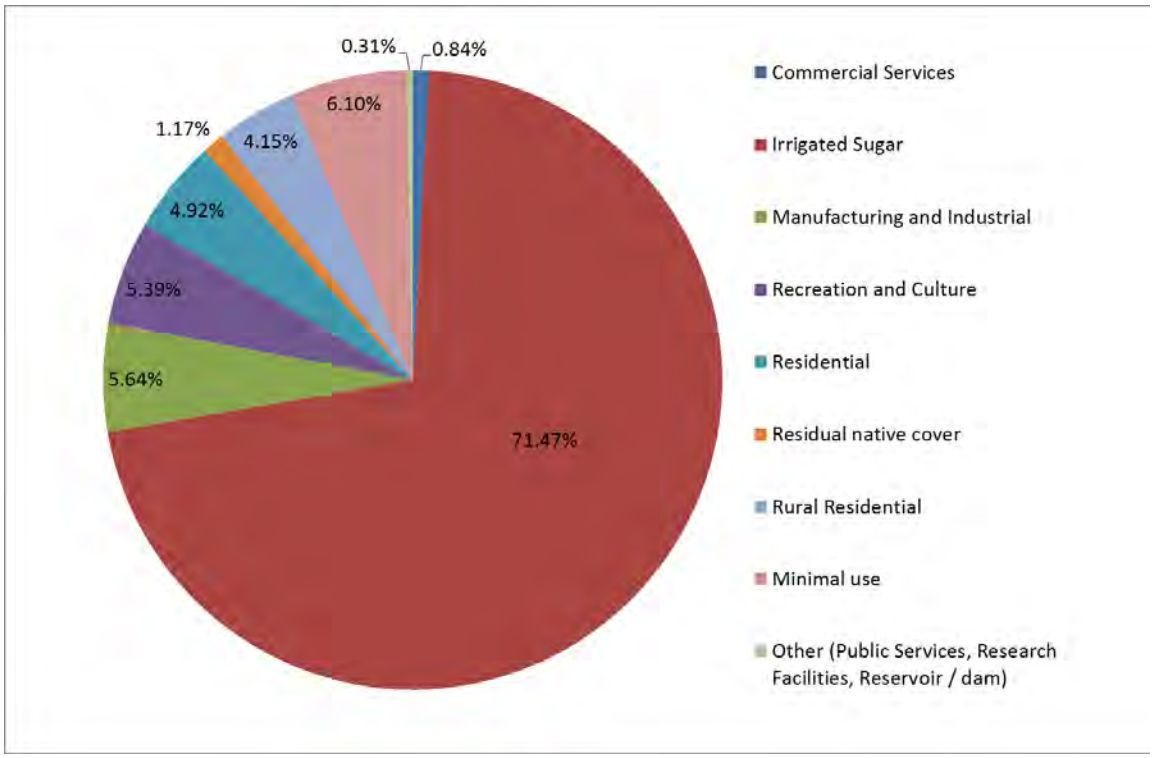


Figure 4: Diagrammatic illustration of landuse proportion within the Lagoons Catchment (by zoning area)

Table 1 lists specific landuses identified as occurring within the catchment along with pollutants typically associated with each activity. This table provides the starting point for target analyte derivation for assessing the Lagoons Catchment waterway health and potential sources of contamination.

Based on the information derived from Table 1, potential surface water contaminants for the Lagoons Catchment can be generally described as follows:

- Nutrients (nitrogen and phosphorus);
- Fertilizers;
- Herbicides;
- Pesticides;
- Fungicides;
- Heavy metals (mostly transition metals in the periodic table);
- Petrochemical products;
- Sewage (possibly via leaks to stormwater system);
- Faecal matter (primarily domestic pets).

Table 1: Pollutants by landuse

Landuse	Pollutants	Water Quality Indicators	Source	Comment
Sugar cane farming	Fertilisers; sediment (particularly when fallow) herbicides and pesticides;	DIN; PN; FRP; PP; nitrates; ammonia; TSS; BOD TDS; pH; OPPs & OCPs; herbicides (e.g. Ametryn; atrazine; diuron; hexazinone; simazine; tebuthiuron; triazine,); EC and pH	Aurecon (2013);	Sugar cane farming is the dominant land use within the Lagoons catchment, coming in at over ten times that of the next largest. The risk of related pollutants from this activity is further increased by the removal of most riparian vegetation.
Sugar cane refining	Heavy metals; oils and greases; cleaning agents; thermal pollutants	Select transition metals; COD; oils & grease; ammonia; MAH; chlorinated organics	Aurecon (2013); WWF (2005)	
Mackay Water Treatment Plant	Heavy metals; aluminium; fluoride and lime	Transition metals; aluminium; fluoride; pH; carbonates.	Aurecon (2013);	Back-flush water discharges into Lagoon.
Urban (including transport corridors)	Wide ranging and often sporadic (e.g. accidental spills). Major forms include heavy metals; petrochemical products; sewage; faecal matter; nutrients; phenols (creosote); herbicides.	Transition metals; TRH; MAH; PAH; chlorinated hydrocarbons; oil and grease; DIN; PN; FRP; PP; nitrates; ammonia; TSS; BOD; Phenols; OPPs & OCPs;	Aurecon (2013); Thomas (2013);	Urban environments are highly dynamic and can be a source of a wide range of contaminants, from petrochemical products through to a range of trace contaminants associated with personal care products. Those provided are the more common forms.
Horticulture (Botanic Gardens)	Fertilizers, insecticides; fungicides and herbicides.	DIN; PN; FRP; PP; nitrates; ammonia; OPPs & OCPs; herbicides (e.g. Ametryn; atrazine; diuron; hexazinone; simazine; tebuthiuron; triazine); carbon;	Aurecon (2013);	
Commercial	Petrochemical; heavy metals; nutrients; pesticides; herbicides; fertilizers; herbicides; abrasive blasting materials	TPH; MAH; PAH; transition metals; phenols; chlorinated hydrocarbons; oil and grease; creosote; DIN; PN; FRP; PP; nitrates; ammonia; OPPs & OCPs; herbicides (e.g. Ametryn; atrazine; diuron; hexazinone; simazine; tebuthiuron; triazine); lead;	DoE (2004)	Commercial activities identified include: car repair centres; petrol station; railway / metal work yard; rural supplies; truck / mobile equipment depots; car rust proofing; cabinet making; electrical workshop. Reliable stormwater drainage network mapping is needed.

2.3 Pollutant Signature Analytes for the Lagoons Catchment

Section 2.2 identified a number of potential pollutant sources and the types of pollutants likely to be present. The following list identifies specific analytes / analyte groups that may be used to detect these types of pollutants:

Physico-chemical:

- pH
- Turbidity
- Oxidation reduction potential (ORP)
- Electrical Conductivity (EC)

Laboratory analytes:

- Heavy metals [Al; As (as total As, As III and As V); Cr (as total Cr and CrVI); Be; B; Cd; Fe; Co; Cu; Hg; Pb; Li; Ni; Mn; Mo; Se; Zn]
- Nitrogen species: Dissolved Inorganic Nitrogen (DIN; Total Nitrogen (TN); Nitrate; Nitrite; ammonia; particulate nitrogen (PN) and oxidised nitrogen.
- Phosphorus: Total phosphorus (TP); filterable reactive phosphorus (FRP); particulate nitrogen (PN)
- Total suspended solids (TSS)
- Organophosphorous pesticides (OPPs)
- Organochloride pesticides (OCPs)
- Herbicides (should include Ametryn; atrazine; diuron; hexazinone; simazine; tebuthiuron; triazine)
- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Phenols
- Chlorinated hydrocarbons
- Monocyclic aromatic hydrocarbons (MAH)
  - Benzene
  - Toluene
  - Ethylbenzene
  - xylene
- Total Recoverable Hydrocarbons (TRH)
- Polycyclic Aromatic Hydrocarbons (PAH)
- Oil and Grease
- Creosote
- Chlorophyll a

3 Determination of Sampling Locations

3.1 Introduction

The purpose of this chapter is to clearly identify sampling location sites, why they were selected and the specifics around how to use the data collected from each to facilitate comparative water quality assessment (Section 4.3).

Important Safety Note: Water sampling in the environment presents multiple potential safety hazards, from driving to site through to bites and stings from fauna and flora and the ever-present hazards associated in working in and over water. A general risk assessment has been conducted for each sample location, the results of which are provided in Appendix B. This can be used to assist with developing safe work methods statements prior to each sampling event.

3.2 Sample Locations and Naming

As detailed in Section 3.3, each sample location has been selected for a specific purpose. These locations are illustrated in Figure 5.

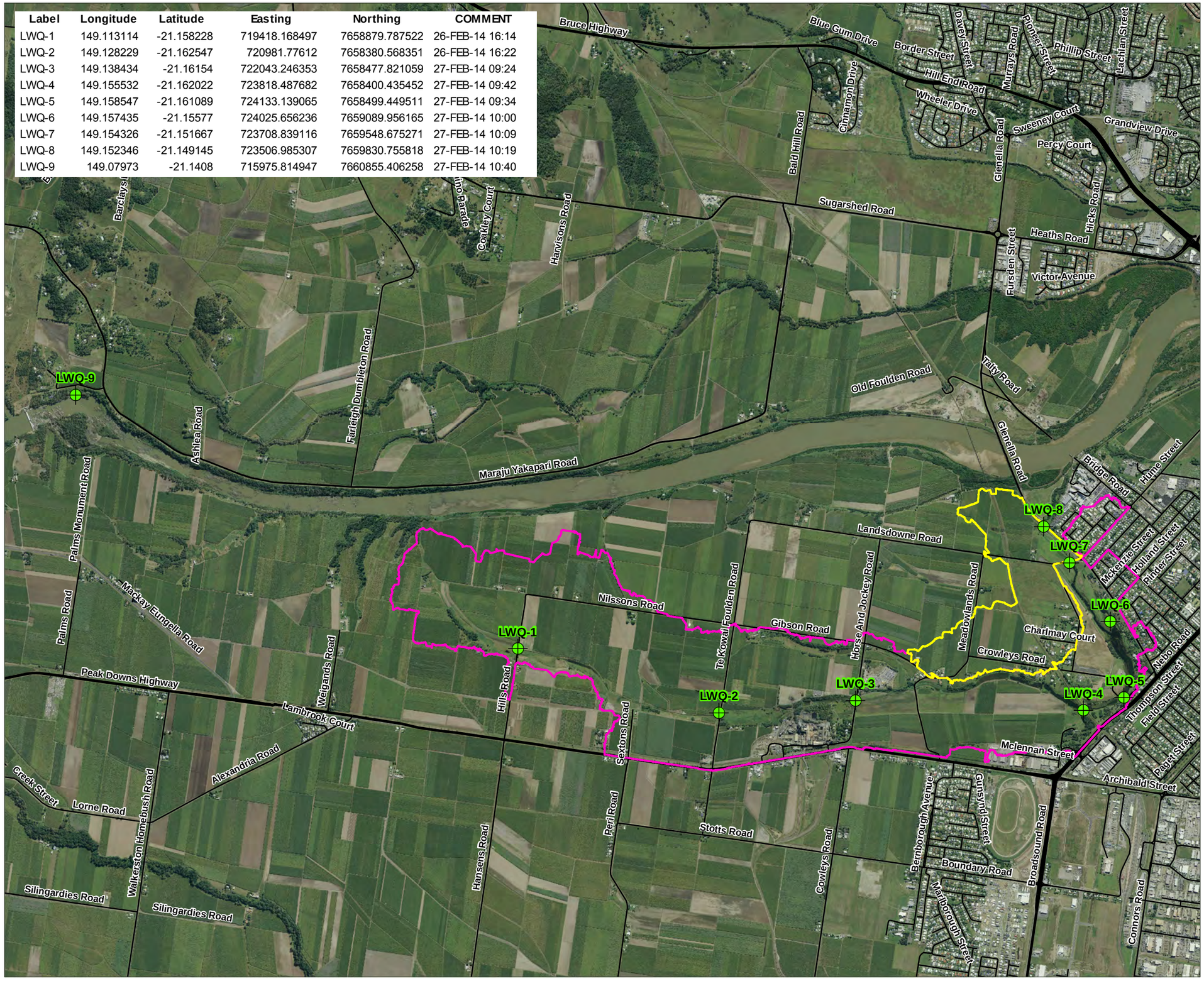
Sample location naming protocols are a fundamental part of any robust sampling and monitoring program as they provide a traceable link between data and location. Improper labelling is one of the most common sources of error, hence strict adherence to sample location naming is a fundamental requirement of this (and any) monitoring program. In order to ensure adherence, a simple sampling naming protocol has been devised as follows:

Each location begins with the letters LWQ, where:

- L = Lagoons
- W = Water
- Q = Quality

Each sample location is then differentiated by simply adding a post-fix integer in sequential order moving down the Lagoons Catchment. For example LWQ-1 is the uppermost sample location in the catchment, whereas LWQ-8 is the lowest. The only exception is LWQ-9 which is collected from the Pioneer River (Section 3.3.10).

Label	Longitude	Latitude	Easting	Northing	COMMENT
LWQ-1	149.113114	-21.158228	719418.168497	7658879.787522	26-FEB-14 16:14
LWQ-2	149.128229	-21.162547	720981.77612	7658380.568351	26-FEB-14 16:22
LWQ-3	149.138434	-21.16154	722043.246353	7658477.821059	27-FEB-14 09:24
LWQ-4	149.155532	-21.162022	723818.487682	7658400.435452	27-FEB-14 09:42
LWQ-5	149.158547	-21.161089	724133.139065	7658499.449511	27-FEB-14 09:34
LWQ-6	149.157435	-21.15577	724025.656236	7659089.956165	27-FEB-14 10:00
LWQ-7	149.154326	-21.151667	723708.839116	7659548.675271	27-FEB-14 10:09
LWQ-8	149.152346	-21.149145	723506.985307	7659830.755818	27-FEB-14 10:19
LWQ-9	149.07973	-21.1408	715975.814947	7660855.406258	27-FEB-14 10:40



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Lagoon Catchment

Sub Catchment A

Sub Catchment B

Road Network Current

Highways

Secondary Roads

Local Roads

Notes:

Date: 29/04/2014

Version: 1

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Coordinate System: GDA 1994 MGA Zone 55

MRGB Lagoons Catchment Water Quality Monitoring Program

Figure 5: Proposed surface water quality sampling locations

3.3 Purpose and application of each Sample Location

3.3.1 General

Each sample location provided in Figure 5 has been chosen for specific reasons. The following sub-sections provide an explanation for each location and how the data collected at each should be used.

3.3.2 Sampling Location LWQ-1 – *Catchment Baseline*

3.3.2.1 Location

Sample location LWQ-1 is located in the upper reaches of the Lagoons Catchment at the Hills Road culvert, accessed from Hills Road (Longitude: 149.113114, Latitude: -21.158228). The proposed sample point is the downstream side of the culvert where access is relatively easy from the northern bank as illustrated in Figure 6.

Figure 6: Sample location LWQ-1 (yellow arrow = suggested sampling point)

3.3.2.2 Purpose

Sampling location LWQ-1 is located in the upper reaches of the Lagoons Catchment in order to access water that is <u>least</u> effected by land uses within the catchment. It provides a baseline comparison for sample locations further downstream, thereby providing a means of assessing catchment landuse impacts (Section 4.3).

3.3.3 Sampling Location LWQ-2 – *Up-stream Sugar Refinery*

3.3.3.1 Location

Sample location LWQ-2 is located immediately up stream of the Racecourse Sugar Mill accessed from Ta Kowai Foulden Road (Longitude: 149.128229, Latitude: -21.162547). The proposed sample point is the upstream side of the culvert where access is relatively easy from the northern bank (Figure 7).

Figure 7: Sample location LWQ-2 (yellow arrow = suggested sampling point)

3.3.3.2 Purpose

Sampling location LWQ-2 was chosen to provide water quality information immediately before the Racecourse Sugar mill and refinery to capture water quality information that includes all up catchment influences except the Sugar Mill. Results from LWQ-2 can then be used for two purposes:

- Comparison with LWQ-1 to identify any water quality changes relative to the upper reaches of the catchment
- Comparison with LWQ-3 to identify any potential impact on water quality that may be related to the sugar mill and refinery operations.

3.3.4 Sampling Location LWQ-3 – *Downstream Sugar Refinery*

3.3.4.1 Location

Sample location LWQ-3 is located immediately downstream of the Racecourse Sugar Mill accessed from Horse and Jockey Road (Longitude: 149.138434, Latitude: -21.16154). The proposed sample point is the upstream side of the culvert (Figure 8).

Figure 8: Sample location LWQ-3 showing access road and sample location (yellow arrow = suggested sampling point)

3.3.4.2 Purpose

Sampling location LWQ-3 will provide water quality data immediately downstream from the Sugar Mill. Comparison with LWQ-2 will allow potential water quality issues associated with the Sugar Mill to be identified.

3.3.5 Sampling Location LWQ-4 – *Upstream Lagoons*

3.3.5.1 Location

Sample location LWQ-4 is located in the upper reaches of Kaliguil Lagoon accessed on foot from Crowleys Road via the MRBG walkway (Longitude: 149.155532, Latitude: -21.162022). The proposed sample point is from underneath the railway bridge, off the walkway Figure 9.

Figure 9: Sample location LWQ-4 (yellow arrow = suggested sampling point)

3.3.5.2 Purpose

The purpose of LWQ4 is to account for all potential contaminant sources upstream of this location, i.e. the status of the water quality entering the Lagoons system. Water quality data collected here can then be compared to LWQ 6 and LWQ7 to determine how water quality may change as water moves through the Lagoon.

It is important to note that given its purpose, this sample location should be located further upstream, closer to where the Kaliguil Lagoon begins, but permission to access private property will be needed to do this.

3.3.6 Sampling Location LWQ-5 – *Mackay Water Treatment Plant Back-flush Water*

3.3.6.1 Location

Sample location LWQ-5 is the filter water discharge point for the Mackay Water Treatment Plan back flush water, located just to the north of Crowleys Road fjord / culvert on the western bank of the Eulamere Lagoon (Longitude: 149.158547, Latitude: -21.161089). The proposed sample point is as close as possible to the outlet Figure 10.

Figure 10: Sample location LWQ-5 (yellow arrow = suggested sampling point)

3.3.6.2 Purpose

The purpose of sampling location LWQ-5 is to provide a water quality check of the back-flush water leaving the water filtration just before it enters the Eulamere Lagoon. It is **important to note** that the sampling and analysis of this water could be a sensitive matter, and consideration should be given to discussing this issue with Mackay Water Treatment Plant management.

3.3.7 Sampling Location LWQ-6 – *Lagoons Water Quality*

3.3.7.1 Location

Sample location LWQ-6 is located towards the tail end of the Lagoons system and is accessed from the MRBG walkway and over-water boardwalk (Longitude: 149.157435, Latitude: -21.15577). The proposed sample point is from the approximate centre of the traverse of the boardwalk on the upstream side as illustrated in Figure 11.

Figure 11: Sample location LWQ-6 (yellow arrow = suggested sampling point)

3.3.7.2 Purpose

Sampling location LWQ-6 will provide both a water quality check as water moves through the Lagoons as well as important data to assess the general aquatic health of the Lagoons from an ecological / habitat perspective.

3.3.8 Sampling Location LWQ-7 – *Lagoons Downstream*

3.3.8.1 Location

Sample location LWQ-7 is located immediately upstream of the Landsdowne Road culvert, accessed from Landsdowne Road (Longitude: 149.154326, Latitude: -21.151667). The proposed sample point is the upstream side of the culvert where access is moderately easy from the western side as illustrated in Figure 12 (sampling on the downstream side should be avoided as water cascades through the culvert and this is likely to bias water quality results, particularly regarding dissolved oxygen content).

Figure 12: Sample location LWQ-7 (yellow arrow = suggested sampling point)

3.3.8.2 Purpose

Sampling location LWQ-7 is located at the end of the Lagoons. When compared to water quality results for LWQ-4, it will give a useful indication of how water quality changes as it moves through the Lagoons systems. It may also give an indication of how landuses impact on water quality of the Lagoons, particularly urban stormwater runoff.

3.3.9 Sampling Location LWQ-8 – *Catchment Downstream*

3.3.9.1 Location

Sample location LWQ-8 is located under the Glenella Road bridge as it passes over the Lagoons creek, accessed from Glenella Road (Longitude: 149.152346, Latitude: -21.146145). The proposed sample point is directly under the bridge as shown in Figure 13. Sampling any further downstream is not advisable as the aquatic environment becomes increasingly estuarine, particularly during high tides.

Figure 13: Sample location LWQ-8 (yellow arrow = suggested sampling point)

3.3.9.2 Purpose

Sampling location LWQ-8 is located as far as possible downstream without being impacted by the estuarine waters of the lower reaches of Pioneer River to provide an indication of the water quality discharging into the Pioneer River. When compared to LWQ-9, this will provide an indication of how the fresh water quality of the Lagoons Catchment system compares to the fresh water quality of the Pioneer River. Comparison with LWQ-1 will provide the capacity to ascertain the overall effect of landuse within the Lagoons Catchment on end point water quality.

3.3.10 Sampling Location LWQ-9 – *Regional Indicator*

3.3.10.1 Location

Sample location LWQ-9 is located immediately downstream of the Dumbleton Weir on the Pioneer River, accessed from Mallia Road, Dumbleton (Longitude: 149.07973, Latitude: -21.149145). The proposed sample point is the downstream side of the weir where access is relatively easy from the northern bank as illustrated in Figure 14.

Figure 14: Sample location LWQ-9 (yellow arrows = suggested sampling point)

3.3.10.2 Purpose

Sampling point LWQ-9 provides an indication of the current regional water quality using the fresh waters of Pioneer Creek. The water data collected at this location can be used to compare to data from any other water sample location to provide a comparative assessment of the Lagoons Catchment with regional water quality.

Important notes:

- Sampling further downstream risks collecting sample waters that are impacted by tidal waters (i.e. increasingly estuarine). Given that the Lagoons Catchment is a freshwater system, it is important to establish a regional baseline that is also fresh water.
- Sampling at this location should preferably be undertaken only when water is passing over the weir (i.e., only when there is connectivity with upstream waters). If this is not possible, an alternative location further upstream should be sampled providing permission from the Pioneer Valley Water Board (PVWB) can be obtained. Further, when flows are low, samples must not be collected from unconnected pools. These precautions are necessary in order to ensure water samples collected are representative of the fresh water of the Pioneer River.
- If possible, LWQ-9 should be located immediately upstream of the Dumbleton Weir to avoid the issues described above, however this land is controlled by Pioneer Valley Water Board (PVWB). It is therefore highly recommended that permission will be sort from the PVWB to move LWQ-9 from its current proposed location to upstream of the weir.

4 Water Quality Assessment

4.1 Introduction

Establishing a meaningful, site specific Water Quality Assessment Criteria (WQAC) is a fundamental component of any catchment management plan. Establishing an appropriate suite of water quality indicators along with meaningful trigger limits and ranges provides an important means of assessing water quality over time.

There are two ways in which water quality can be effectively assessed. For the Lagoons Catchment these are:

- Comparison against published water quality assessment targets / trigger levels, including
  - Localised water quality targets, i.e., those published in *Water Quality Improvement Plan - Final report for Mackay Whitsunday Region* (Healthy Waterways, 2008)
  - Regional water quality baseline, i.e. those published in *Testing the Waters, A Report on the Quality of Queensland Waters* (DEH & DER, 1999)
  - General guidelines such as the ANZECC 2000 Freshwater Guidelines (ANZECC and ARMCANZ, 2000a)
- Comparing water quality data with other water quality data collected from other locations, including:
  - Water quality data collected as far as possible upstream of the catchment ("catchment baseline").
  - Water quality data collected at a location that is representative of the region ("regional baseline")
  - Comparison of water quality data collected immediately upstream and downstream of a particular landuse ("impact baseline")
  - Comparison between historic and current water quality results ("historic baseline").

The former have the advantage of being seen as accepted, government endorsed water quality guidelines and provide a rapid means of assessing water quality results. However they do not always represent local conditions and only a very small number of water quality indicators have reliable published water quality trigger / investigation levels.

The latter provide a more localised indication of water quality change within the subject catchment and provide a much more reliable means of assessing water quality change over temporal and spatial scales. Their downside is that it is often time-consuming, costly or simply impossible to establish a true indication of undisturbed / "natural" conditions, particularly when dealing with catchments that have been subject to land use impacts over long periods of time, which is the case for the Lagoons Catchment.

In order to establish a thorough means of assessing water quality and how it changes at the Lagoons Catchment, both approaches to water quality assessment have been adopted.

The followings section defines these WQAC for the Lagoons Catchment and provides an explanation as to how they were derived and how they should be used.

4.2 Published Water Quality Assessment Criteria for the Lagoons Catchment

4.2.1 Localised Water Quality Targets

In 2008, Healthy Waterways released the publication *Water Quality Improvement Plan Final Report for the Mackay Whitsunday Region* (Healthy Waterways, 2008). This Queensland and Federal Government sponsored publication provides localised water quality assessment criteria for major catchments in the Mackay and Whitsunday region, incorporating target levels for water quality now and water quality targets for 2050. One of these catchments, the *Mackay City Management Area*, incorporates the Lagoons Catchment (Figure 15). Given the spatial resolution, the water quality indicators reported for this catchment are considered adequate for providing representative "local" water quality indicators for the Lagoons Catchment and are provided in Table 2.

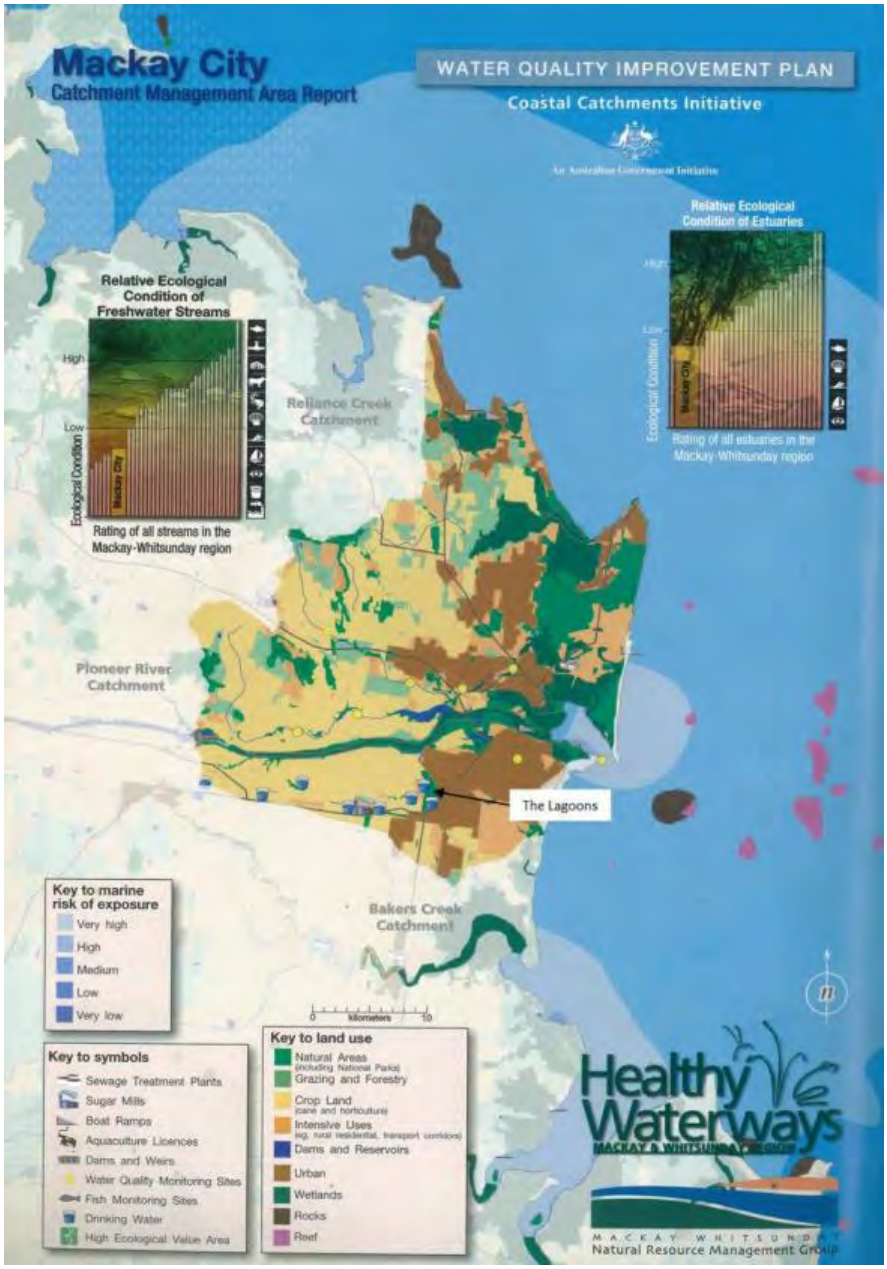

Figure 15: The Mackay City Management Area (Source: Healthy Waterways 2008)

Table 2: Lagoons Catchment Water Quality Assessment Criteria as derived from Healthy Waterways 2008

Analyte / Parameter	Unit	MCMA 2014*	MCMA 2050^	ANZECC (2000)†
Dissolved Inorganic Nitrogen (DIN)	mg / L	0.107	0.030	NR
Particulate nitrogen (PN)‡	mg / L	0.110	As for 2014	NR
Particulate phosphorus (PP)	mg / L	0.020	As for 2014	
Filterable Reactive phosphorus (FRP)	mg / L	0.025	0.015	0.004
Total Suspended Solids (TSS)	mg / L	5	As for 2014	NR
Ametryn‡	µg / L	0.02	As for 2014	NR
Atrazine‡	µg / L	0.09	As for 2014	13¥
Diuron‡	µg / L	0.19	As for 2014	NR
Hexazinone‡	µg / L	0.20	As for 2014	NR
Tebuthiuron‡	µg / L	< LOD	As for 2014	2.2¥
Dissolved Oxygen saturation (DO)	%	40 – 120	As for 2014	85 – 120
pH	No units	7.3 – 7.5	As for 2014	6.0 – 8.0
Electrical Conductivity (EC)	µS / cm	527	As for 2014	20 – 250
Turbidity	NTU	NR	NR	2 – 15
Oxides of Nitrogen as nitrogen (NOx-N)	mg / L	NR	NR	0.001
Ammonia (NH_3)	mg / L	NR	NR	0.9¥
Total Phosphorus (TP)	mg / L	0.045Ω	0.035 Ω	0.004
Total Nitrogen (TN)	mg / L	NR	NR	0.3
Faecal Coliforms	cfu / 100 mL	NR	NR	1000€

Table Notes:

* - 2014 target value for the Mackay City Management Area (MCMA) as reported in Healthy Waterways (2008)

^ - 2055 target value for the Mackay City Management Area (MCMA) as reported in Healthy Waterways (2008)

† - Derived from Table 3.3.4 or Table 3.3.5 of the ANZECC (2000) guidelines (ANZECC and ARMCANZ, 2000a) – Tropical Australia, lowland river (unless otherwise specified)

¥ - Derived from Table 3.4.1 of ANZECC 2000, trigger values for freshwater level of protection of 95% of species

‡ - Target values reported for the Mackay City Management Area (MCMA) but no testing known to have been undertaken

€ - Derived from Table 5.2.2 of ANZECC 2000, water quality guideline for recreational waters Secondary Contact

Ω - Determined by adding together the FRP and particulate phosphorus target concentrations for the MCMA respectively

LOD – limit of detection

NR – No value or range reported

4.2.2 Regional Water Quality Targets

4.2.2.1 General

Two published guidelines are readily available that may be used to establish regional based water quality guideline values for the Lagoons Catchment. These are:

- *Queensland Water Quality Guidelines 2009, Version 3* (EHP, 2013)
- *Testing the Waters – A Report on the Quality of Queensland Waters* (DEH & DER, 1999)

Typically, the hierarchy for adopting water quality guidelines would require that the *Queensland Water Quality Guidelines* (QWQG) be used as it post-dates *Testing the Waters*. However, in the case of the Lagoons Catchment the QWQG has not been used, and water quality indicators from *Testing the Waters* have been adopted where appropriate / relevant for the following reasons:

- *Testing the Waters* provides a useful means of qualitatively assessing water quality within the Lagoons, i.e. regionalised water quality ranges for a limited range of mostly physico-chemical parameters that can be used to provide a rapid and simple expression of indicative water quality.
- "In the absence of better data, the guidelines adopted for freshwaters are for the most part the default ANZECC 2000 Guidelines" (Table 3.2.1a, Note 10 of the QWQG), hence they add little to no value over the National Guidelines (Section 4.2.3)
- "The WQIP (Mackay-Whitsunday Water Quality Improvement Plan) contains recommended long term water quality objectives for all of its defined catchment management areas. The freshwater long term water quality objective values for each management area have been adopted as sub-regional (i.e. local) guidelines by the QWQG. These values have been derived using appropriate methodologies and are clearly the most appropriate values for these waters." (Section 3.2.2, Second Paragraph of the QWQG).

4.2.2.2 Testing the Waters – A Report on the Quality of Queensland Waters

In 1999, the Queensland Department of Environment and Heritage (DEH) and the Queensland Department of Natural Resources (DNR) published the *Testing the Waters – A Report on the Quality of Queensland Waters*. The aim of this publication was to provide the most comprehensive possible overview of water quality in Queensland and provides data for major waterways throughout Queensland, including the Pioneer River. This publication has been adopted for the Lagoons Catchment as it includes a simple water quality rating system at a regional level for a select number of water quality indicators that can be applied rapidly and can be used to relay water quality information to a wide audience (i.e., beyond those with the a background in water quality science). This rating system is provided in Table 3 below.

Table 3: Pioneer River Water Quality Baseline – *Testing the Waters* (DEH & DER, 1999)

Analyte / Parameter	Unit	Pioneer River 1999	Reported water quality ranges		
			Good	Moderate	Poor
Dissolved Oxygen	%	NR	> 85 and < 110	65 to 85 or 110 to 120	< 65 or > 120
Conductivity	µS/cm	Fresh	< 800*	800 to 8,000^	> 8,000†
Turbidity	NTU	Good	< 5	5 to 50	> 50
Total Phosphorus	mg/L	Good	< 0.05	0.05 to 0.10	>0.10
Oxidise Nitrogen	mg/L	Good	< 0.04	0.04 – 0.30	> 0.30
Chlorophyll a	µg/L	Moderate	< 2	2 to 10	> 10

Table Notes:
* - Fresh
^ - Marginal to brackish
† - Saline

4.2.3 National Guidelines – ANZECC 2000

4.2.3.1 Environmental Protection

National guidelines for a wide range of water quality indicators have been published in Chapter 3 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* guidelines (ANZECC and ARMCANZ, 2000a). These guidelines provide water quality targets for a broad range of water quality parameters. Those published water quality indicators that also have been identified as potential contaminants for the Lagoons Catchment (Section 2.3) are presented in Table 4 below.

These indicators have been drawn from Table 3.3.4 (Tropical Australia) and Table 3.41 of the ANZECC 2000 guidelines (Chapter 3). When interpreting Table 3.4.1, the trigger values have been derived for highly disturbed systems (90%), freshwater. The highly disturbed option has been selected as the Lagoons Catchment has been almost completely denuded of its original vegetation for a range of landuses (predominately sugar cane). This includes the removal of the majority of riparian vegetation.

It is important to note that trigger values for highly disturbed systems are not particularly stringent, hence the meeting of these water quality indicators should not be interpreted as "all is well". The decision to adopt this class of water quality indicators was taken due to the length of time the Lagoons Catchment has been subject to anthropogenic landuse (over 100 years), and that most of the natural vegetation has been removed. However, water quality data should be closely monitored during the first two to three years of data collection and, if warranted, the water quality indicator class should be lifted to a more stringent level. Further, the aim of the Lagoons CMP should always be to improve water quality towards higher levels of quality (within particle limitations).

Table 4: Lagoons Catchment Assessment Criteria – ANZECC 2000 Aquatic Ecosystem Water Quality, Table 3.3.4 and Table 3.4.1

Analyte / Parameter	Unit	Target value / range
pH	–	6.0 – 8.0
Turbidity	NTU	2 – 15 or 2 – 200*
Dissolved Oxygen (DO)	%	85 – 120 or 90 – 120*
Electrical Conductivity (EC)	µS /cm	20 – 250 or 90 – 900*
Aluminium (AL)	µg / L	80
Arsenic (As III)	µg / L	94
Arsenic (As V)	µg / L	42
Chromium VI	µg / L	6
Boron	µg / L	680
Cadmium	µg / L	0.4
Cupper	µg / L	1.8
Mercury	µg / L	1.9
Lead	µg / L	5.6
Nickel	µg / L	13
Manganese	µg / L	2500
Selenium	µg / L	18
Total Nitrogen (TN)	µg N / L	300 or 350-1200*
Nitrate	µg / L	3400
Oxidised nitrogen (NO_x)	µg N / L	10

Analyte / Parameter	Unit	Target value / range
Ammonia	µg N / L	10 or 1430†
Total Phosphorus (TP)	µg P / L	10 or 10-50*
Filterable Reactive Phosphorus	µg P / L	4 or 5-25*
Organophosphorous pesticides		
Azinphos methyl	µg P / L	0.05
Chlorpyrifos	µg P / L	0.11
Diazinon	µg P / L	0.2
Dimethoate	µg P / L	0.2
Fenitrothion	µg P / L	0.3
Malathion	µg P / L	0.2
Parathion	µg P / L	0.01
Organochloride pesticides		
Chlordane	µg P / L	0.14
DDT	µg P / L	0.02
Endosulfan	µg P / L	0.6
Endrin	µg P / L	0.04
Heptachlor	µg P / L	0.25
Lindane	µg P / L	0.4
Toxaphene	µg P / L	0.3
Herbicides and Fungicides		
Diquat	µg P / L	10
2,4-D	µg P / L	450
2,4,5-T	µg P / L	100
Molinate	µg P / L	14
Thiobencarb	µg P / L	4.6
Thiram	µg P / L	0.8
Atrazine	µg P / L	45
Simazine	µg P / L	11
Tebuthiuron	µg P / L	20
Glyphosate	µg P / L	1,200
Trifluralin	µg P / L	6
Phenols		
Phenol	µg P / L	600
2-chlorophenol	µg P / L	630
4-chlorophenol	µg P / L	280
2,4 dichlorophenol	µg P / L	200
2,4,6-trichlorophenol	µg P / L	40
2,3,4,6- tetrachlorophenol	µg P / L	25
Pentachlorophenol	µg P / L	17
Chlorinated hydrocarbons		
1,1,2-trichloroethane	µg P / L	7,300

Analyte / Parameter	Unit	Target value / range
Hexachloroethane	µg P / L	420
Monocyclic aromatic hydrocarbons		
Benzene	µg P / L	1,300
o-xylene	µg P / L	470
p-xylene	µg P / L	250
Polycyclic Aromatic Hydrocarbons		
Naphthalene	µg P / L	37
Chlorophyll a	µg / L	< 5 or < 10*

Table Notes:

* - the former applies to the Lagoons waterway and the latter applies to the Lagoons themselves.

† - the former is from Table 3.3.4 and represents expected conditions for natural systems and the latter is from Table 3.4.1 and represents highly disturbed freshwater systems, 90% protection of species.

4.2.3.2 Beneficial Uses

The Lagoons Catchment Analysis (Aurecon, 2013) identified a number of beneficial uses likely to be attributed to the Lagoons Catchment. Of these, the following have water quality assessment criteria published in the ANZECC 2000 guidelines:

- Irrigation (focus on sugar cane)
- Secondary recreation

Water quality assessment criteria for the above are provided in Table 5. It is important to note that exceedance of any of the water quality criteria listed in this table should involve further investigation and, if warranted, mitigation action as exceedences may represent a threat to the long term viability of economic activities with the Lagoons Catchment (particularly sugar cane cropping) and, more importantly, human health.

Table 5: ANZECC 2000 Beneficial Uses water quality assessment criteria – Lagoons Catchment Beneficial Uses

Analyte / Parameter	Unit	Target value / range	ANZECC 2000 source
Irrigation Waters for Sugar Cane			
Thermotolerant coliforms	Cfu / mL	1000	Table 4.2.2
Salinity	dS/m	2.5	Table 4.2.4 (loam soil assumed)
Chloride	mg/L	< 350	Table 4.2.7 – above which there is a moderate risk of increased cadmium uptake.
Aluminium	mg/L	< 5	Table 4.2.10 (long term use)*
Arsenic	mg/L	< 0.1	Table 4.2.10 (long term use)*
Beryllium	mg/L	< 0.1	Table 4.2.10 (long term use)*
Boron	mg/L	< 0.5	Table 4.2.10 (long term use)*
Cadmium	mg/L	< 0.01	Table 4.2.10 (long term use)*
Chromium	mg/L	< 0.1	Table 4.2.10 (long term use)*
Cobalt	mg/L	< 0.05	Table 4.2.10 (long term use)*
Copper	mg/L	< 0.2	Table 4.2.10 (long term use)*
Fluoride	mg/L	< 1	Table 4.2.10 (long term use)*
Iron	mg/L	< 0.2	Table 4.2.10 (long term use)*
Lead	mg/L	< 2	Table 4.2.10 (long term use)*

Analyte / Parameter	Unit	Target value / range	ANZECC 2000 source
Lithium	mg/L	< 2.5	Table 4.2.10 (long term use)*
Manganese	mg/L	< 0.2	Table 4.2.10 (long term use)*
Mercury	mg/L	< 0.002	Table 4.2.10 (long term use)*
Molybdenum	mg/L	< 0.01	Table 4.2.10 (long term use)*
Nickel	mg/L	< 0.2	Table 4.2.10 (long term use)*
Selenium	mg/L	< 0.02	Table 4.2.10 (long term use)*
Uranium	mg/L	< 0.01	Table 4.2.10 (long term use)*
Vanadium	mg/L	< 0.1	Table 4.2.10 (long term use)*
Zinc	mg/L	< 2	Table 4.2.10 (long term use)*
Total Nitrogen	mg/L	< 5	Table 4.2.11 (long term use)*
Total Phosphorus	mg/L	< 0.05	Table 4.2.11 (long term use)*
Herbicide^			
Acrolein	mg/L	0.1	Table 4.2.12
Amitrol	mg/L	0.002	Table 4.2.12
Diuron	mg/L	0.002	Table 4.2.12
2,2-DPA (Dalapon)	mg/L	0.004	Table 4.2.12
pH	–	6-9	Protection against corrosion and fouling. Refer also to Table 4.2.14.
Hardness	mg/L $CaCO_3$	60 - 350	Table 4.2.14 and Table 4.2.15. Below 60 corrosion becomes a risk and above 350 fouling becomes a risl
Recreational Water Quality and Aesthetics			
Faecal coliforms†	Faecal coliform organisms / 100mL	1000	Section 5.2.3.1 – minimum of five samples / month, with four at of five containing less than 600.
Enterococci †	Enterococci organisms / 100 mL	230	Section 5.2.3.1 – no single sample to exceed.
Surface films	–	Not visible	Oil and petrochemicals should not be noticeable as a visible film on the water, nor detectable by odour.
Floating debris	–	Not visible	Section 5.2.2.3, any sort of gross pollutant (e.g. plastic bottles; polystyrene; soft drink cans, etc).
Undesirable aquatic life‡	–	Not visible	Section 5.2.2.3, algal blooms; dense aquatic plant growth, insect proliferation.

Table Notes:

* - Sugar cane has been cultivated for over 100 years in the Lagoons Catchment

^ - Trigger values provided for herbicides focus on adverse impacts on crop growth, not aquatic health and are based on relatively limited information.

† - The Lagoons Catchment is not known to be a popular swimming area, hence these figures are based on secondary contact such as boating, fishing and the like.

‡ - Local natural conditions must be taken into account.

In addition to Table 5, the risk of soil structure degradation in cane fields should also be determined. A preliminary assessment can be determined by calculating the sodium absorption ratio (SAR) and plotting it against the waterways measured EC value on the graph provided in Figure 16. The SAR value can be calculated by taking the concentrations of sodium (Na^+); Calcium (Ca^{2+}) and magnesium (Mg^{2+}) as $mmole_c/L$ (where subscript C is change) and applying the following formula (ANZECC and ARMCANZ, 2000d):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

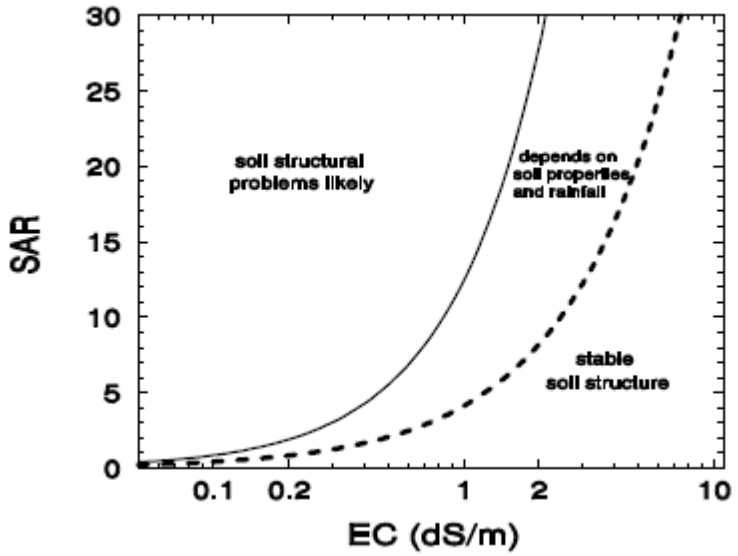

Figure 16: Relationship between SAR and EC of irrigation water for predicting soil structural stability (source: Figure 4.2.2, ANZECC 2000)

Should the resultant SAR ratio consistently fall outside of the "stable soil structure" zone provided in Figure 16, then further investigation should be undertaken, involving the assessment local farming soils to establish if water extracted from the Lagoons Catchment represents a threat to the long term viability of irrigated soils.

4.2.4 Adopted Water Quality Assessment Criteria for the Lagoons Catchment – Published Water Quality Targets

Section 3.2 provided an overview of the local; regional and national published water quality targets as they relate to the Lagoons Catchment. When selecting published guidelines to establish Water Quality Assessment Criteria (WQAC) for a given water body / catchment, it is important to take into account the local context versus the available published limits to arrive at water quality target / trigger levels for the water / catchment under consideration. It is also important to consider the intent of the water quality targets, e.g. whether they are to protect ecological values or beneficial uses. In some instances it is appropriate to select more than one guideline for a given analyte and, even where particular targets are not selected, it is still useful to keep these in mind as additional references to help establish the degree to which water quality results meet or don't meet water quality guidelines.

This process and the subsequent adoption of WQAC for the Lagoons Catchment is provided in Table 6. The only exception is the determination of risk to soils degradation, which must be determined by calculation as described in Section 4.2.3.2.

It is important to note that the parameters set out in Table 6 represent a starting point for water quality assessment of the Lagoons Catchment. The goal should always be to make the listed water quality indicators increasingly relevant / site specific. This should be undertaken by periodical updating this water quality monitoring program, primarily by:

- Reviewing the listed water quality parameters against water data collected from LWQ-9 (every 2 years)
- Annual update reports should always highlight that the less stringent (2014) local water quality indicators are being used and assess if / when a movement to the more stringent (2050) water quality indicators should be adopted (Healthy Waterways, 2008)
- Cross check the listed water quality parameters against relevant updated / newly published water quality guidelines following their official release.
- Comprehensive review of the water quality monitoring program every 10 years.

Table 6: Adopted Water Quality Assessment Criteria for the Lagoons Catchment (greyed in cell indicate adopted guideline values applicable to the Lagoons Catchment)

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
Miscellaneous							
Total Suspended Solids (TSS)	mg/L	**< 5**	< 5	NR	NR	NR	TSS results should ideally come in at or below 5 mg/L.
Chloride	mg/L	NR	NR	NR	NR	**< 350 (Irrigation)**	This parameter applies to irrigation waters, hence should be below the stated level particularly upstream of the Lagoons.
Fluoride	mg/L	NR	NR	NR	NR	**< 1 (Irrigation)**	This parameter applies to irrigation waters, hence should be below the stated level particularly upstream of the Lagoons.
Hardness	mg/L $CaCO_3$	NR	NR	NR	NR	**60-350 (Irrigation)**	This parameter applies to irrigation waters, hence should be below the stated level particularly upstream of the Lagoons.
Surface films	–	NR	NR	NR	NR	**Not visible (recreation and aesthetics)**	Oil and petrochemicals should not be noticeable as a visible film on the water, nor detectable by odour.
Floating debris	–	NR	NR	NR	NR	**Not visible (recreation and aesthetics)**	Any sort of gross pollutant (e.g. plastic bottles; polystyrene; soft drink cans, etc.). Note that this also has important aquatic life implications for the Lagoons Catchment, Pioneer River and the GBR.
Undesirable aquatic life	–	NR	NR	NR	NR	**Not visible (recreation and aesthetics)**	Algal blooms; dense aquatic plant growth, insect proliferation.
Physico-chemical parameters							
Electrical Conductivity (EC)	µS/cm	**< 527**	< 527	**< 800 = good (fresh)** **800 – 8,000 = moderate** **> 8,000 = poor**	20-150 (stream) 90 – 900 (wetlands)	**2,500 (irrigation)**	Aim should be 527 or better. The regional guidelines provide a means of assessing the general state of the Lagoons Catchment waters, however it is **highly recommended** that the "moderate" range be adjusted down to 2,500 as beyond this use for irrigation of crops becomes compromised.
Dissolved oxygen (DO)	%	**< 40-120**	< 40-120	**> 85 and < 110 = good** **65 to 85 = Moderate** **< 65 or > 120 = poor**	85-120 (stream) 90-120 (wetlands)		Target is between 40 and 120, and the regional guidelines provide a good basis to provide a qualitative assessment of water quality within the Lagoons catchment.

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
pH	–	**7.3-7.5**	7.3-7.5	NR	6.0 – 8.0	**6 – 9 (Irrigation)**	Target, at this stage, should be as per local guidelines, providing sample point LWQ-9 regularly meets this criteria. If pH goes outside irrigation recommended range, a serious pollution incident is likely to have occurred.
Turbidity	NTU	NR	NR	**< 5 = good** **5 to 50 = moderate** **> 50 = poor**	2 – 15 (stream 2 – 200 (wetlands)		Target should be less than 5. Regional guidelines provide a good basis to provide a qualitative assessment of water quality within the Lagoons catchment.
Nutrients							
Total Nitrogen (TN)	mg/L	NR	NR	NR	**0.3 (stream)** **Up to 1.2 (wetlands)**	< 5 (Irrigation)	In lieu of more local target, use 0.3 as primary target and anything above 1.2 in Lagoons as a serious concern. It may be advisable to replace this with results from LWQ-9 once a data base has been established.
Total Phosphorus (TP)	mg/L	**< 0.045**	< 0.035	**< 0.05 = good** **0.05 – 0.10 = moderate** **> 0.10 = poor**	0.1 (natural) 10-50 (90% protection)	<0.05 (Irrigation)	The 2014 local water quality target should be adopted until multiple results show improvement, then target should shift towards achieving the 2050 target. Regional targets provide excellent qualitative assessment, however it is advised that "good" be redefined as < 0.045 and that moderate be 0.045 – 0.10.
Oxides of nitrogen (NOx-N)	mg/L	NR	NR	**< 0.04 = good** **0.04 – 0.30 = moderate** **> 0.30 = poor**	< 0.01	NR	Regional targets provide excellent qualitative assessment.
Ammonia	mg/L	NR	NR	NR	**0.01 (natural)** **1.43 (90% protection)**	NR	Adopt as shown. Depending on results from LWQ-9, this may be adjusted downward after a historical data base of at least ten data points is established (based on at least 10 data points).
Nitrate	mg/L	NR	NR	NR	**< 3.4**	NR	As above.
Dissolved inorganic nitrogen (DIN)	mg/L	**< 0.107**	< 0.03	NR	NR	NR	The 2014 local water quality target should be adopted until multiple results show improvement, then target should shift towards achieving the 2050 target.
Particulate Nitrogen	mg/L	**< 0.110**	< 0.110	NR	NR	NR	Adopt local guidelines as shown

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
Particulate Phosphorus	mg/L	**< 0.020**	<0.020	NR	NR	NR	Adopt local guidelines as shown
Filterable Reactive Phosphorus (FRP)	mg/L	**< 0.025**	< 0.015	NR	0.004 (natural) 0.05 – 0.025 (90% protection)	NR	Adopt local guidelines as shown
Microbiology							
Faecal Coliforms	cfu/100mL	NR	NR	NR	NR	**< 1000 (recreation and aesthetics)**	Adopt guideline as shown.
Enterococci	cfu/100mL	NR	NR	NR	NR	< 230 (recreation and aesthetics)	Adopt guideline as shown.
Chlorophyll a	µg/L	NR	NR	**< 2 = good** **2 to 10 = moderate** **> 10 = poor**	< 5 (stream) < 10 (wetland)	NR	Adopt guideline as shown. The regional guidelines combined make an excellent opportunity to provide a general qualitative assessment of the health of the Lagoons Catchment.
Metals							
Aluminium (AL)	µg/L	NR	NR	NR	**< 80**	**< 5,000 (Irrigation)**	Adopt both guidelines as they have a different purpose, i.e., the former is protection of species and the latter is suitability for irrigation.
Arsenic (Total)	µg/L	NR	NR	NR	NR	**< 100 (Irrigation)**	Adopt as shown
Arsenic (As III)	µg/L	NR	NR	NR	**< 94**	NR	Adopt as shown. Adjust downward if LWQ-9 is consistently below this (at least ten data points).
Arsenic (As V)	µg/L	NR	NR	NR	**< 42**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Chromium (total)	µg/L	NR	NR	NR	MR	**< 100 (Irrigation)**	Adopt as shown.
Chromium VI	µg/L	NR	NR	NR	**< 6**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Beryllium	µg/L	NR	NR	NR	NR	**< 100 (Irrigation)**	Adopt as shown.
Boron	µg/L	NR	NR	NR	**< 680**	**< 500 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
Cadmium	µg/L	NR	NR	NR	**< 0.4**	**< 10 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Cupper	µg/L	NR	NR	NR	**< 1.8**	**< 200 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Iron	µg/L	NR	NR	NR	NR	**< 200 (Irrigation)**	Adopt as shown.
Mercury	µg/L	NR	NR	NR	**< 1.9**	**< 2 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Lead	µg/L	NR	NR	NR	**< 5.6**	**< 200 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Lithium	µg/L	NR	NR	NR	NR	**< 2,500 (Irrigation)**	Adopt as shown.
Nickel	µg/L	NR	NR	NR	**< 13**	**< 200 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Manganese	µg/L	NR	NR	NR	**< 2500**	**< 200 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Molybdenum	µg/L	NR	NR	NR	NR	**< 10 (Irrigation)**	Adopt as shown.
Selenium	µg/L	NR	NR	NR	**< 18**	**< 20 (Irrigation)**	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Zinc	µg/L	NR	NR	NR	NR	**< 200 (Irrigation)**	Adopt as shown.
Herbicides / pesticides - General							
2,2-DPA (Dalapon)	µg/L	NR	NR	NR	NR	**< 4 (Irrigation)**	Adopt as shown.
2,4-D	µg/L	NR	NR	NR	**< 450**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
2,4,5-T	µg/L	NR	NR	NR	**< 100**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Acrolein	µg/L	NR	NR	NR	NR	**< 100 (Irrigation)**	Adopt as shown.
Ametryn	µg/L	**< 0.02**	< 0.02	NR	NR	NR	Adopt as shown.
Amitrol	µg/L	NR	NR	NR	NR	**2 (Irrigation)**	Adopt as shown.

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
Atrazine	µg/L	**< 0.09**	< .09	NR	45	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Diquat	µg/L	NR	NR	NR	**< 10**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Diuron	µg/L	**< 0.19**	< 0.19	NR	NR	**2 (Irrigation)**	Adopt as shown. Emphasis to be given to local guideline
Hexazinone	µg/L	**< 0.20**	< 0.20	NR	NR	NR	Adopt as shown.
Molinate	µg/L	NR	NR	NR	**< 14**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Simazine	µg/L	NR	NR	NR	**< 11**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Glyphosate	µg/L	NR	NR	NR	**< 1,200**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Tebuthiuron	µg/L	**< LOD**	< LOD	NR	< 20	NR	Adopt as shown. Tebuthiuron should not be detected in catchment waters
Thiobencarb	µg/L	NR	NR	NR	**< 4.6**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Thiram	µg/L	NR	NR	NR	**< 0.8**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Trifluralin	µg/L	NR	NR	NR	**< 6**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Organophosphorous pesticides							
Azinphos methyl	µg/L	NR	NR	NR	**< 0.05**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Chlorpyrifos	µg/L	NR	NR	NR	**< 0.11**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Diazinon	µg/L	NR	NR	NR	**< 0.2**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Dimethoate	µg/L	NR	NR	NR	**< 0.2**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
Fenitrothion	µg/L	NR	NR	NR	**< 0.3**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Malathion	µg/L	NR	NR	NR	**< 0.2**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Parathion	µg/L	NR	NR	NR	**< 0.01**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Organochlorine pesticides							
Chlordane	µg/L	NR	NR	NR	**< 0.14**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
DDT	µg/L	NR	NR	NR	**< 0.02**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Endosulfan	µg/L	NR	NR	NR	**< 0.6**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Endrin	µg/L	NR	NR	NR	**< 0.04**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Heptachlor	µg/L	NR	NR	NR	**< 0.25**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Lindane	µg/L	NR	NR	NR	**< 0.4**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Toxaphene	µg/L	NR	NR	NR	**< 0.3**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Phenols							
Phenol	µg/L	NR	NR	NR	**< 600**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
2-chlorophenol	µg/L	NR	NR	NR	**< 630**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
4-chlorophenol	µg/L	NR	NR	NR	**< 280**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
2,4 dichlorophenol	µg/L	NR	NR	NR	**< 200**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).

Analyte	Unit	Source					Explanation and application.
		Local: Health Waterways (2008)		Regional: DEH & DER 1999	National: ANZECC 2000 – protection of 90% of species	National: ANZECC 2000 – Beneficial uses	
		2014	2050				
2,4,6-trichlorophenol	µg/L	NR	NR	NR	**< 40**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
2,3,4,6-tetrachlorophenol	µg/L	NR	NR	NR	**< 25**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Pentachlorophenol	µg/L	NR	NR	NR	**< 17**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Chlorinated hydrocarbons							
1,1,2-trichloroethane	µg/L	NR	NR	NR	**< 7,300**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Hexachloroethane	µg/L	NR	NR	NR	**< 420**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Monocyclic aromatic hydrocarbons							
Benzene	µg/L	NR	NR	NR	**< 1,300**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
o-xylene	µg/L	NR	NR	NR	**< 470**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
p-xylene	µg/L	NR	NR	NR	**< 250**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).
Polycyclic Aromatic Hydrocarbons							
Naphthalene	µg/L	NR	NR	NR	**< 37**	NR	Adopt as shown. Adjust protection target downward if LWQ-9 is consistently below this (at least ten data points).

Table Notes:
NR – Not Reported

4.3 Comparative Water Quality Assessment Methodology for the Lagoons Catchment

4.3.1 General

In addition to the direct comparison of water quality results to water quality targets / trigger levels (Section 4.2), it is also useful to establish comparative water quality assessment to determine important factors such as the impact of upstream land use activities on downstream waters and the impact of water quality mitigation measures on downstream water quality over spatial and temporal scales. The following subsection details the types of comparative water quality assessment criteria that could be established for the Lagoons Catchment and how they can be used to effectively manage the Lagoons Catchment.

4.3.2 Upstream Water Quality Results

Using water quality results taken from upstream locations and comparing them with water quality results from downstream locations can be an extremely useful way of determining the impact of landuses between two given sample locations as well as the cumulative effect of landuse on water quality for the whole of the catchment. Using the sampling locations provided in Figure 5 in conjunction with knowledge of landuse within the lagoons Catchment, it is not only possible to form an understanding of the surface water quality within the Lagoons Catchment, but also to identify likely land use activities that are contributing to water quality impacts. Suggested ways of applying this approach to water quality are outlined in Table 7 below.

Table 7: Comparative water quality assessment guide – how to use the data collected at each sample location.

Sample Location	Comparative location(s)	Purpose / derivable information
LWQ-1	All other locations	Provides a "best case" scenario for the current water quality of the Lagoons Catchment as it is located farthest up the catchment where landuse impacts are likely to be lowest.
LWQ-2	LWQ-3	Provides a means to compare upstream water quality (LWQ-2) with downstream water quality (LWQ-3), allowing potential water quality impacts of the Racecourse Sugar mill to be inferred.
LWQ-4	LWQ-6 and LWQ-7	The Lagoons are likely to represent an important change in aquatic environment due to changes in flow energies and will likely provide some natural attenuation in water quality through a combination of physical, chemical and biological process. To complicate this, they may also be impacted by a number of Landuses (Figure 2). LWQ-4 provides an indication of water quality in the upper reaches of the Lagoons, and can be used to ascertain how water quality changes as it moves through the Lagoon system and if a net benefit in water quality is being achieved.
LWQ-5	LWQ-4, LWQ6 and LWQ-9	LWQ-5 is the back-flush waters from the back flushing of the Mackay Water Treatment Plant water filters. The detritus on such filters is likely to contain concentrated toxins and pathogens. By comparing LWQ-5 with water quality coming into the lagoons (LWQ-4) and water quality within the Lagoons (LWQ-6) it will be possible to ascertain the contribution of this water to pollutants within the Lagoons system. Comparison to LWQ-9 will provide a comparison with regional water quality.
LWQ-8	LWQ-1; LWQ-9	LWQ-8 provides a means of determining the net water quality of the Lagoons system in relation to the quality of water within the Lagoons system at its "cleanest" (LWQ-1) and relative to regional freshwater quality (LWQ-9). Note that because the Lagoons system is non-estuarine, it is not appropriate to take a water sample any further downstream than LWQ-8 as the Lagoons Catchment waterway becomes increasingly estuarine downstream of this location.
LWQ-9	All other locations	Provides an indication of regional water quality which can be used to assess the quality of water at various locations throughout the Lagoons catchment relative to current regional conditions.

4.3.3 Rolling Regional Water Quality

In order to establish a more holistic understanding of the water quality within the Lagoons system, it is also useful to be able to compare results with a regional baseline collected (preferably) on the same day as water quality samples are collected from within the Lagoons Catchment. Such data can then be used to ascertain the relative health of the Lagoons Catchment compared to the region as a whole. Ideally, this would involve collecting water samples from multiple representative water bodies within the Mackay region. However, the costs involved to do this are likely to be prohibitive. Fortunately, the Lagoons Catchment is located alongside the Pioneer River, which is the main channel for the regions watershed. Providing water samples are collected far enough upstream to be representative of fresh water quality, this should suffice as a reasonable benchmark of the region's fresh water quality. Water sample location LWQ-9 has been established for this purpose.

Note: Ideally, this sample should be taken from behind the Dumbleton Weir, however access to this location is controlled by the Pioneer Valley Water Supply Authority and permission will need to be granted before this location can moved.

4.3.4 Cumulative Historic Water Quality

As water sampling events progress, a water quality database will begin to build (providing protocols are established to manage this data appropriately). This data can then be used to develop seasonal and water quality trends which can be used to:

- Establish a more robust understanding of the Lagoons Catchment health (single event batch sampling is not sufficient to provide a robust understanding of waterway health)
- Provide localised data for modelling purposes (e.g. MUSIC)
- Provide a means to measure the impact of long term landuse change
- Provide a means to measure the impact of water quality improvement measures (e.g. riparian restoration programs and the established of constructed wetlands)

5 Conclusions and Recommendations

5.1 General

This chapter draws together the determinations of the Water Quality Monitoring Plan and provides a concise summary of the key findings.

5.2 Conclusions

5.2.1 Water Quality Target Analytes for the Lagoon Catchment

Based on the Lagoons Catchment Analysis and subsequent derivation of water quality indicators detailed in Section 2, the target analytes should be as follows:

Physico-chemical:

- Temperature
- pH
- Turbidity
- Dissolved oxygen (measured as percent saturation)
- Oxidation reduction potential (ORP)
- Electrical Conductivity (EC)

Laboratory analytes:

- Heavy metals [Al; As (as total As, As III and As V); Cr (as total Cr and CrVI); Be; B; Cd; Fe; Co; Cu; Hg; Pb; Li; Ni; Mn; Mo; Se; Zn]
- Nitrogen species:
  - Dissolved Inorganic Nitrogen (DIN)
  - Total Nitrogen (TN)
  - Nitrate (NO_3^-)
  - Nitrite (NO_2^-)
  - Ammonia (NH_3)
  - particulate nitrogen (PN)
  - oxidised nitrogen (NOx-N)
- Phosphorus:
  - Total phosphorus (TP);
  - filterable reactive phosphorus (FRP);
  - particulate phosphorus (PP)
- Total suspended solids (TSS)
- Organophosphorous pesticides (OPPs), should include
  - Azinphos methyl
  - Chlorpyrifos
  - Diazinon
  - Dimethoate
  - Fenitrothion
  - Malathion
  - Parathion

- Organochloride pesticides (OCPs), should include
  - Chlordane
  - DDT
  - Endosulfan
  - Endrin
  - Heptachlor
  - Lindane
  - Toxaphene
- Herbicides, should include
  - *2,2-DPA (Dalapon*
  - *2,4-D*
  - 2,4,5-T
  - Ametryn
  - Amitrol
  - Atrazine
  - Diquat
  - Diuron
  - Glyphosate
  - Hexazinone
  - Molinate
  - Simazine
  - Tebuthiuron
  - Thiobencarb
  - Thiram
  - Triazine
  - Triffluralin
- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Phenols, should include
  - Total phenols
  - 2-chlorophenol
  - 4-chlorophenol
  - 2,4 dichlorophenol
  - 2,4,6-trichlorophenol
  - 2,3,4,6-tetrachlorophenol
  - Pentachlorophenol
- Chlorinated hydrocarbons, should include
  - 1,1,2-trichloroethane
  - Hexachloroethane
- Monocyclic aromatic hydrocarbons (MAH), should include
  - Benzene
  - Toluene
  - Ethylbenzene
  - Xylene (as total xylene; o-xylene; p-xylene)
- Total Recoverable Hydrocarbons (TRH)
- Polycyclic Aromatic Hydrocarbons (PAH)
  - Naphthalene
- Oil and Grease
- Creosote
- Chlorophyll a
- Microbiology
  - Faecal coliforms
  - Enterococci
  - Chlorophyll a
- Chloride
- Fluoride
- Hardness (as $CaCO_3$)

5.2.2 Sampling Locations

Sampling locations are identified in Figure 5. These sample locations have been specifically chosen to provide a robust understanding of the catchments water quality and how it changes over both space and time. Such information is pivotal to the ongoing management of the Lagoons Catchment, particularly with regards to the following:

- Determining the general health and contamination status of the Lagoons and their catchment as a whole
- Identifying likely sources of pollutants
- Provision of quantitative evidence for the need to improve catchment water quality
- Measuring the impact of landuse changes in the Lagoons Catchment
- Measuring the impact of water quality improvement strategies and measures adopted within the Lagoons Catchment
- Protecting current and future beneficial uses, including the extraction of surface water for agricultural; commercial and industrial purposes, as well as enhancing community space and tourism.

For details on the purpose of each sampling location and for important access and site safety information, refer to Section 3.

5.2.3 Water Quality Assessment Criteria and Protocol for the Lagoons Catchment

A two pronged approach has been taken for assessing water quality for the Lagoons Catchment, i.e.:

- Comparison against published guidelines as detailed in Section 4.2 and, in particular, the adopted water quality indicators listed in Table 6
- Comparative water quality assessment which involves comparing water quality data from different sample locations to provide a means of assessing water quality change of time and space, as well as providing a means of assessing the Lagoons Catchment against regional water quality in “real-time” as detailed in Section 4.3.

5.3 Recommendations

5.3.1 Rolling out the Water Quality Monitoring Program

5.3.1.1 General

Whilst this document contains a rigorous assessment of the requirements for assessing the water quality within the Lagoons Catchment, two issues remain to be addressed. The first is the sheer number of water quality indicators listed as potential contaminants (Section 5.2.1). The other is the need to update some of the adopted water quality indicators provided in Table 6, particularly those drawn from National Guidelines (Section 4.2.3).

The large number of water quality indicators presents two problems. The first is cost - undertaking the required laboratory analysis to facilitate this list of indicators on an ongoing basis will likely be prohibitive expensive. Secondly, the logistics associated with the preparation and transport of sample bottles, and the collection of the amounts of water required, will make the collection of water samples at all nine sites close to impossible in a single day (this will also add to cost). In order to solve this problem, and to facilitate the “localisation” of guideline values solely sourced from the ANZECC 2000

guidelines, it is recommended that the WQMP be rolled out in a staged manner. This process is described below and illustrated in Figure 17.

5.3.1.2 Stage 1: Preliminary Assessment – Analyte Screening

The purpose of the screening processes is to reduce the number of analytes required to facilitate the identified water quality indicators for ongoing routine monitoring. It involves two sampling rounds over a one year period (i.e. one for the wet season and one for the dry) using a reduced number of sampling locations, i.e. LWQ-1; LWQ-4; LWQ-6 and LWQ-8. At the end of this 12 month period, the data is then assessed and analytes that return either "non-detects" (pollutant not detected), or are significantly below specified targets, can be considered for removal from the routine sampling program. This approach will reduce both the cost of the screening stage and the remaining stages of the water quality monitoring program by establishing a "targeted" sampling program. Recommended reduced sampling locations for Stage 1 are:

- LWQ-1: provides "cleanest" point for catchment as furthest up stream
- LWQ-4: provides water quality indication entering the Lagoons (aquatic chemistry can change significantly between running water and large, relatively still Lagoons)
- LWQ-6: provides water quality indication well within the Lagoon system
- LWQ-8: provides water quality indication entering the Pioneer River and an indication of the sum total of all landuse impacts at the point of confluence.

5.3.1.3 Stage 2: Bedding in – Refining Water Quality Targets

The purpose of this stage is to assess the need to alter the adopted published water quality indicators that rely solely on ANZECC 2000 ("national") guidelines. Such guidelines are only meant as a guide and local indicators should be adopted wherever possible (ANZECC and ARMCANZ, 2000a).

This stage now sees the implementation of all sample locations (Figure 5), with four sampling events per year (i.e., one per season) over a two year period. At the end of this period, if results for LWQ-1 through LWQ-9 warrant it, some or all of these water quality indicators can be adjusted.

5.3.1.4 Stage 3: Mature Water Quality Monitoring Program

This stage represents the effective end point for establishing the Lagoons WQMP. Sampling can now continue at all sample locations, four times per year. However, as illustrated in Figure 17, Stage 1 and Stage 2 should be revisited every 10 years, or when a significant change in landuse occurs, to ensure the WQMP remains consistent with current conditions (see also Section 5.3.4).

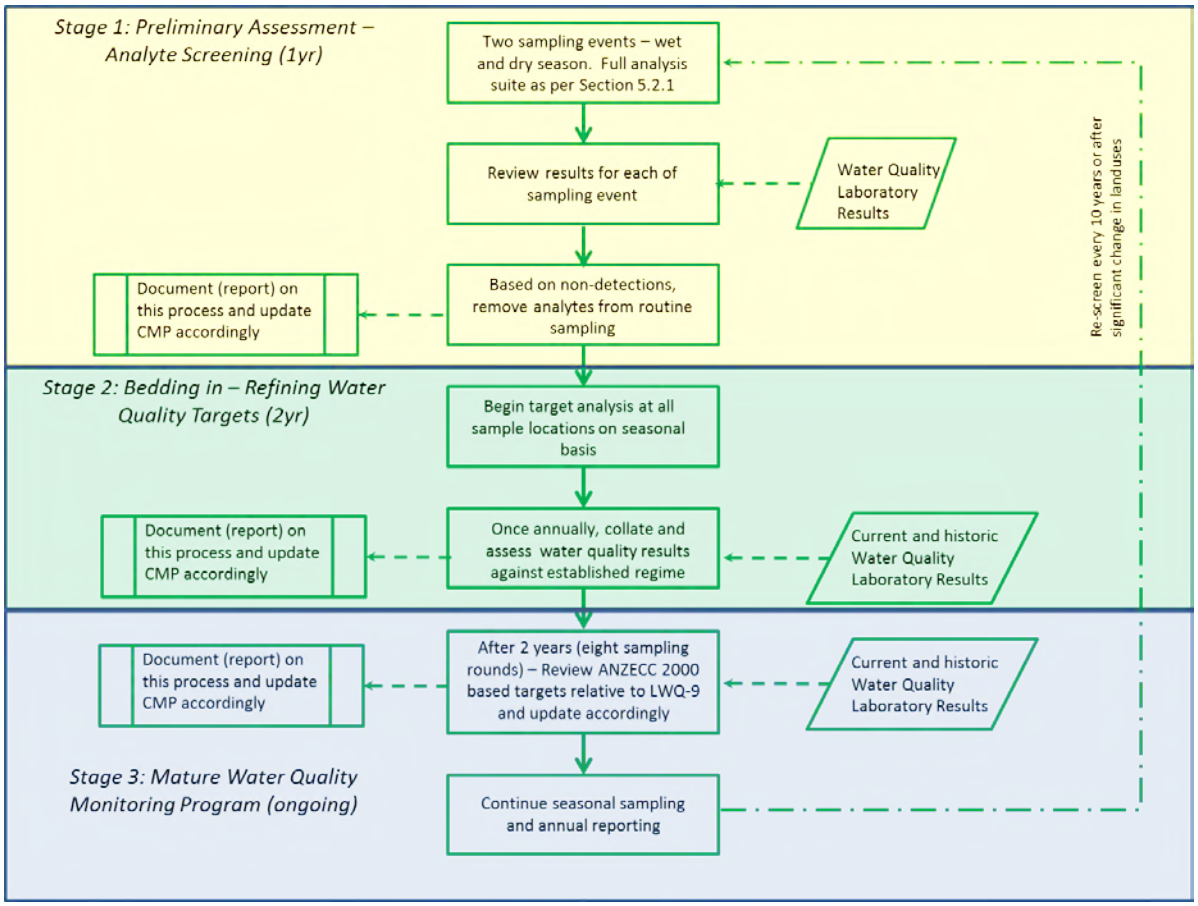

Figure 17: Process for rolling out the Lagoons Catchment WQMP.

5.3.2 Water Sample Collection and analysis

The proper collection of water samples is paramount to the success of this (and any) water quality monitoring program. Failure to adhere to appropriate sample collection and preservation requirements can lead to erroneous results and bring into question all other components of delivering a reliable water quality monitoring program (i.e. data analysis and reporting). For this reason, it is highly recommended that the following guideline be adopted for the collection of samples for this water quality monitoring program:

- *Monitoring and Sampling Manual* (EHP, 2009)

Further, all water samples should be analysed by a NATA certified Laboratory at detection limits that are less than the adopted Water Quality Assessment Criteria for the Lagoons Catchment (Table 6).

5.3.3 Establish a "Report Card" System for the Lagoons Catchment

Whilst a robust water quality monitoring program is important to ascertain the surface water quality status of a given catchment (e.g. justify funding for mitigation programs and projects), the presentation of such results to a wider audience who may not have a water quality background can be overwhelming. This is particularly problematic when trying to convey the status of the Lagoons Catchment to important decision makers such as executive managers; elected representatives; special interest lobby groups and the general public.

To facilitate a simple but effective means of communicating the health of the Lagoons and their catchment to audiences that are not technically proficient in water quality, a "report card" system can

be extremely useful. Such report card systems are already used for Darwin Harbour (Appendix C) and readily be adopted for the Lagoons Catchment. The water quality assessment system published in *Testing the Waters* publication (i.e. “good”, “moderate” and “poor” categories, Section 4.2.2.2) should provide a suitable bases to develop a report card system for the Lagoons Catchment.

5.3.4 Periodic Review of the Lagoons Catchment Water Quality Monitoring Program

In order to make the most of the investment into the development and roll out of this water quality monitoring program, it is important to make sure that it remains up-to-date with the relevant water quality science and guidelines. Further, where practical, water quality indicators should be “localised”, i.e., local water quality data (e.g. that collected from LWQ-9 if appropriate) should be used to replace guideline water quality indicators, particularly those derived from national guidelines (ANZECC and ARMCANZ, 2000c). To achieve these goals, the following review regime is recommended:

- Following the first year of implementation, review water quality results and eliminate water quality analytes that are non-detect (consideration should also be given to naturally occurring analytes that are well within their water quality indicator limits) (Section 5.3.1.2)
- Every two years, review water quality data and, where appropriate, use LWQ-9 data to revise water quality indicators, particularly those derived from national guidelines (Table 6).
- Every two years, assess historic trends and assess if the stringency levels should be lifted for the national and local water quality parameters.
- Update water quality indicators if / when new and / or updated published guidelines become available
- Every 10 years, undertake a comprehensive review of the program in order to ensure that:
  - the above have been addressed adequately
  - sampling and analysis protocols and methodologies are consistent with Queensland and Federal requirements
  - Field equipment is consistent with changes in technology
  - The program, as a whole is still appropriately aligned with the Lagoons CMP and the current condition of the Lagoons Catchment and community needs.

Appendix A References

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Appendix B
General Safety Assessment of Water Quality Sampling Locations

Sample Location LWQ-1

Safety and access considerations for LWQ-1 are summarised in Table A1 below. It should be noted that the information contained in Table A1 is based on site conditions on the day the inspection was carried out (26 February 2014, 16:15) which may change over time. Hence the information in Table A1 should be used as a guide only and sampling sites should always be assessed for safe access within one week prior to a sampling event.

Figure A1: Sample Location LWQ-1

Table A1: Safety and access considerations for LWQ-1

Risk	Risk	Comments
Open water	Low to moderate	Any open water is a potential drowning hazard, however water depth is unlikely to be above knee height (depth dependent on antecedent rainfall).
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Dependent on how recent mowing has taken place at the designated sampling point.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	Low to moderate	Access is by road (Hills Road is unsealed but well maintained). Access on foot is relatively flat. Note that the groundwater supply line depicted in Figure 1A will need to be traversed to access this sample location.
Traffic	Moderate	Hills road is a minor road; however traffic should still be expected. Care should always be taken when exiting the road to park and re-joining traffic when leaving the sample location.
Fall	Low to moderate	The only observable fall risk is traversing the groundwater supply line depicted in Figure 1A
Heights	Negligible	Height is not an issue for this location.
Mobile equipment interaction	Low to moderate	Large agricultural mobile equipment may use this road. As per traffic risk.
Restricted area	`Not applicable	While strictly freehold land, sampling location is outside canfield boundaries and close to road and culvert.
Restricted access (e.g. dense vegetation, long walk, private property)	Low	As for uneven surface / steep terrain risk
Limited communications	Low to moderate	Two to three bars of mobile phone service (out of a possible five)
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 15 m of sample location
People	Low	Not a highly populated area, hence contact with general public is expected to be minimal.

Sample Location LWQ-2

Safety and access considerations for LWQ-1 are summarised in Table A2 below. It should be noted that the information contained in Table A2 is based on site conditions on the day the inspection was carried out (27 February 2014, 16:22) which may change over time. Hence the information in Table A2 should be used as a guide only.

Figure A2: Sample Location LWQ-2

Table A2: Safety and access considerations for LWQ-1

Risk	Risk	Comments
Open water	Low to moderate	Any open water is a potential drowning hazard, however water depth is unlikely to be above knee height (depth dependent on antecedent rainfall).
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Dependent on how recent mowing has taken place at the designated sampling point.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	Low to moderate	Accessible by sealed road. Providing location has been recently mowed, access on foot is relatively flat.
Traffic	Moderate	Ta Kowai Foulden Road is a sealed road with some traffic, including commercial vehicles (mostly farming related). Care should always be taken when exiting the road to park and re-joining traffic when leaving the sample location.
Fall	Low	Trips are possible, however surfaces are flat and access is easy (providing area has been recently mowed).
Heights	Negligible	Height is not an issue for this location.
Mobile equipment interaction	Low to moderate	As per traffic risk, but actual sampling location is unlikely to have mobile equipment in the area (cane harvest mobile equipment notwithstanding).
Restricted area	Not applicable	While strictly freehold land, sampling location is outside canfield boundaries and close to road and culvert.
Restricted access (e.g. dense vegetation, long walk, private property)	Low	As for uneven surface / steep terrain risk
Limited communications	Low to moderate	Two to three bars of mobile phone service (out of a possible five)
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 15 m of sample location
People	Low	Not a highly populated area, hence contact with general public is expected to be minimal.

Sample Location LWQ-3

Safety and access considerations for LWQ-3 are summarised in Table A3 below. The information contained in Table A3 is based on site conditions on the day the inspection was carried out (27 February 2014, 09:25). It is important to note that site conditions may change over time. Hence the information in Table A3 should be used as a guide only and is not a substitute for a safe work method statement (or similar) which should undertake prior to each sampling event.

Figure A3: Sample location LWQ-3 showing access road and sample location (yellow arrow = suggested sampling point)

Table A3 Safety and access considerations for LWQ-3

Risk	Risk	Comments
Open water	Low to moderate	Any open water is a potential drowning hazard, however water depth is unlikely to be above knee height (depth dependent on antecedent rainfall).
Fauna (insect, spider, snake, dogs; etc.)	Moderate to high	Sampling location is currently covered in dense vegetation (mostly grasses and shrubs and aquatic plants) and provides ideal habitat for snakes, spiders and the like.
Flora (sting, poisonous, other)	Moderate	No stinger species or potentially poisonous species observed, however dense vegetation means the presence of such flora cannot be confirmed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	High	Accessible by road. However, sample point LWQ-3 is currently densely covered in vegetation, obscuring the ground surface almost completely, hence this location is not considered safe for sampling. Mowing and weed control will be needed before access for sampling can be re-assessed for safe access.
Traffic	Moderate to high	Traffic along Horse and Jockey Road consists of fast moving private and commercial vehicles. Further, while a potential parking location is evident (gravel road (Figure A3), mowing and weed control is required to establish a safe parking area.
Fall	High	Due to dense vegetation present at this location, the ground surface is highly obscured and falls are likely.
Heights	Moderate	Height does not appear to be an issue for this location, however the presence of dense vegetation may be obscuring the true hazards associated with this location.
Mobile equipment interaction	Moderate	Existing gravel road suggests mobile equipment may pass close to this sampling location.
Restricted area	Not applicable	While strictly freehold land, sampling location is outside canfield boundaries and close to road and culvert.
Restricted access (e.g. dense vegetation, long walk, private property)	High	As for uneven surface / steep terrain risk
Limited communications	Low	Strong mobile phone signal
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 15 m of sample location
People	Low	Not a highly populated area, hence contact with general public is expected to be minimal.

Sample Location LWQ-4

Figure A4: Sample location LWQ-4 (yellow arrow = suggested sampling point)

Safety and access considerations for LWQ-4 are summarised in Table A4 below. It should be noted that the information contained in Table A4 is based on site conditions on the day the inspection was carried out (27 February 2014, 09:45) which may change over time. Hence the information in Table A4 should be used as a guide only.

TableA4: Safety and access considerations for LWQ-4

Risk	Risk	Comments
Open water	Low to moderate	Samples are to be collected from behind the hand rail shown in Figure A4. This handrail should always be inspected visually immediately prior to sampling to ensure it is securely bolted in place as there is a fall hazard over rocks to water and he depth of water at this location is not known, and may be overhead.
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Snakes may be an issue during warmer months especially.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	Low to moderate	Access is on foot via Crowleys Road, entirely along relatively flat walkways.
Traffic	Moderate	While car and truck vehicle traffic is minimal, MRBG service vehicles and bicycles should be expected.
Fall	Low to moderate	The only possible fall risk is falling through the handrail as shown in Figure A4.
Heights	Negligible	Height is not an issue for this location.
Mobile equipment interaction	Low to moderate	As per traffic risk
Restricted area	`Not applicable	Public access area.
Restricted access (e.g. dense vegetation, long walk, private property)	Negligible	Well maintained walkway
Limited communications	Low	Regular foot traffic. Strong mobile phone reception.
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 50 m of sample location. Walkway is well maintained and easily trafficable.
People	Low to moderate	Contact with public is likely at this location and questions may be asked about the purpose of water sampling.

Sample Location LWQ-5

Safety and access considerations for LWQ-5 are summarised in Table A5 below. It should be noted that the information contained in Table A5 is based on site conditions on the day the inspection was carried out (27 February 2014, 09:35) which may change over time. Hence the information in Table A5 should be used as a guide only.

Figure A5: Sample location LWQ-5 (yellow arrow = suggested sampling point)

Table A5: Safety and access considerations for LWQ-5

Risk	Risk	Comments
Open water	moderate	Any open water is a potential drowning hazard. Water depth at this location is unknown, but may be at least waist deep. Use of sampling pole and strict sampling protocols that avoid leaning over to collect water samples should be implemented and adhered to at this location to prevent accidental fall into water.
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Snakes may be an issue during warmer months especially.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	Low to moderate	Access is on foot via Crowleys Road, then shared pedestrian and cycle way. Final descent to sample location is on grass covered surface which may contain hidden depressions and rocks
Traffic	Moderate	While car and truck vehicle traffic is minimal, MRBG service vehicles; bicycles and pedestrians should be expected.
Fall	Low	As per open water risk, there is potential to fall into the Lagoon. However, given that sampling is to take place as close as possible to the filtration plant outlet pipe, this risk is reduced.
Heights	Low	Issue is related to presence of water rather than height.
Mobile equipment interaction	Low to moderate	As per traffic risk
Restricted area	`Not applicable	Public access
Restricted access (e.g. dense vegetation, long walk, private property)	Low to moderate.	As for uneven surface / steep terrain risk
Limited communications	Low	Regular foot traffic. Strong mobile phone reception. Will be influenced by regularity of mowing.
Toxins / pathogens	Moderate	Back-flush water is water that has been used to back-flush water filters. Hence, it is possible that such water has come into contact with fine detritus containing concentrated inorganic and organics which may contain toxins and pathogens.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 30 m of sample location. Walkway is well maintained and easily trafficable.
People	Low	Contact with public is likely at this location and questions may be asked about purpose of water sampling.

Sample Location LWQ-6

Safety and access considerations are for LWQ-6 are summarised in Table A6 below. It should be noted that the information contained in Table A6 is based on site conditions on the day the inspection was carried out (27 February 2014, 10:00 am) which may change over time. Hence the information in Table A6 should be used as a guide only.

Figure A6: Sample location LWQ-6 (yellow arrow = suggested sampling point)

Table A6: Safety and access considerations for LWQ-6

Risk	Risk	Comments
Open water	Low to moderate	Any open water is a potential drowning hazard. Water depth at this location is unknown, but may be overhead. Use of sampling pole and strict sampling protocols that avoid leaning over to collect water samples should be implemented and adhered to at this location to prevent accidental fall into water.
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Snakes may be an issue during warmer months especially.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	Low to moderate	Access is on foot via MRGB walkways off Glenella Road. Pathways can be relatively steep, however they are well maintained and mostly hardstand.
Traffic	Low to moderate	Carparks should be used along Glenella Road to avoid road traffic. Bicycles and MRGB service vehicles should be expected.
Fall	Low to moderate	As per open water risk, there is potential to fall of the side of the culvert as there is no handrail, hence use of sampling pole and strict sampling protocols must be developed and adhered to that prevent the need to lean over the open water to collect samples.
Heights	Negligible	Issue is related to presence of water rather than height.
Mobile equipment interaction	Low to moderate	As per traffic risk
Restricted area	`Not applicable	Public access
Restricted access (e.g. dense vegetation, long walk, private property)	Low	As for uneven surface / steep terrain risk
Limited communications	Low to moderate	Regular foot traffic. Strong mobile phone reception.
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 50 m of sample location. Walkway is well maintained and easily trafficable.
People	Low	Contact with public is likely at this location and questions may be asked about purpose of water sampling.

Sample Location LWQ-7

Safety and access considerations are for LWQ-7 are summarised in Table A7 below. It should be noted that the information contained in Table A7 is based on site conditions on the day the inspection was carried out (27 February 2014, 10:10 am) which may change over time. Hence the information in Table A7 should be used as a guide only.

Figure A7: Sample location LWQ-7 (yellow arrow = suggested sampling point)

Table A7: Safety and access considerations for LWQ-7

Risk	Risk	Comments
Open water	Low to moderate	Any open water is a potential drowning hazard, however water depth is unlikely to be above knee height (depth dependent on antecedent rainfall).
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Dependent on how recent mowing has taken place at the designated sampling point.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	moderate	Access is via the embankment on the upstream western side of the culvert. Surface is relatively even, but not hardstand and conditions may change depending on vegetation growth and erosion. Hence, a moderate and changeable trip hazard exists.
Traffic	Moderate to high	Landsdowne Road is trafficked by private and commercial vehicles, including trucks. Safe work method statements must include management of this specific risk, including the identification of a designated parking area off this road. It is also noted that a shared bicycle and pedestrian path is present at this location.
Fall	Low to moderate	As per uneven surfaces risk, a fall is possible down the embankment.
Heights	Negligible	Height is not an issue for this location providing sampling is undertaken as shown in Figure A7 and not from the top of the culvert.
Mobile equipment interaction	Low to moderate	As per traffic risk
Restricted area	Not applicable	Public access
Restricted access (e.g. dense vegetation, long walk, private property)	Low	As for uneven surface / steep terrain risk
Limited communications	Low	Highly visible site with strong mobile signal.
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 15 m of sample location
People	Low	Contact with public is likely at this location and questions may be asked about purpose of water sampling.

Sample Location LWQ-8

Safety and access considerations are for LWQ-8 are summarised in Table A8 below. It should be noted that the information contained in Table A8 is based on site conditions on the day the inspection was carried out (26 February 2014, 16:15) which may change over time. Hence the information in Table A8 should be used as a guide only.

Figure A8: Sample location LWQ-8 (yellow arrow = suggested sampling point)

Table A8: Safety and access considerations for LWQ-8

Risk	Risk	Comments
Open water	Low to moderate	Any open water is a potential drowning hazard, however water depth is unlikely to be above knee height (depth dependent on antecedent rainfall).
Fauna (insect, spider, snake, dogs; etc.)	Low to moderate	Dependent on how recent mowing has taken place at the designated sampling point.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	moderate	Access to the sampling location is mostly on relatively flat surfaces, partly grassed and partly hardstand (depending on Council mowing). However, the last part of the traverse from the shared pedestrian / bicycle path is covered in small (10 to 20 cm diameter) river rocks, creating a potential fall and twisted ankle hazard.
Traffic	Moderate	Access is via Glenella Road Mackay Bypass trafficked by high speed private and commercial vehicles. Access must only be via the south bound lane and this will need to be addressed specifically in Safe Work Method Statements created for sampling at this location. Further, the pathway under the Glenella Road bridge over the Lagoons creek is a shared pedestrian / bicycle path requiring particular care regarding collision with cyclists.
Fall	Moderate	As per uneven surfaces risk above,
Heights	Negligible	Height is not an issue for this location.
Mobile equipment interaction	Low	Council mowing equipment notwithstanding, the likelihood of mobile equipment being in close contact with this sample location is low.
Restricted area	Not applicable	Public access
Restricted access (e.g. dense vegetation, long walk, private property)	Low	As for uneven surface / steep terrain risk
Limited communications	Low	Regular foot and cycle traffic. Strong mobile phone reception.
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 15 m of sample location
People	Low	Contact with public is likely at this location and questions may be asked about purpose of water sampling.

Sample Location LWQ-9

Safety and access considerations for LWQ-9 are summarised in Table A9 below. It should be noted that the information contained in Table A9 is based on site conditions on the day the inspection was carried out (26 February 2014, 16:15) which may change over time. Hence the information in Table A9 should be used as a guide only.

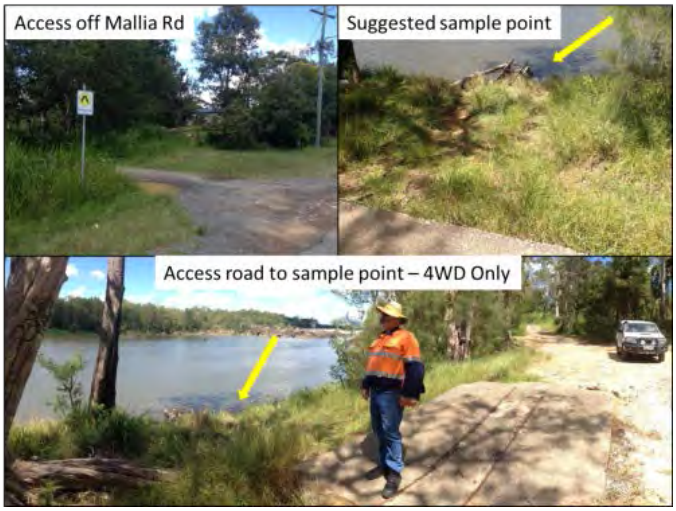


Figure A9: Sample location LWQ-9 (yellow arrow = suggested sampling point)

Table A9: Safety and access considerations for LWQ-9

Risk	Risk	Comments
Open water	Moderate	Any open water is a potential drowning hazard. Given the variable nature of river flows and altered flow regimes created by the Dumbleton weir, access to an appropriate sample location and the depth of water is likely to vary considerably between sampling events.
Fauna (insect, spider, snake, dogs; etc.)	moderate	LWQ-9 is a moderately disturbed riparian environment, hence snakes, spiders, insects etc. can be expected, particularly during the warmer months.
Flora (sting, poisonous, other)	Low	No stinger species or potentially poisonous species observed.
Uneven surfaces / steep terrain (consider access with sampling equipment in tow).	moderate	Providing permission can be obtained to drive down the 4WD accessible road off Mallia Road, much of the access issues to this sample location should be avoidable. However, access down the northern bank to the sample point is via a relatively steep slope with uneven surfaces (Figure A9).
Traffic	Low	Mallia Road is a no-through road with minimal traffic.
Fall	Low to moderate	The possibility of a fall exists accessing the sample location. Further, when water levels are low, it may be necessary to clamber of rocks and stream beds, increasing the risk of a fall.
Heights	Negligible	Height is not an issue for this location.
Mobile equipment interaction	Low	The sporadic presence of maintenance vehicles should be expected as a pump station is present at this location..
Restricted area	Moderate	Access via the road off Mallia Road is marked as foot access only, however this access is easily navigable via 4WD. For safety reasons, it is recommended that permission be sought from the land owner / manager to access this location via 4WD.
Restricted access (e.g. dense vegetation, long walk, private property)	Low	Assuming access by 4WD, this risk is consider to be low.
Limited communications	moderate	Mobile phone signal strength tends towards being low and variable. Area is not regularly frequented by public.
Toxins / pathogens	Low	No specific concerns identified, however it should be noted that toxins and pathogens can occur naturally and the potential always exists for issues such as illegal dumping or accidental release.
Exposure (dehydration; heat; cold; rain)	Low	Vehicle access to within 15 m of sample location (assuming access via 4WD)
People	Low	Not a highly populated area, hence contact with general public is expected to be minimal.

Appendix C
Example of a Water Quality Report Card

Shoal Bay and Buffalo Creek Report Cards

Darwin Harbour

Shoal Bay and Buffalo Creek

Summary

Water quality in outer Shoal Bay is in excellent condition. Several water quality indicators at some Shoal Bay upper estuary monitoring sites do not comply with water quality objectives, but water quality is in good condition. Water quality at the freshwater monitoring sites is in very good condition. The water-bug community is equivalent to reference condition at three out of four biological monitoring sites.

Estuarine water quality at monitoring sites in Buffalo Creek is in very poor condition. For some water quality indicators, water quality objectives are greatly exceeded. Of the sites monitored, the Buffalo Creek sites have the most degraded water quality in the Darwin Harbour region.

Nature of system

- Shallow embayment
- Series of sandbars changing with tides
- Light limitation during the wet season
- Perennial freshwater inflow from Howard River, typically most years in the wet and the dry seasons

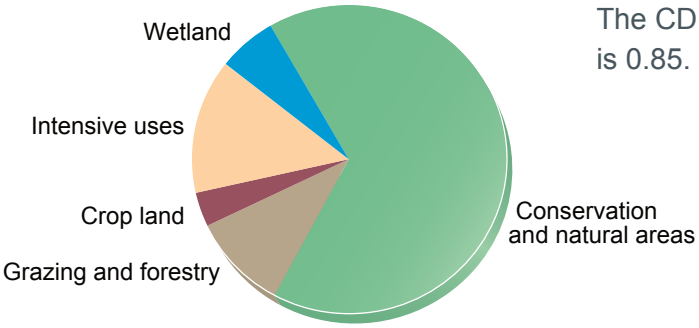
Sources of pollution

- Wet season diffuse source loads are received from the Howard and Shoal Bay sub-catchments
- Sediment and nutrient loads are high with runoff during the wet season
- Sewage treatment plant wastewater discharge at Buffalo Creek

Migratory shorebirds feeding between Lee Point and Buffalo Creek. Dogs are not permitted in this section of the beach to prevent disturbance to shorebirds as they provision for their northward journey. Photo: Brian Thistleton

Shoal Bay and Buffalo Creek catchment showing rivers and monitoring sites

Land use in the catchment

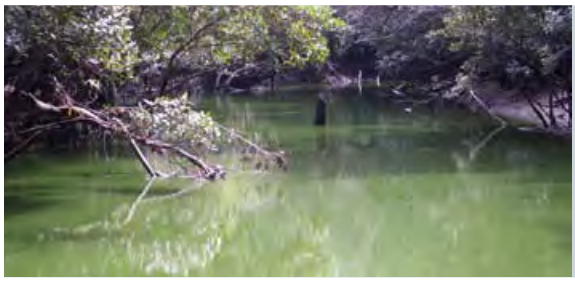


Catchment disturbance index

The CDI for the Shoal Bay catchment is 0.85.

Water quality issues in the catchment

Sampling sediment for assessing pollutant content near the Leanyer-Sanderson sewage treatment plant outfall.



Buffalo Creek receives treated wastewater discharge from the Leanyer-Sanderson sewage treatment plant. Water quality is poor.

Lower Buffalo Creek is a popular recreation area, but subject to pollution from a sewage treatment plant.

Salvinia molesta is a free-floatin aquatic fern that forms mats over water surfaces. Infestations can lead to degradation of water quality and reduced habitat quality for aquatic organisms. It occurs in the lower Howard River.

A grass swale (a water sensitive urban design feature), located in the centre of the road, is treating road runoff at Lyons residential development in Darwin before it discharges to Darwin Harbour.
Photo: Equatica

Shoal Bay catchment ambient freshwater quality

Indicator and units	Water quality objective	Current condition	Number of samples	Compliance
Electrical conductivity (µS/cm)	<200	39	8	✓
Turbidity (NTU)	<20	4.7	8	✓
pH	6.0–7.5	6.1–6.5	8	✓
Dissolved oxygen (%)	50–100	74–84	8	✓
Total suspended solids (mg/L)	<5	NA	NA	
Chlorophyll a (µg/L)	<2	<1	8	✓
NOx (µg N/L)	<8	3	8	✓
Ammonia (µg N/L)	NA	11	8	
Total nitrogen (µg N/L)	<230	260	8	✗
Total phosphorus (µg P/L)	<10	10	8	✓
Filterable reactive phosphorus (µg P/L)	<5	2	8	✓

Period sampled for current condition is 2009. NA Not available

B

Biological health using the AUSRIVAS score

Site	2003	2009	Change
DW42	A	A	No change
DW43	B	B	No change
DW45	A	A	No change
DW70		A	

Shoal Bay upper area marine ambient water quality

Indicator and units	Water quality objective	Current condition	Number of samples	Compliance
Electrical conductivity (µS/cm)	NA	55000	10	
Turbidity (NTU)	NA	19	10	
pH	6–8.5	7.7–8.0	10	✓
Dissolved oxygen (%)	80–100	65–77	10	*
Total suspended solids (mg/L)	<10	38	10	*
Chlorophyll a (µg/L)	<4	7	10	✗
NOx (µg N/L)	<20	2	10	✓
Ammonia (µg N/L)	<20	15	10	✓
Total nitrogen (µg N/L)	<300	360	10	✗
Total phosphorus (µg P/L)	<30	28	10	✓
Filterable reactive phosphorus (µg P/L)	<10	10	10	✓

Period sampled for current condition is Sep 2008 to Dec 2009. NA Not available. * WQO currently under revision

C

Outer Shoal Bay area marine ambient water quality

Indicator and units	Water quality objective	Current condition	Number of samples	Compliance
Electrical conductivity (µS/cm)	NA	53400	10	
Turbidity (NTU)	NA	3.4	10	
pH	7.0–8.5	8.0–8.3	10	✓
Dissolved oxygen (%)	80–100	71–78	10	*
Total suspended solids (mg/L)	<10	18	10	*
Chlorophyll a (µg/L)	<2	0.5	10	✓
NOx (µg N/L)	<20	1	10	✓
Ammonia (µg N/L)	<20	6	10	✓
Total nitrogen (µg N/L)	<270	180	10	✓
Total phosphorus (µg P/L)	<20	5	10	✓
Filterable reactive phosphorus (µg P/L)	<5	4	10	✓

Period sampled for current condition is Sep 2008 to Dec 2009. NA Not available. * WQO currently under revision

A

Buffalo Creek marine ambient water quality

Indicator and units	Water quality objective	Current condition	Number of samples	Compliance
Electrical conductivity (µS/cm)	NA	49800	9	
Turbidity (NTU)	NA	17	9	
pH	6–8.5	7.3–8.0	9	✓
Dissolved oxygen (%)	80–100	38–66	9	*
Total suspended solids (mg/L)	<10	28	9	*
Chlorophyll a (µg/L)	<4	29	9	✗
NOx (µg N/L)	<20	76	9	✗
Ammonia (µg N/L)	<20	533	9	✗
Total nitrogen (µg N/L)	<300	1510	9	✗
Total phosphorus (µg P/L)	<30	375	9	✗
Filterable reactive phosphorus (µg P/L)	<10	318	9	✗

Period sampled for current condition is Sep 2008 to Dec 2009. NA Not available. * WQO currently under revision

The Buffalo Creek monitoring site in the estuary is influence by the treated wastewater discharged from the Leanyer-Sanderson sewage treatment plant outfall. The treatment plant is subject to a Waste Discharge Licence. In 2009, four additional sites were also monitored. All sites were between the outfall and upstream of the boat ramp. The licensed mixing zone is yet to be fully determined. It is possible that the Buffalo Creek monitoring site is located within the discharge mixing zone, and that the water quality objectives may not apply to this site.

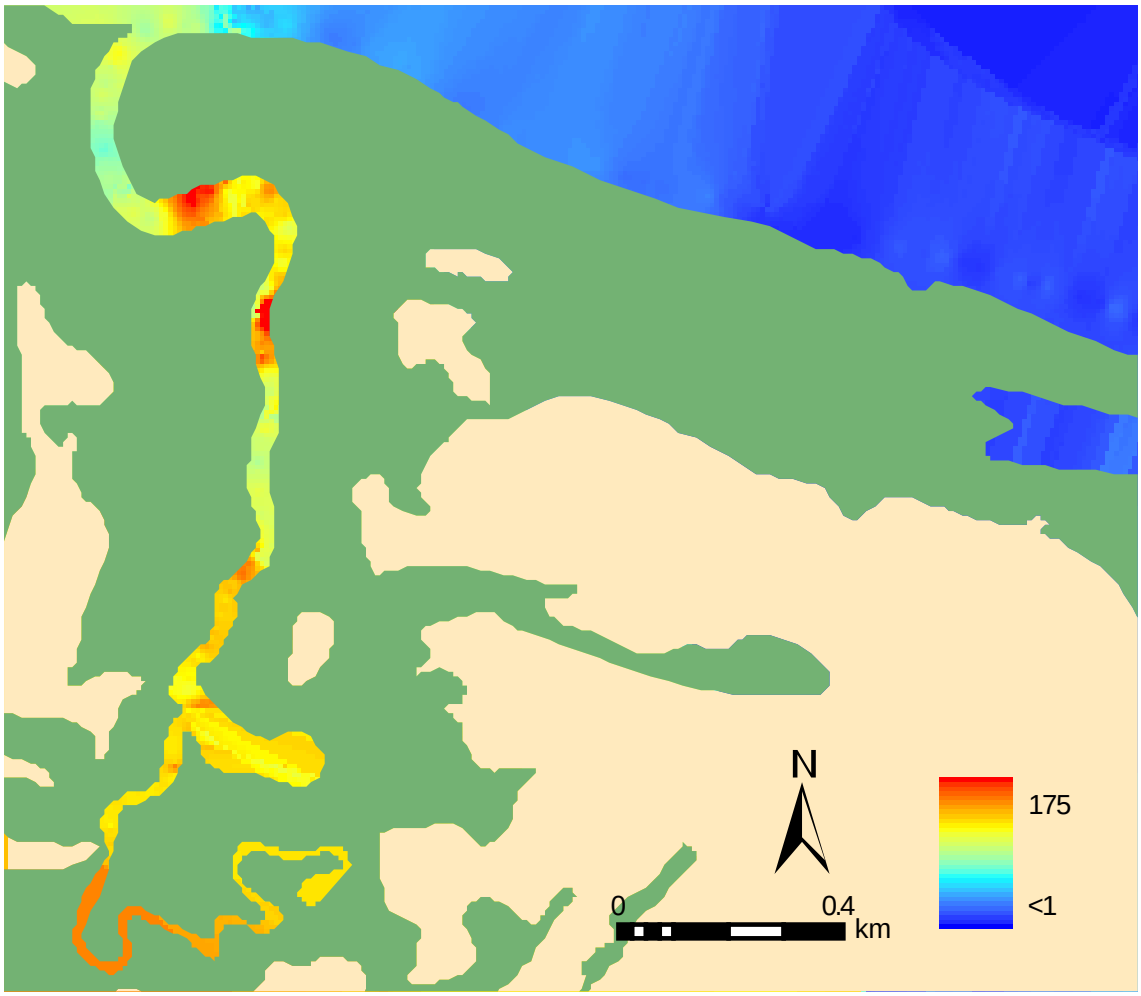
The Leanyer-Sanderson wastewater treatment plant uses a treatment system in waste stabilisation lagoons utilising a combination of sunlight, micro-organisms and algae to break down the raw wastewater. The presence of elevated concentrations of chlorophyll in Buffalo Creek may be largely due to the algae present in the treated wastewater discharge.

Other monitoring

Chlorophyll *a* mapping in Buffalo Creek

Chlorophyll *a* concentration in Buffalo Creek was mapped during the dry season in 2009 and wet season in 2010. In July 2009 chlorophyll *a* values were very high (>200 μg/L) in the upper estuary, with values <10 μg/L further downstream near a popular boat ramp.

In March 2010, chlorophyll *a* values were high (>80 μg/L) in the upper navigable part of the estuary. Greater chlorophyll *a* values (100–170 μg/L) were observed in parts of the mid estuary. Chlorophyll *a* values were approximately 60–75 μg/L near the boat ramp in the lower estuary, and <1 μg/L in Shoal Bay. The Darwin Harbour water quality objective for chlorophyll *a* is <4 μg/L for upper estuaries. These results show water quality in many parts of the estuary is in very poor condition.



Distribution of chlorophyll *a* (μg/L) in Buffalo Creek in March 2010.

Water quality sampling in Buffalo Creek. Buffalo Creek receives treated wastewater discharge from the Leanyer-Sanderson sewage treatment plant. Water quality is poor, with very high chlorophyll levels – hence the noticeable green colour of the water during this sampling. Photo: Julia Fortune

Shoal Bay and Buffalo Creek

Summary

Water quality in outer Shoal Bay was in excellent condition. Water quality at Shoal Bay upper estuary monitoring sites was in moderate condition. Water quality at freshwater sites was in very good condition for the 2011 reporting year. The water-bug community at the biological monitoring sites was assessed as similar to reference condition at two sites and signif cantly impaired at two sites. Water quality at the estuary monitoring site in Buffalo Creek was in very poor condition. For some water quality indicators in Buffalo Creek, water quality objectives were greatly exceeded.

Nature of system

- Shallow embayment with series of sandbars changing with tides
- Possible light limitation of upper reaches of the estuary/marine waters during the wet season
- Perennial freshwater inf ows from Howard River

Potential sources of pollution

- Wet season diffuse source loads from the Howard and Shoal Bay sub-catchments
- Sediment and nutrient loads are high with runoff during the wet season
- Sewage treatment plant wastewater discharges to upper Buffalo Creek. Of note, in October 2011, the Territory Government improved and modernised the licensing regime for sewage treatment plant discharges into Darwin Harbour, including by increasing the monitoring and reporting requirements and focussing on improvements in wastewater discharge quality over time.

Aerial view across part of southern Shoal Bay region towards Buffalo Creek and Darwin Hospital. Photo: Barry Ledwidge

Shoal Bay freshwater and marine water quality

Indicator and units	Freshwater		Outer Marine		Upper Estuary Marine	
	Water quality objective	Compliance	Water quality objective	Compliance	Water quality objective	Compliance
Electrical conductivity (µS/cm)	<200	23 ✓	NA		NA	
Turbidity (NTU)	<20	3.9 ✓	NA		NA	
pH	6.0–7.5	6.8-7.3 ✓	7.0–8.5	7.8-8.2 ✓	6–8.5	7.7-8.1 ✓
Dissolved oxygen (%)	50–100	79-88 ✓	80–100	*	80–100	*
Total suspended solids (mg/L)	<5	3 ✓	<10	*	<10	*
Chlorophyll a (µg/L)	<2	0.25 ✓	<2	1 ✓	<4	3 ✓
NOx (µg N/L)	<8	4 ✓	<20	2 ✓	<20	2 ✓
Ammonia (µg N/L)	NA		<20	5 ✓	<20	25 ✗
Total nitrogen (µg N/L)	<230	165 ✓	<270	150 ✓	<300	310 ✗
Total phosphorus (µg P/L)	<10	10 ✓	<20	5 ✓	<30	45 ✗
Filterable reactive phosphorus (µg P/L)	<5	6.5 ✗	<5	2 ✓	<10	6 ✓
Number of samples		4		8		8
2011 rating		B		A		C
2010 rating (2009 data)		B		A		C
2009 rating (2001–2008 data)		C		A		C

Note[1]: (nd). Limited or no data available Note[2]: (NA). Not applicable, no WQO developed * WQO currently under revision.

Note that many of the median nutrient concentrations for the Shoal Bay upper estuary marine sites at Mickett Creek and Howard River estuary only exceeded the water quality objectives by a small amount. For example, the median total nitrogen concentration for the Shoal Bay upper estuary marine sites exceeded the water quality objective by only 3%.

Buffalo Creek marine water quality

Indicator and units	Water quality objective	Compliance
pH	6–8.5	7.3–7.8 ✓
Chlorophyll a (µg/L)	<4	45 ✗
NOx (µg N/L)	<20	40 ✗
Ammonia (µg N/L)	<20	1775 ✗
Total nitrogen (µg N/L)	<300	2735 ✗
Total phosphorus (µg P/L)	<30	548 ✗
Filterable reactive phosphorus (µg P/L)	<10	326 ✗
Number of samples		4
2011 rating		E
2010 rating (2009 data)		E
2009 rating (2001–2008 data)		E

* WQO currently under revision.
The Buffalo Creek monitoring site in the estuary is inf uenced by the treated wastewater discharged from the Leanyer-Sanderson sewage treatment plant outfall. The treatment plant is subject to a Waste Discharge Licence. The licensed mixing zone is yet to be fully determined. It is possible that the Buffalo Creek monitoring sites are located within the discharge mixing zone, and that the water quality objectives may not apply to this site. The Leanyer-Sanderson wastewater is treated by waste stabilisation lagoons utilising a combination of sunlight, micro-organisms and algae to break down the raw wastewater. The presence of elevated concentrations of chlorophyll in Buffalo Creek may be largely due to the algae present in the treated wastewater discharge.

Biological health using the AUSRIVAS score

Site	2009	2010	Change
DW42	A	B	Change
DW43	B	B	No change
DW45	A	A	No change
DW70	A	A	No change

Mangroves are a feature of Shoal Bay

Appendix D
Budget Estimate for Stage 1 of the Lagoons Catchment Water Quality Monitoring Program

General

The following cost estimates are based on the meeting held on 1 April 2014 ("the Meeting") at Mackay Regional Botanic Gardens (MRBG) attended by:

- Dale Arvidsson (Curator, MRBG)
- Andrew Thomas (Aurecon, Senior Environmental Scientist – Water)
- Grant Paterson (Aurecon, Senior Environmental Scientist – Ecology)

It is important to note that the following does not constitute an offer of service or quotation. Rather, it is intended to provide MRBG with an understanding of potential costs associated with the listed initiatives to begin addressing hydrological and water quality issues associated with the Lagoons for MRBG budgeting purposes.

Note that bathymetry and groundwater costs estimates are not included in this memo. These will be provided in their respective Lagoons Catchment Management Plan sub-reports.

Introduction

The following cost estimate is for the role out of Stage 1of the Lagoons Water Quality Monitoring Plan, *Preliminary Assessment – Analyte Screening* as illustrated in Figure 1 (yellow section).

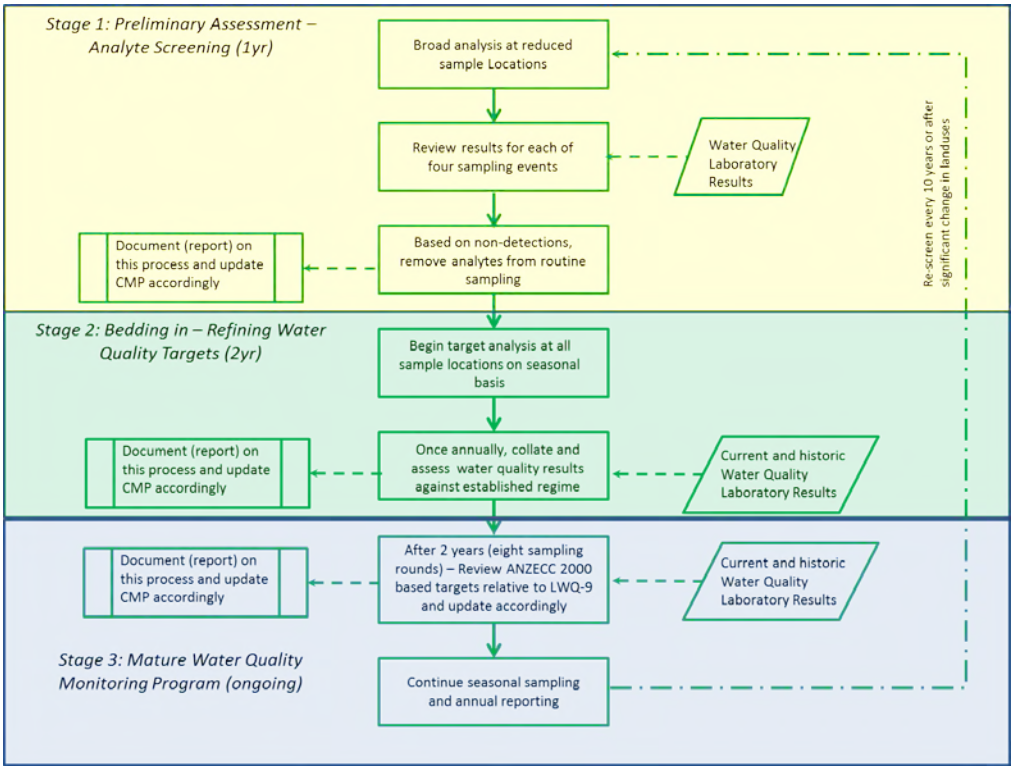


Figure 1: Flow diagram for the role out of the Lagoons Water Quality Monitoring Plan (cost estimate applies to Stage 1: *Preliminary Assessment – Analyte Screen* only)

Scope of Works

As per Section 5 of the *Lagoons Catchment Management Plan Discussion Paper: Water Quality Monitoring Plan* ("Monitoring Plan") tabled at the Meeting, the role out of Stage 1should involve the following:

- Water samples to be collected at each location to be analysed for the full analysis suite as detailed in Section 5.2.1 of the Monitoring Plan at a reduced number of sample locations (reduced from 9 to 4) as per Section 5.3.1.2 of the Monitoring Plan
- Two sampling events over 12 months (one for the wet season and one for the dry season) bringing the total number of sample collections to 10, i.e. (four sampling locations + one QA sample) × two sampling rounds = 10 sample collections
- Provision of a brief memo style summary report to MRBG for the first sampling event. This will include a summary table results for the given event against water quality assessment criteria and dot points outlining findings (purpose is to give MRBG a quick update on water quality results and to ensure project is tracking properly).
- At the completion of the fourth monitoring round, full analysis of all results and subsequent updating of the monitoring plan and Lagoons Catchment Management Plan ("Lagoons CMP").

Outputs

The completion of Stage 1 of the Monitoring Plan should provide the following outcomes and information for the Lagoons Catchment:

- A robust understanding of the types of contaminants / pollution present in the Lagoons Catchment surface waters.
- Establishment of a targeted suite of analytes for monitoring (this will likely be a reduced suite as it is not unusual for some general potential pollutants to not be present is specific situations).
- Provision of a preliminary understanding of the water quality status of the Lagoons Catchment that can be readily applied to identifying contaminating activities of interest.
- Updated / re-issuing of the Monitoring Plan to facilitate the roll out of the remaining stages.
- Updated / re- issuing of the Lagoons CMP, including adjusted water quality assessment criteria and potential changes to action plan.

Cost Estimates

The estimated cost of rolling out Stage 1 of the Monitoring Plan, *Preliminary Assessment – Analyte Screening,* is provided in Table 1.

Table 1: Estimated cost of rolling out Stage 1 of the Lagoons Catchment Water Quality Monitoring Plan

Item	Cost Estimate	Details
Administration	$3,500	Includes Project Management; Safety risk assessment and management; and client liaison over the entire 12 month period
Sampling Event 1	$24,000	
Labour	$9,500	Includes establishing protocols for ongoing sampling (SAQP; liaison with laboratory; setting up field equipment; establishing field protocols; bedding in program); undertaking sampling; data compilation and data review and memo report to MRBG
Laboratory	$13,800	Full suite of analytes as per Section 5.2.1 of the Monitoring Plan
Field equipment, vehicle and sample handling	$700	Vehicle costs; multi-probe water quality meter hire; sample preservation and transport to laboratory
Sampling Event 2	$20,500	If Sampling Event 1 occurs during the dry season then Sampling Event 2 must occur during the wet season
Labour	$6,000	As above. Reduction in labour costs due to sampling regime and protocols having been established in Sampling Event 1
Laboratory	$13,800	Full suite of analytes as per Section 5.2.1 of the Monitoring Plan
Field equipment, vehicle and sample handling	$700	Vehicle costs; multi-probe water quality meter hire; sample preservation and transport to laboratory
Final Analysis and Update o45f Monitoring Plan and Lagoons CMP	$10,000	
Data collation and analysis	$3,000	Collation of all data from all events; analysis of results to determine new water quality target analytes for Stage 2 of the Monitoring Plan
Reporting	$7,000	Reporting will take the form of an updated / new issuing of the Monitoring Plan and Lagoons CMP with findings and altered monitoring regime to facilitate Stage 2. Price includes internal review and verification as per Aurecon's ISO 9001 and 14001 certified quality system.
Total cost estimate for Stage 1 (GST not included)	$58,000	NOTE: Approximately 48% of this cost is lab analysis (subcontracted to NATA certified laboratory).

Summary

Total cost estimate to complete Stage 1 *Preliminary Assessment – Analyte Screening* of the Monitoring Plan is $58,000. The following should be noted in relation to this cost estimate:

- Just under half of the cost is laboratory analysis (subcontracted to NATA certified laboratory), noting that it is highly likely that after the completion of Stage 1, this price will reduce significantly.
- The quoted price is based on the delivery of a professional, quality outcome that will meet the needs of the Lagoons Catchment and the MRBG. There is scope to reduce this cost, however it should be noted that this will come with a potential reduction in quality and therefore certainty in the data collected and analysed, and findings thereafter (depending on how this is managed).
- The preparation of sampling sites for safe access sampling (e.g. mowing and slashing) have not been included as it is assumed that MRBG will arrange this through Mackay Regional Council (MRC).

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