Palmerston Lakes Management Plan

City of Palmerston

DOCUMENT CONTROL RECORD

Job	EZ21200
Document ID	205900-12
Author(s)	Adele Faraone (EcOz), Emma Smith (EcOz)

DOCUMENT HISTORY

Version	Purpose	Date	CoP Reviewer
1	LMP issued	6 November 2020	Katie O'Neill
2	LMP update to include Durack Heights Lake	10 November 2021	Peter Lander

Recipients are responsible for eliminating all superseded documents in their possession.

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... **V**

1 INTRODUCTION **1**

1.1 Purpose and scope 1

2 EXISTING ENVIRONMENTAL CONDITIONS **4**

2.1 Rainfall and runoff 4

2.2 Palmerston lakes history and uses 5

2.3 Lake physical features and current condition 5

2.3.1 Durack Lakes 6
2.3.2 Sanctuary Lakes 7
2.3.3 Marlow Lagoon 7
2.3.1 Durack Heights Lake 7

2.4 Lake water quality 11

2.4.1 Quarterly water quality monitoring results 11
2.4.2 Dissolved oxygen lake survey results 14

3 LAKE FUNCTIONS **18**

4 MANAGEMENT TARGETS **19**

5 MANAGEMENT MEASURES **27**

5.1 Vegetation management 27

5.2 Salvinia management 28

5.2.1 Proposed salvinia management plan 29

5.3 Algae management 30

5.4 Sediment management 31

5.5 Aeration devices 31

5.6 Irrigation management plan 32

5.7 Community education and engagement 33

6 WATER QUALITY MONITORING PROGRAM **34**

6.1 Monitoring objectives 34

6.2 Monitoring sites 35

6.3 Frequency of sampling and sampling parameters 38

6.4 Sampling methodology 38

6.5 Assessment criteria 39

6.6 Reporting 39

6.7 Documentation 39

6.8 Site inspection checklists 40

7 NON-CONFORMANCE AND CORRECTIVE ACTIONS **41**

8 REFERENCES **43**

Tables

Table 2-1. Palmerston lakes physical features, lake fill water source and environmental condition. 10
Table 2-2. Quarterly water quality monitoring trends summary. 11
Table 2-3. DO survey results summary. 14
Table 3-1. Current functions and desired priority functions for all lakes. 18
Table 4-1. Lake 1a strategy. 19
Table 4-2. Lake 1b strategy. 19
Table 4-3. Lake 3 strategy. 20
Table 4-4. Lake 4 strategy 21
Table 4-5. Lake 5 strategy 21
Table 4-6. Lake 6 strategy 22
Table 4-7. Lake 7a, 7b and 7c strategy 22
Table 4-8. Lake 8 strategy 23
Table 4-9. Lake 9 strategy 23
Table 4-10. Lake 10a and 10b strategy 24
Table 4-11. Sanctuary Lakes A, B and C strategy 24
Table 4-12. Marlow Lagoon strategy 25
Table 4-13. Durack Heights strategy 25
Table 5-1. Salvinia control methods (adapted from CRC Weed Management, 2003) 28
Table 5-2. Recommended size and number of aeration systems for Palmerston lakes taken from EcOz advice letter, July 2020. 32
Table 6-1. Monitoring site location details. 35
Table 6-2. Monitoring program sampling frequency and parameters. 38
Table 6-3. Documents and records summary 40
Table 7-7-1. Corrective actions for continual improvement. 41

Figures

Figure 1-1. Map of Palmerston lakes. 3
Figure 2-1. Average monthly rainfall. 4
Figure 2-2. Map of Palmerston lakes water flows and groundwater bores. 9
Figure 2-3. Dissolved oxygen in-situ depth profiles. *DO survey for Durack Heights was undertaken in the morning; therefore, only morning readings are presented in the graph for this lake.* 16
Figure 5-1. Management of rooted and floating aquatic and fringing vegetation 27
Figure 5-2. SPEL Vortceptor (left) and SPEL Stormceptor (right) (SPEL Environment, 2020) 31
Figure 6-1. Sampling plan map (Durack Lakes, Durack Heights and Marlow Lagoon). 36
Figure 6-2. Sampling plan map (Sanctuary Lakes). 37

Appendices

Appendix A Site inspection report
Appendix B Palmerston Lakes Water Quality Report Card
Appendix C Salvinia Signage

ACRONYMS

ANZECC	Australian and New Zealand Environment and Conservation Council
BOD	biochemical oxygen demand
BoM	Bureau of Meteorology
CDUDS	Monitoring site - Downstream of CDU Campus
Chl-a	chlorophyll-a
CoP	City of Palmerston
DENR	Department of Environment and Natural Resources (Northern Territory)
DLD	Monitoring site – Durack Lake 1b
DLDS	Monitoring site – Downstream of Durack Lakes
DLE	Monitoring site – Durack Lake 1a
DLG	Monitoring site – Durack Lake 7
DLBORE	Monitoring site – Durack Lake Bore
DH	Monitoring site – Durack Heights
DO	dissolved oxygen
EC	electrical conductivity
EcOz	EcOz Environmental Consultants
GPT	gross pollutant trap
LMP	Lakes Management Plan
LOR	limit of reporting
ML	Monitoring site – Marlow Lagoon near outlet
MLBORE	Monitoring site – Marlow Lagoon Bore
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NATA	National Association of Testing Authorities
NOx	nitrate NO_3 + nitrite NO_2
NT	Northern Territory
NT EPA	Northern Territory Environment Protection Authority
QA/QC	quality assurance, quality control
SLA	Monitoring site – Sanctuary Lakes, Lake C
SLB	Monitoring site – Sanctuary Lakes, Lake A
SLBORE	Monitoring site – Sanctuary Lakes Bore
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
WMPC Act	Waste Management and Pollution Control Act (Northern Territory)
WQO	Water quality objectives
WSUD	water sensitive urban design

EXECUTIVE SUMMARY

This Lakes Management Plan (LMP) covers the City of Palmerston (CoP)-managed lakes, comprising the Durack Lakes, Sanctuary Lakes and Marlow Lagoon. Community expectations and CoP requirements of the lakes are many and varied, and include:

- Stormwater retention and water quality treatment
- Amenity, recreation and aesthetic values for those living near the lakes and using parklands around the lakes
- Water source for irrigation of the Palmerston golf course and CoP-managed parklands surrounding the lakes
- Habitat for wildlife including fish, birds and reptiles
- Recreational fishing, whereby the lakes are periodically stocked with barramundi for this purpose

Routine maintenance activities undertaken by CoP in and around the Palmerston lakes includes:

- Frequent removal of aquatic plants from the lakes
- Irrigation, mowing and maintenance of lawn and parklands around the lakes
- Topping up of lake water levels during the dry season using groundwater from nearby bores

Excessive aquatic plant growth in the lakes and incidences of low dissolved oxygen are of particular concern for addressing in this LMP.

This LMP defines the priority purposes and functions of the Palmerston lakes, and provides strategies for maintaining these; noting that maintaining good lake water quality is always the highest priority, given all other functions rely on this.

A number of staged studies and reviews were undertaken to support development of this LMP that included defining the priority functions/purposes of each of the Palmerston lakes, the current environmental condition of each lake, and a review of current management and maintenance practices.

These investigations identified that current management practices and lake functions could be improved by:

- Changing the Palmerston lakes water quality monitoring program to focus on dissolved oxygen (DO) as an indicator.
- The current harvesting regime is appropriate for the management of vegetation such as rooted and floating aquatic plants (lilies) and fringing vegetation (bullrushes and typha). A more targeted approach to salvinia and algae management is required.
- Management of catchment related sediment inputs are crucial to reduce the nutrient load within the lakes.
- Recommendation to develop an irrigation management plan for lake water utilised for irrigation purposes (largely by Palmerston Golf Course).
- The importance of community education and engagement when it comes to looking after the lakes.

This first version LMP will require periodic revision and updating to align with any changes to community expectations, and to incorporate improved knowledge of how the lakes function and which management practices work best.

.

1 INTRODUCTION

This Lakes Management Plan (LMP) covers the City of Palmerston (CoP)-managed lakes, comprising the Durack Lakes, Sanctuary Lakes, Marlow Lagoon and the Durack Heights Lake (herein referred to as the Palmerston lakes). All these lakes were constructed as features of suburban developments in the mid to late 1990's (except for Marlow Lagoon, which is natural).

Community expectations and CoP requirements of the lakes are many and varied, and include:

- Stormwater retention and water quality treatment
- Amenity, recreation and aesthetic values for those living near the lakes and using parklands around the lakes
- Water source for irrigation of the Palmerston golf course and CoP-managed parklands surrounding the lakes
- Habitat for wildlife including fish, birds and reptiles
- Recreational fishing, whereby the lakes are periodically stocked with barramundi for this purpose

Routine maintenance activities undertaken by CoP in and around the Palmerston lakes includes:

- Frequent removal of aquatic plants from the lakes
- Irrigation, mowing and maintenance of lawn and parklands around the lakes
- Topping up of lake water levels during the dry season using groundwater from nearby bores

Excessive aquatic plant growth in the lakes and incidences of low dissolved oxygen are of particular concern for addressing in this LMP.

1.1 Purpose and scope

This LMP defines the priority purposes and functions of the Palmerston lakes, and provides approaches for maintaining these; noting that maintaining good lake water quality is always the highest priority, given all other functions rely on this.

CoP commissioned EcOz Environmental Consultants (EcOz) to develop this LMP in accordance with specified requirements and with continued input from CoP during the LMP development process. This first version LMP will require periodic revision and updating to align with any changes to community expectations, and to incorporate improved knowledge of how the lakes function and which management practices work best.

A number of staged studies and reviews were undertaken by EcOz, in consultation with CoP, to support development of this LMP, comprising:

- Stage 1: *Functional objectives of Palmerston lakes*, July 2020 - identification of primary, secondary and incidental lake functions (Excel spreadsheet)
- *Stage 2: Lake Condition Report*, August 2020 - outlines the current environmental condition of each of the Palmerston lakes in terms of water quality and stormwater treatment
- Stage 3: *Lake management targets*, September 2020 - identifying priority management actions to be undertaken for each lake (Excel spreadsheet)
- Stage 4: *Review of Lake Management Practices* report, September 2020 – review of current lake management practices and recommendations for improvements
- Supplementary Report: *Lake Water Quality and Maintenance Review*, September 2020 – review of all available water quality monitoring data for the Palmerston lakes, including quarterly monitoring since 2014, monthly sampling of two lakes throughout 2019, and a dissolved oxygen survey of all lakes in August 2020. The aim was to improve understanding of controls on lake water quality.

The main findings of these studies and reviews are utilised in this LMP, however for more detail, please refer to the relevant above-listed documents.

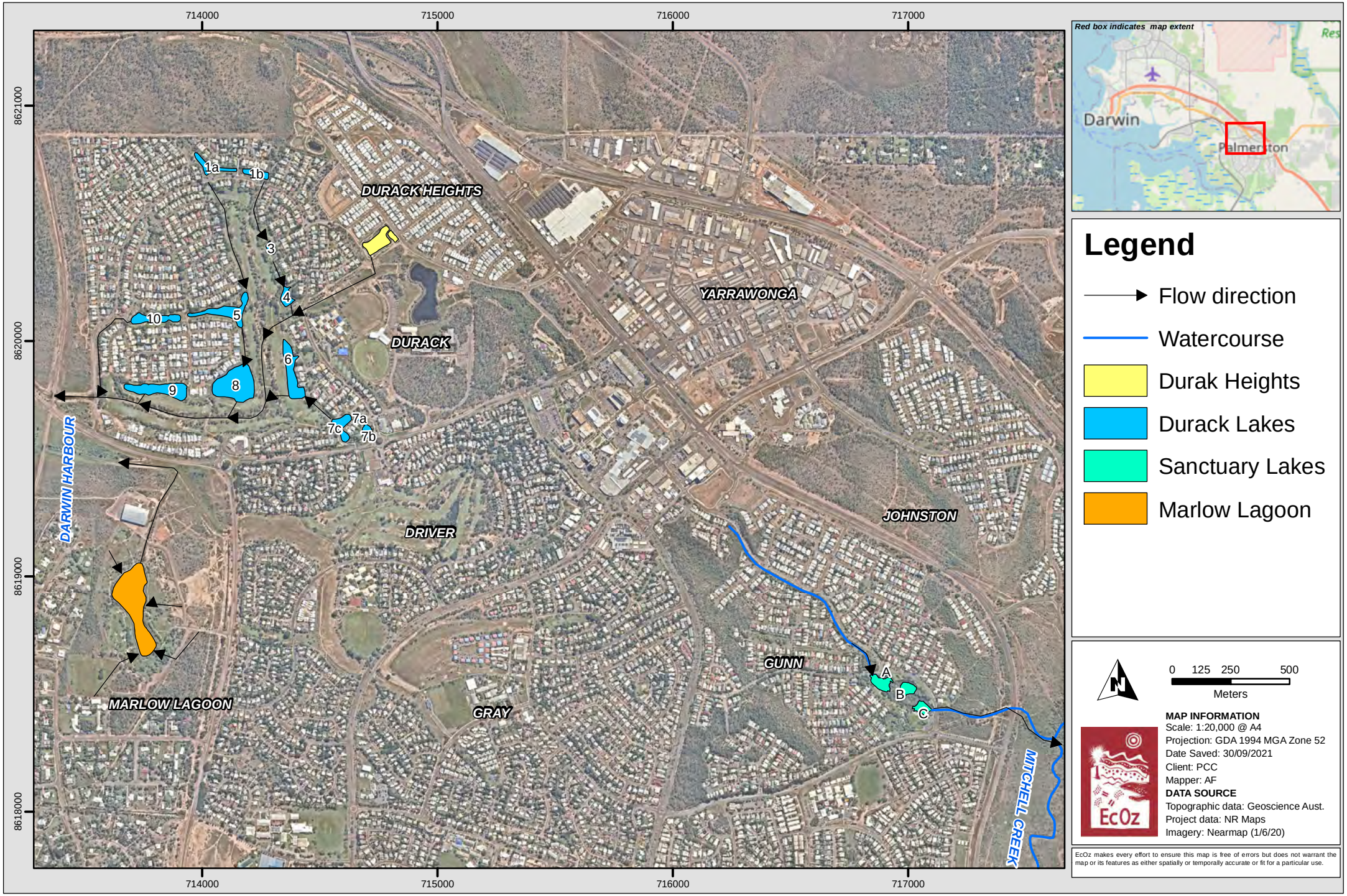
In addition to the above, the Durack Heights Lake was added to the Lakes Management Plan as of September 2021.

CoP management and operations staff were consulted during development of the studies and reviews listed above when determining lake functions and purposes, and current management practices. These CoP staff have an understanding of the Palmerston community's values and uses of the lakes; however, no direct community consultation was undertaken. Community consultation regarding specific aspects of this LMP may be undertaken to inform future LMP revisions.

This LMP sets out the following:

- The current existing environmental setting, physical features, lake water quality and condition of each lake
- The primary and secondary functions/purpose of each lake
- Management targets for each of the lakes based on current environmental characteristics and functional objectives
- Assessment of current management practices concerning the lakes and recommendations for improvement
- Targeted actions, timelines for implementation of improved lake practices on management and departmental responsibilities
- Water quality monitoring plan and lake condition reporting
- Non-conformance and corrective actions

This first version LMP will require periodic revision and updating to align with any changes to community expectations, and to incorporate improved knowledge of how the lakes function and which management practices work best.



Path: Z:\01 EcOz_Documents\04 EcOz Vantage GIS\EZ19022 - Palmerston Lakes Water Quality and Maintenance Review\01 Project Files\Fig X-X Landscape A4 Z52 (revised).mxd

Figure 1-1. Location of Palmerston Lakes

2 EXISTING ENVIRONMENTAL CONDITIONS

This section provides information on the current environmental setting and condition of the Palmerston lakes. This information is relevant when defining appropriate lake functions and management targets in later sections of this LMP.

2.1 Rainfall and runoff

Lake water quality changes seasonally in response to the region's wet-dry tropical monsoon climate, where most rainfall occurs during the wet season (November to April) and almost no rain during the dry season (May to October). Management of the lakes also changes seasonally, whereby the lakes are heavily utilised as an irrigation water source during the dry season and constantly topped up with water from groundwater bores. The rate of aquatic plant growth and frequency of harvesting is also greatest during the dry months when water flow through the lakes is minimal.

Average annual rainfall is 1,723 mm, based on records from the nearest Bureau of Meteorology (BoM) station with consistent long-term data (i.e. Darwin Airport, BoM station no. 14015). The mid-wet season months are the wettest, with January recording an average monthly rainfall of 429 mm, followed by February with 370 mm, and March with 314 mm (Figure 2-1). During these months, monsoonal periods can occur, where rain falls consistently; sometimes lasting several weeks. Less rain falls during the early wet season (December average 249 mm, November average 143 mm). This usually occurs as short storm events.

Rainfall in April and May is infrequent, with average monthly totals of 102 mm and 21 mm respectively. Normally, no rain falls in June, July and August (<5 mm total monthly average), and very little in September and October (16 mm and 70 mm respectively).

The first storms of the wet season often start October/November, but can occur as early as September. The first rains following the dry season months of May to August are referred to as the 'first flush'. Runoff at this time is characterised by relatively higher contaminant levels and poorer water quality due to the build-up of contaminants on surfaces over the dry season. Section 2.4 below further discusses seasonal lake water quality patterns.

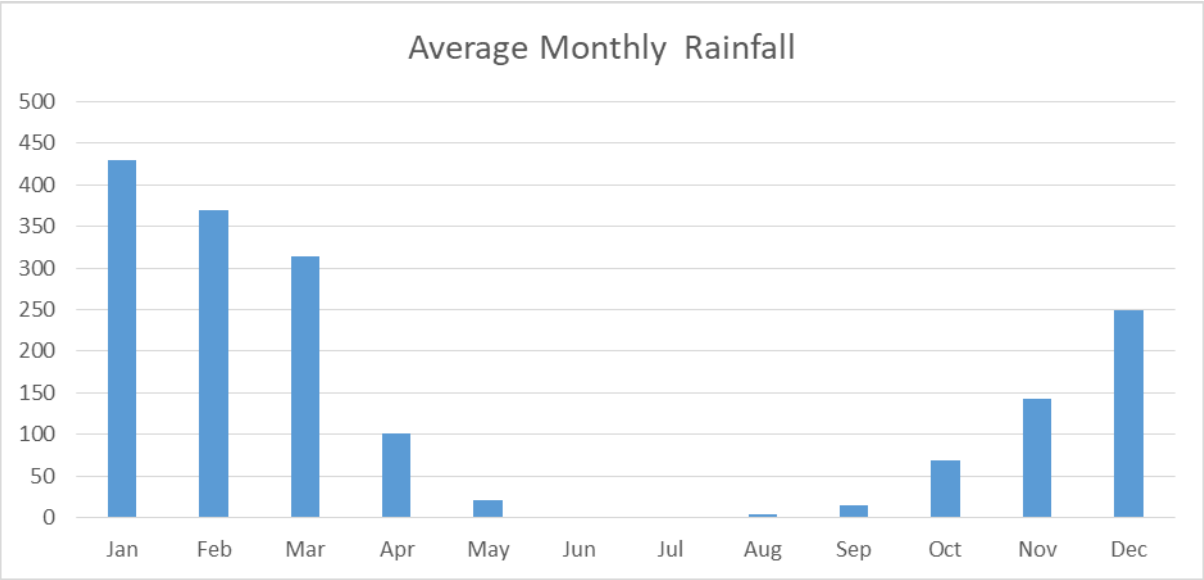


Figure 2-1. Average monthly rainfall.
Taken from BoM station Darwin Airport No. 14015.

2.2 Palmerston lakes history and uses

Durack Lakes and Sanctuary Lakes are man-made lake systems constructed during the mid to late 1990's as part of the housing developments of the suburbs of Durack and Gunn respectively (Figure 1-1). These lakes were designed to provide some level of stormwater retention and treatment, as well as visual amenity to local residents living around the lakes. The parklands, footpaths and bike paths immediately surrounding the lakes are also used by the Palmerston community for recreation.

The Palmerston golf course is incorporated into the areas surrounding the Durack Lakes, with the fairways and greens of holes 1 to 9 situated around lakes 3, 4, 5, 6, 7, 8 and 9.

Marlow Lagoon is a natural freshwater lake, now within a recreation area that features parklands, footpaths, a children's playground and pet exercise park. This recreation area is surrounded by the suburbs of Marlow Lagoon and Driver.

The Durack Heights Lake is comprised of a small sediment pond and larger wetland (i.e. 2 water bodies), which is surrounded by a series of pedestrian pathways and is surrounded by the suburb of The Heights Durack. South-east of the Durack Heights Lake, is another man-made lake which is managed by Charles Darwin University.

CoP is responsible for maintaining all three lake systems, as well as the surrounding parklands and associated infrastructure.

Recreational fishing in all three lake systems is encouraged by CoP, and the lakes are periodically stocked with barramundi for this purpose.

Swimming is not permitted within any of the three lake systems due to the potential presence of saltwater crocodiles, and given the urban catchments, water quality cannot be guaranteed as free of pathogens or other contaminants potentially unsafe to human health.

During the dry season, lake water levels are maintained by adding water sourced from nearby groundwater bores. All the lakes, excluding Lake 5 and Marlow Lagoon, are used to irrigate the parklands immediately surrounding the lakes. Palmerston golf course has to date utilised Lake 6 as a water source for irrigation, in addition to their two groundwater bores.

2.3 Lake physical features and current condition

The following section summarises the physical features and current environmental condition of the Palmerston lakes. For more detail, please refer to the Stage 2 *Lake Condition Report* and Supplementary Report, *Lake Water Quality and Maintenance Review* listed in Section 1.1 above.

The environmental condition of each lake has been given a qualitative rating of "**good**", "**ok**", or "**poor**"; see Table 2-1. This rating is based on site inspections undertaken by EcOz in July and August 2020, and observations of aquatic plant assemblage and biomass, water clarity, sediment build-up etc. The rating also incorporates the findings of lake water balance modelling, and modelled sediment and nutrient inputs/outputs reported in the Stage 2 Lake Condition Report.

Important factors determining the functioning and condition of each lake include the size of catchment contributing runoff into each lake, and the lake's surface area, volume and depth. These statistics are provided in Table 2-1 and discussed in the sections below.

Table 2-1 also includes the estimated parkland/golf course area irrigated using water from each lake and the specific groundwater bores used to top up each lake. This provides a relative indicator of which lakes and bores are drawn from most heavily for irrigation.

2.3.1 Durack Lakes

Physical features

The Durack Lakes comprise 14 interconnected lakes; see Figure 2-2 for lake ID numbers and water flow directions. The total combined catchment area of The Durack lakes is around 136 ha. This catchment is predominantly residential, with the immediate areas around the lakes mainly comprising golf course and parklands. All the lakes have residences within close proximity. The combined catchment area of Lakes 1a and 1b is by far the largest of all the Durack Lakes (45.53 ha); followed by Lake 5 (18.9 ha). All other lakes have catchment areas less than 14 ha.

The total combined water surface area of the lakes is almost 92,000 m^2, with depths ranging between 1.5 m and 3.6 m. Lake 8 has by far the largest surface area and volume, followed by Lake 9, then Lake 5. Likewise, Lake 8 is the deepest, followed by Lakes 1a, 1b, 9 and 6. Lakes 3, 4, 5 and 10 are all relatively shallow and less than 2 m deep. These depths are based on manual depth measurements taken by EcOz during the late dry season in August 2020. The lakes have never been dredged and the build-up of sediment and organic material on the bottom of the lakes since their construction in the mid 1990's is unknown.

Two local bores (Sabal and Crowson) are utilised in the dry season to maintain water levels for lake aesthetics and as an irrigation water source (Lake 5 is the only lake not involved in irrigation). The Sabal bore (RN035414) is used for topping up Lakes 1a, 1b, 3, 4, 5, and 10. The Crowson bore (RN031124) is used for topping up lakes 6, 7, 8 and 9. Note however, that pipe systems and pumps allow water exchange between the various lakes, e.g. Lake 8 can be topped up directly from the Crowson Bore, or via overflows from Lake 10 and Lake 5, which get their water from the Sabal bore.

The outlet from the Durack Lakes system discharges through a channel under Woodlake Boulevard before entering the Hudson Creek tidal inlet of the Darwin Harbour estuary.

Environmental condition

Based on site inspection, Lake 6 was observed as being in poor condition with a microalgae-dominated plant assemblage i.e. green, murky water. Contributing factors may include the high usage of this lake for irrigation water for the Palmerston golf course and/or high usage of fertilisers or other nutrient sources in the catchment. Modelling results for Lake 6 are in contrast to these visual observations, as they indicated the lake's sizing in relation to a simple, mainly residential catchment is appropriate for treating inputs of nutrients in runoff. These results are indicating that additional factors, not accounted for in the model, are having a detrimental impact on lake water quality.

Lakes 1a, 1b, 3 and 4 were observed to have poor to ok condition, with the relatively small water areas and volumes of these lakes likely a contributing factor. Compared to the other Durack Lakes, these four lakes have very large catchment areas relative to lake water volume i.e. over 66 ha of catchment to a combined total lake volume of 40,000 m^3. Lakes 3 and 4 are shallower than 1a and 1b, which is potentially why these lakes appear in poorer condition than Lakes 1a and 1b. Modelling showed very large sediment inputs in runoff from the catchment of these four lakes, which is also obvious in historic aerial imagery during the wet season, where Lakes 1a, 1b, 3 and 4 are extremely turbid in comparison to the other Durack Lakes. Modelling results for these four lakes also indicated they were ineffective in treating nutrient inputs from the catchment.

Lakes 5, 7, 9 and 10 were observed to be in relatively good condition, however, aquatic vegetation growth is still very rapid. Modelling results for these four lakes indicated their sizing was sufficient for effectively treating the predicted nutrients inputs in runoff from the catchment.

Lake 8 appears to have the best water quality and least amount of plant growth. This is due to the fact this lake is relatively deep, has a relatively large water volume and small catchment compared to the other lakes. Modelling results indicated this lake was most effective in treating the predicted nutrient inputs. This lake also benefits from the pre-treatment of stormwater through Lake 5 prior to entering the lake.

2.3.2 Sanctuary Lakes

Physical features

The Sanctuary Lakes are located in the Palmerston suburb of Gunn (Figure 1-1 and Figure 2-2). These lakes comprise three sequential lakes (denoted A, B and C), with a total surface area of approximately 17,600 m^2. Lake depths range between 2.8 m and 3.5 m, based on the manual depth measurements taken by EcOz in August 2020. The lakes have never been dredged and the build-up of sediment and organic material on the bottom of the lakes since their construction in the mid 1990's is unknown.

During the dry season, a local bore (RN032101) tops up the lakes, in order to maintain the lakes' amenity and aesthetics. Bore water is also used to irrigate the parklands surrounding the lakes.

Surface flows into Sanctuary Lakes are primarily from the surrounding residential areas of Gray and Gunn, and have a total contributing catchment of 66.4 ha.

Overflows from the lakes flow east into Mitchell Creek, which then flows south into the tidal reaches of the Elizabeth River, prior to entering Darwin Harbour.

The middle lake (Lake B) has a small island, which potentially restricts flows to the western side of the lake.

Environmental condition

The Sanctuary Lakes were observed to be in poor condition, due to excessive plant growth, especially algae and salvinia. Modelling also showed these lakes to be largely ineffective in treating nutrient inputs in runoff due to their small size in comparison to catchment size.

2.3.3 Marlow Lagoon

Physical features

Marlow Lagoon is an augmented natural freshwater lagoon located within the Palmerston suburb of Marlow Lagoon (Figure 1-1 and Figure 2-2). It has a surface area of approximately 31,600 m^2 and is very shallow with a maximum depth of 1.2 m. Surface water flows into Marlow Lagoon are from the surrounding suburban catchment area totalling 30.43 ha. The lagoon overflows and discharges into a channel near the intersection of Kirkland Road and Elrundie Avenue into the Hudson Creek tidal inlet of the Darwin Harbour estuary.

The lagoon has an island in centre, with pedestrian causeways on either side that potentially restrict water exchange between the northern and southern basins of the lagoon.

Lagoon water levels drop during the dry season, however, enough water remains that topping up the lagoon with bore water is not normally undertaken. Two nearby bores are utilised by CoP to irrigate the surrounding parklands and top up the lake (if required); RN023582 and RN022721. Irrigation of the surrounding parklands is predominantly taken directly from the groundwater bore RN023582.

Environmental condition

Marlow Lagoon was observed to be in relatively good condition. This lagoon has a relatively large water volume compared to catchment area and the lake is not usually topped up with bore water or utilised as an irrigation water source. Aquatic plant removal using the harvester is also not currently undertaken in this lake.

2.3.1 Durack Heights Lake

The Durack Heights Lake is a constructed lake, which is comprised of a sedimentation basin (upstream) and a larger water body, known as the 'basin' which is used to retain stormwater. The sediment pond has a surface area of 1,060 m^2, a depth of 0.6 m and a volume of 1,060 m^3. Surface and piped flows from the Heights Durack catchment, enter the sediment pond via three 1,350 mm culverts off Packard Ave. Flows from the sediment pond discharge through to the larger lake body via two 1,350 mm culverts.

The larger lake body has a surface area of 6,880 m^2, is 2 m deep and has a total volume of 10,320 m^3. Stormwater is discharged from the lake by four 600 x 900mm box culverts.

Environmental condition

The Durack Heights Lake was observed to be in very poor condition. Both the sediment pond and the lake were, covered in Salvinia and other floating plants. Water quality was observed to be turbid. The bottom of both water bodies were unable to be observed due to the large amount of plant material and poor transparency of water. However, there was a large population of different species of birds observed in and around the water bodies. A number of small fish were observed as well.

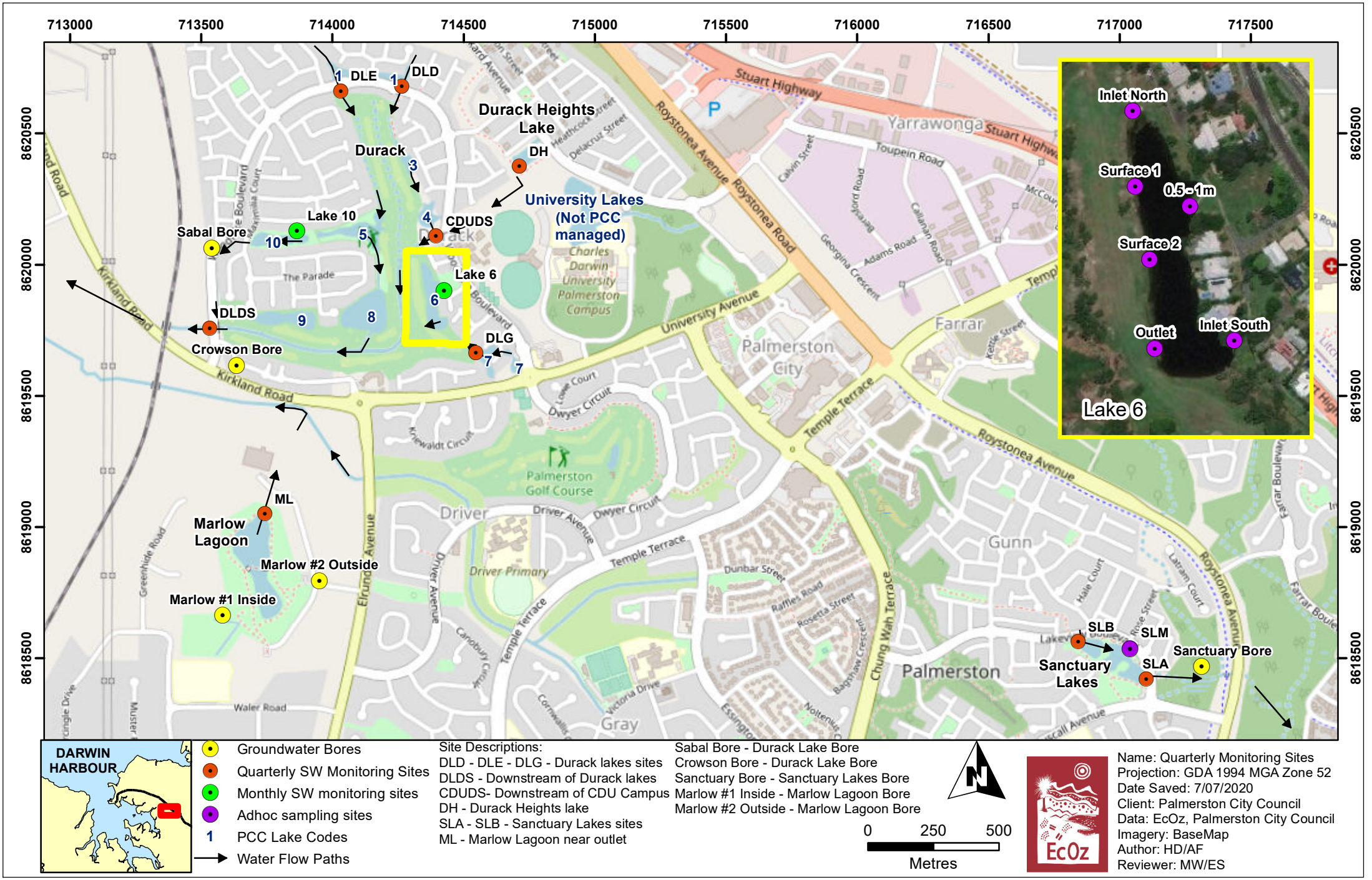


Figure 2-2. Map of Palmerston lakes water flows and groundwater bores.

Path: Z:\01 EcOz_Documents\04 EcOz Vantage GIS\EZ19115 - Palmerston Lakes Water Monitoring and Reporting\01 Project Files\Quarterly Monitoring Sites.mxd

Table 2-1. Palmerston lakes physical features, lake fill water source and environmental condition.

Data for lake catchment area, volume, surface area and irrigated area supplied by CoP, lake depths taken from EcOz manual measurements during DO survey in August 2020. Lake condition rating based on site inspections July/August 2020 and modelling – see Stage 2 Lake Condition Report for more detail. Lake condition rating for the Durack Heights Lake derived from DO survey conducted in August 2021.

Lake	Catchment area (ha)	Vol. at outlet level (m^3)	Lake surface area (m^2)	Lake depth in centre (m)	Area irrigated using lake water (m^2)	Lake fill water source	Lake condition rating
Lake 1a	45.53	10,000	4,170	3.35	27,760	Sabal bore (RN035414)	**Ok**
Lake 1b		12,070	5,030	3.50			**Ok**
Lake 3	13.11	6,560	3,200	2.00	6,555	Sabal bore (RN035414) via pumping from Lake 4	**Poor**
Lake 4	8.11	11,900	5,600	2.00	27,400	Sabal bore (RN035414)	**Poor**
Lake 5	18.90	25,200	12,900	1.90	Not used for irrigation	Sabal bore (RN035414) via overflow from Lake 10 or pumped up from Lake 8	**Good**
Lake 6	8.92	23,200	11,600	3.40	61,000	Crowson bore (RN031124)	**Poor**
Lake 7a	13.75	19,250	400	~1.5	41,700	Crowson bore (RN031124)	**Good**
Lake 7b			1,860	2.40			**Good**
Lake 7c			4610	3.05			**Good**
Lake 8	6.49	68,300	22,700	3.60	3,245	Sabal bore via Lake 10 or directly from Crowson bore	**Good**
Lake 9	12.67	39,600	11,400	3.40	6,335	Crowson bore (RN031124)	**Good**
Lake 10	8.68	16,900	8,400	2.00	66,226	Sabal bore (RN035414)	**Good**
Sanctuary Lakes A	66.40	54,500	5,700	3.50	33,200	Sanctuary bore (RN032101)	**Ok**
Sanctuary Lakes B			6,500	3.05			**Ok**
Sanctuary Lakes C			5,400	2.80			**Poor**
Marlow Lagoon	30.43	79,000	31,600	1.20	Lake water not used for irrigation	Lake not normally topped up, water levels are lower during dry season but lake doesn't dry out	**Ok**
Durack Heights Lake	23.18	10,320	6,880	2.00	Lake water not used for irrigation	No fill.	**Very Poor**

2.4 Lake water quality

Water quality monitoring of the Palmerston lakes was undertaken routinely (usually quarterly) between March 2014 and March 2020. This program involved the sampling of nine sites each monitoring round at representative locations throughout the lake systems (Figure 2-2). Site locations focussed on determining the water quality of runoff entering the lakes from the surrounding urban areas, and then discharged from the lake systems into Darwin Harbour.

In August 2020, a survey was undertaken measuring dissolved oxygen (DO) levels throughout the water column of each of the Palmerston lakes during both the morning and afternoon. This was to gain a better understanding of lake condition and controls on water quality and plant growth. DO is a key indicator of lake function and condition. A lake that has a large biomass of plants and algae will typically experience very low DO concentrations in the early morning and high concentrations in the afternoon. A lake that is stratified will also typically record very high DO concentrations in the surface layer and low concentrations in the bottom layer.

The results of these and other water quality surveys undertaken in the Palmerston lakes were discussed in detail in the Supplementary Report, *Lake Water Quality and Maintenance Review*. A summary of the findings for the quarterly monitoring and DO survey results is provided below.

2.4.1 Quarterly water quality monitoring results

Table 2-2 summarises the quarterly monitoring water quality trends observed at the outlet points for each of the three lake systems i.e. Durack Lakes, Sanctuary Lakes and Marlow Lagoon; corresponding to the monitoring sites DLDS, SLA and ML respectively (Figure 2-2). The results from the three lake systems are combined to give one qualitative rating of "**good**", "**ok**", or "**poor**" for each water quality parameter.

Concentrations are compared against the NT Government's Water Quality Objectives (WQO's) for the Darwin Harbour Region; specifically, those for the 'upper estuary' and 'freshwater rivers and streams' where relevant.

This sampling program was retired in early 2020 and replaced by the recommended program as outlined in this LMP starting August 2020. Note the Durack Heights Lake was not included in the quarterly monitoring program until August 2021.

Table 2-2. Quarterly water quality monitoring trends summary.

Parameter	Trends	Condition rating
Temperature	Temperature ranged between 21.6°C (measured at ML in June 2019) and 38.6°C (measured at DLDS in December 2019). It follows a strong seasonal pattern, with the lowest temperatures in June and July, and highest between December and March. Temperatures are more variable during the wet season months January and February, due to monsoonal periods, where rainfall, freshwater inflows and longer periods of overcast days can lower water temperatures. The high temperatures experienced at times during the period December to March could be detrimental to aquatic fauna.	**Ok to Good**
pH	pH generally ranged between 6.0 and 8.5, with the average of concentrations being 7.48 for DLDS, 6.79 for ML and 7.18 for SLA. DLDS often exceeds the WQO upper limit of 8.5 during the early wet season, likely associated with increased plant productivity in the lakes. At times during the wet season, pH decreases below the WQO range due to the input of rainfall and runoff, which is naturally slightly acidic.	**Ok to Good**

Parameter	Trends	Condition rating
Electrical Conductivity	All sites have a clear seasonal EC trend. Concentrations are lowest during the wet season and highest during the late dry season. EC decreases with the first flush of rain in November/December and continues to decrease over the wet season. This pattern is especially pronounced at site DLDS (i.e. Durack Lakes outlet site), which fluctuates between <200 µS/cm during the late wet season, to over 600 µS/cm at the end of the dry season. EC values at SLA and ML are lower than at DLDS, with dry season concentrations at SLA around 400 µS/cm and EC concentrations at ML always below 200 µS/cm. Relatively higher dry season EC's in all three lake systems is due to evapo-concentration and the lack of fresh rainwater input. This is exacerbated in the Durack and Sanctuary Lakes by the topping up of these lakes with bore water. The Crowson and Sabal bores used to top up the Durack Lakes are relatively more saline than the Sanctuary Lakes bore.	**Ok**
Dissolved Oxygen	DO is highly variable, as this parameter changes over the course of each day depending on plant biomass and photosynthesis, wind strength and direction, rainwater inputs, cloud cover, water depth etc. This diurnal variability confounds the interpretation of quarterly DO spot measurements, which range between 7 %saturation and 140 %saturation, with high and low concentrations occurring at any time of the year. Of note is that all recorded fish kills to date have coincided with very low DO levels throughout the water column and throughout the lake where the fill kill occurred, often during the early wet season. Circumstances leading to such low DO levels include a large biomass of algae and salvinia, and high ambient temperatures, which mean that DO levels become very low during the night when plants only respire and consume oxygen and do not photosynthesis and produce oxygen. This is compounded if algae is in a phase of die-off, whereby the breakdown of dead algae consumes oxygen in the water column during both the day and night.	**Ok**
Ammonia	Ammonia concentrations range from <0.01 to 0.08 mg/L, with the majority of concentrations above the WQO (0.02 mg/L) at all sites. Ammonia concentrations fluctuate between monitoring rounds, with no clear seasonal pattern. Relatively high concentrations can occur at any time of the year.	**Ok**
Total Nitrogen	TN concentrations range from 0.1 to 2.1 mg/L. The majority of concentrations at site SLA remaining below the WQO (0.2 mg/L). Approximately 50% of the concentrations at site DLDS were around the WQO, with the majority of the concentrations from ML above the WQO. No apparent seasonal trend was identified at any of the sites nor was there an increasing trend identified.	**Good**
Total Phosphorus	TP concentrations range from <0.01 to 0.19 mg/L. The majority of concentrations remain below the WQO (0.03 mg/L). There is no apparent seasonal trend identified, nor any increasing concentration trends. Trends were observed at sites DLD and DLE (representative of the outflows from Lakes 1a and 1b), which saw increased levels of phosphorous during December (i.e. early wet season), which relates to increased sediment loads entering the system during the first flush of wet season rainfall.	**Ok to Good**

Parameter	Trends	Condition rating
Chlorophyll-a	Chlorophyll-a concentrations are generally always below the WQO (4 mg/m^3) at site DLDS with occasional concentrations above this. At sites ML and SLA, chlorophyll-a concentrations varied quite largely and were generally above the WQO. However the trend in historical data does indicate that algal blooms occur periodically within the lakes.	**Ok to Good**
Dissolved metals	Concentrations at all monitoring sites were below the applicable guideline values (ANZECC default guidelines for 95% species protection in freshwater). Except in 2018, where there was a slight increase in copper and zinc concentrations at DLDS, however there was no increasing trend in concentrations in the next sampling round, with the concentration being below the LOR.	**Good**
Hydrocarbons (TPH/TRH /BTEXN)	All concentrations at all sites were always below detection limits.	**Good**
Bacteriological	Bacteriological indicators are only measured during the annual extended parameter round, which to date, has always occurred during March each year. As such, the results are only indicative of the situation during the mid-wet season. Bacteriological concentrations during other times of the year could be higher or lower. During the mid-wet season, *E.Coli* and enterococci concentrations generally always exceeded the recreational guideline value (100 CFU/100mL and 50 CFU/100mL respectively) at all sites.	**Ok to poor**

Conclusions and recommendations from quarterly water quality monitoring results

The quarterly water quality monitoring results show that dissolved metals and hydrocarbon concentrations are usually low and below the guideline values. These contaminants do not appear to be an issue for the Palmerston lakes and continued monitoring of these is not considered a priority. These parameters may be sampled on an ad hoc basis if a spill or leak containing these contaminants was to occur, or if activities/industries in the catchment involving these contaminants were to be undertaken.

Nutrient concentrations in the lakes (i.e. ammonia, nitrogen, phosphorus) are highly variable and difficult to interpret. Possibly, this is because the concentrations of these nutrients is not indicative of actual nutrient loads into the lakes, given during the dry season plants would uptake a proportion of nutrients prior to sampling, and during the wet season, a large proportion of nutrients would be flushed through the lakes and not retained. It is difficult to draw conclusions from this data useful for informing management actions. Based on the six years of data, overall, concentrations do not appear to be increasing. Continued monitoring of these parameters is not considered a priority.

Chlorophyll-a concentrations are useful for indicating the presence of algal blooms, although measuring DO during the morning and afternoon throughout the water column (see section below), would also indicate this.

Bacteriological indicators have to date only been sampled on an annual basis and always during the wet season. Concentrations at this time have been very high and above the recreational guidelines; although this is expected during the wet season and these types of levels are typically seen in waterways across the Darwin area. High levels during the wet season also presents a low risk to the community given swimming is never permitted in the lakes and the water is not used for irrigation at this time. It is advised that the lakes be tested for bacteriological parameters during the dry season.

Measuring temperature, pH and electrical conductivity is useful for monitoring potential stressors on aquatic organisms and clear seasonal trends in these parameters is evident.

Of note is that the quality of the groundwater being pumped into the lakes during the dry season in large volumes is largely unknown. It would be useful to sample the water from the Sabel, Crowson and Sanctuary bores on a regular basis to determine if this water contains a level of nutrients or bacteriological contamination.

The increasing salinity of these bores due to high extraction volumes and saline intrusion is also a concern and regular sampling would assist in tracking this.

2.4.2 Dissolved oxygen lake survey results

In August 2020, initial in-situ DO measurements (and also other physical parameters) were recorded using a hand-held field meter in each of the Palmerston lakes (totalling 33 sites across 17 lakes) during the early morning (6.30 am to 8.30 am) and afternoon (12 noon to 4 pm). These 17 lakes comprised:

- Thirteen lakes in the Durack Lakes (1a, 1b, 3, 4, 5, 6, 7a, 7b, 7c, 8, 9, 10a and 10b)
- Three at Sanctuary Lakes (Lakes A, B and C)
- One at Marlow Lagoon

As the Durack Heights Lake was added to the LMP, after the initial revision of the LMP, it was later sampled on the 24 August 2021.

Monitoring sites are shown in Figure 6-1 and Figure 6-2; these same sites are proposed for the water quality monitoring program outlined in Section 6 below.

During each of the morning and afternoon sampling times, DO (and also the other field parameters temperature, pH, EC and turbidity) were measured at the surface and at regular depths throughout the water column. The depth of each site to the lake bottom was also measured using a pole and tape measure. Observations of weather conditions, plant coverage and species, and any other aspects relevant to water quality were noted.

Figure 2-3 presents the DO water column profiles measured at each site during the morning and afternoon. Based on these profiles, the condition of each lake is described in Table 2-3 and given a qualitative rating of "**good**", "**ok**", "**poor**" or "**very poor**". Sites that were well oxygenated throughout the water column during both the morning and afternoon were assessed as good, whereas sites that had low DO during the morning/afternoon or anywhere within the water column were assessed as ok or poor depending on the degree and extent of hypoxia.

Table 2-3. DO survey results summary.

Lake	DO sampling results	Condition rating
Lake 8	Lake 8 was observed to have the best DO results out of all the lakes. This lake is well oxygenated throughout the water column at all times of the day. This lake is the deepest and largest of all the lakes. Water flows into this lake are also via Lake 5; therefore, water inflows from the catchment have a higher level of treatment. Sediment and nutrient loads into Lake 8 are reduced after having passed through Lake 5.	**Good**
Lakes 6, 7, 9 and 10	Lakes 9, 10, 6, 7 and Sanctuary Lakes are also generally well oxygenated throughout most of the water column, most of the time. A general trend from these lakes is that they have low DO near the lake bed.	**Ok**
Lake 5	Lake 5 is also moderately well oxygenated, with some areas of the lakes (northern and western arms) recording low DO levels during the morning period.	**Ok**
Lakes 1a, 1b, 3 and 4	Lakes 1a, 1b, 3 and 4 appear to have signs of stratification and low DO, particularly at depth and are considered to have the worst quality out of all the lakes. These lakes are smaller than the other Durack Lakes but their catchment areas are of a similar size, or even larger, in the case of Lakes 1a and 1b.	**Poor**

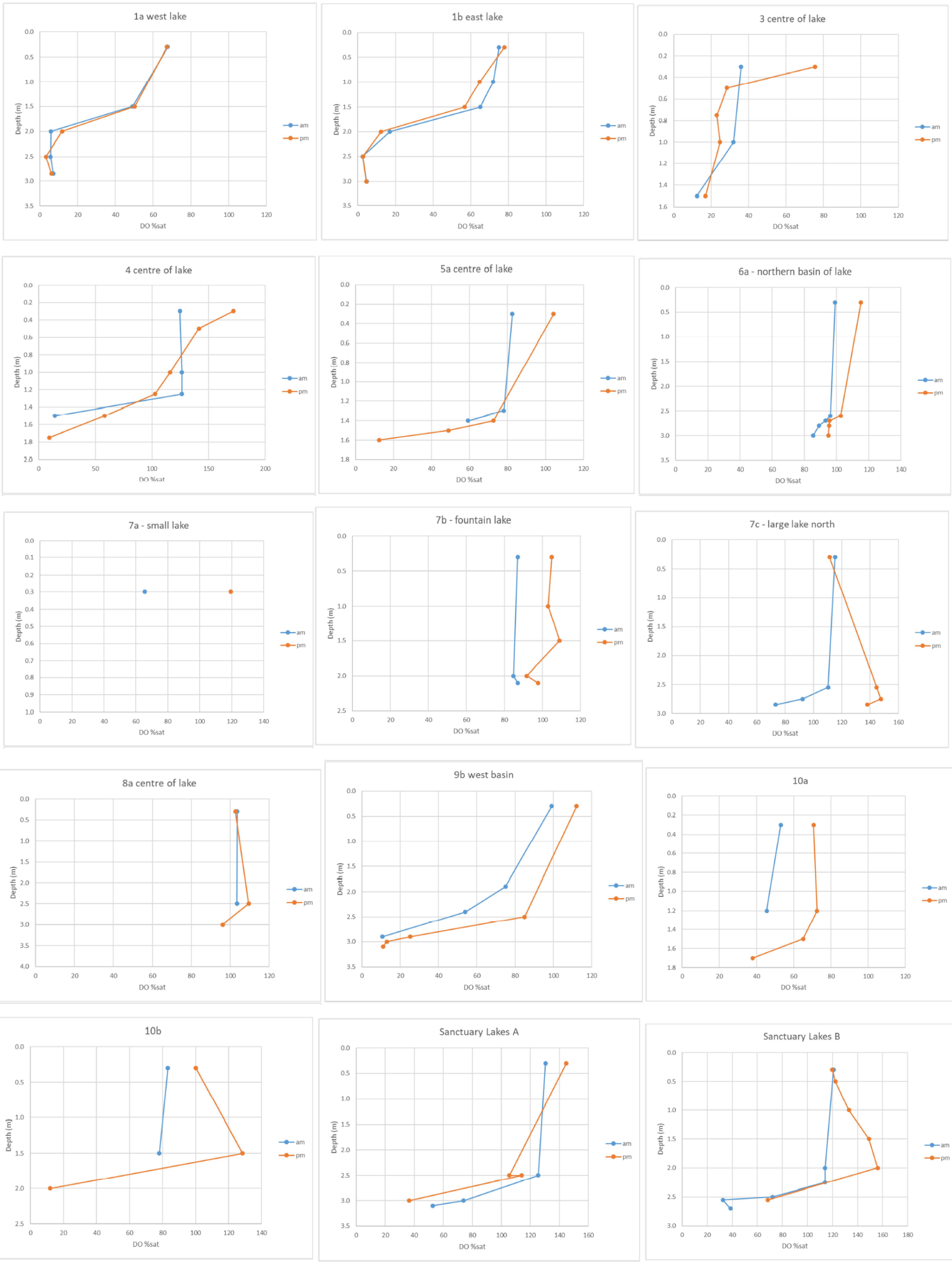
Lake	DO sampling results	Condition rating
Sanctuary Lakes	In contrast to all the Durack Lakes, DO concentrations in Sanctuary Lakes A, B and C were higher at depth (1.5-2.0 m) compared to the surface. This is attributed to rapidly growing macro algae that was observed smothering the rooted vegetation growing on the lake bottom. The Sanctuary Lakes had been harvested a week prior to the DO survey. The removal of shading aquatic plants, and the disturbance of bottom sediments and release of nutrients has likely caused this rapid growth. Similar rapid plants growth would be expected in the Durack Lakes following harvesting.	**Poor**
Marlow Lagoon	Marlow Lagoon is moderately well oxygenated throughout the water column. As it is the only natural waterbody in the observed lake systems within this study and is not currently topped up with water from the local bores, this is reflected in the lower EC and pH results.	**Good**
Durack Heights	DO is very low throughout the water column. Floating plants (*Salvinia*, lilies, algae) cover a small area of the lake surface. A thick vegetation layer is present at the bottom of the lake. Water is clear/turbidity is low. TN concentration (0.5 mg/L) is above target value. Future concentrations to be monitored closely. TP concentration (0.04 mg/L) is above target value. Future concentrations to be monitored closely. Enterococci concentration (610 CFU/100mL) is relatively high and indicates that there is a level of risk to human health in irrigation water.	**Very poor**

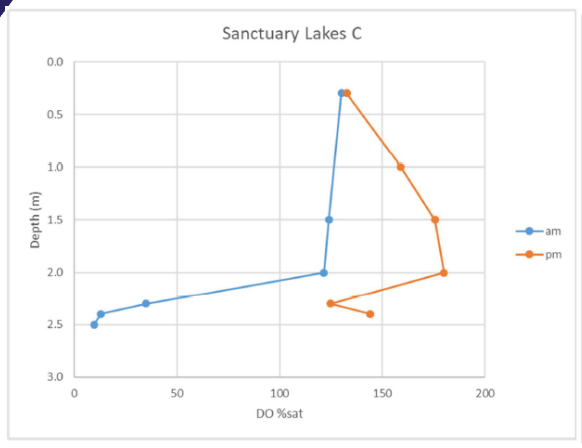
Conclusions and recommendations from DO survey results

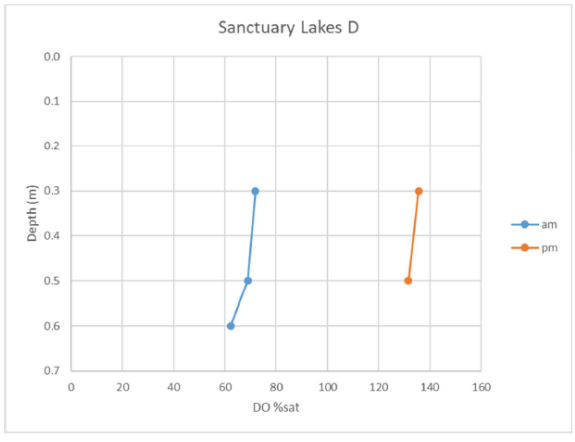
The DO survey results are useful for understanding the environmental condition of each individual lake and the degree of plant growth; including microalgae, which may not be immediately visible during lake inspections. Aquatic plant growth is currently the most problematic issue for the Palmerston lakes; it also has implications for fish health, given a large mass of plants/algae can cause low DO levels in the pre-dawn.

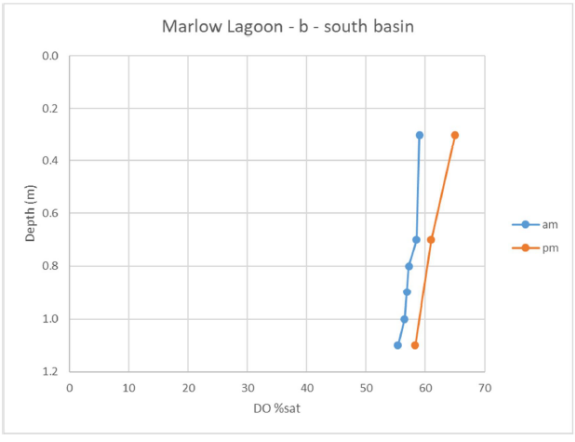
The DO surveys undertaken in August 2020 and August 2021 (Durack Heights Lake) are a snapshot representing late dry season conditions. It would be of value to repeat this survey during the early wet season (build-up), mid wet season and early dry season to see if the condition (plant biomass) of different lakes changes seasonally with the input of catchment runoff. Noting how long plant harvesting was undertaken in each lake prior to each survey would also assist in monitoring how the lakes respond to the harvesting operations.

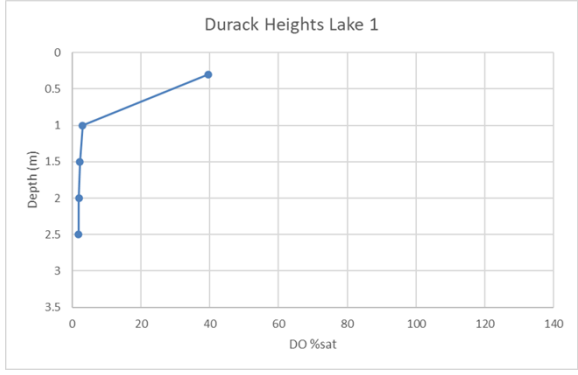
Figure 2-3. Dissolved oxygen in-situ depth profiles. *DO survey for Durack Heights was undertaken in the morning; therefore, only morning readings are presented in the graph for this lake.*

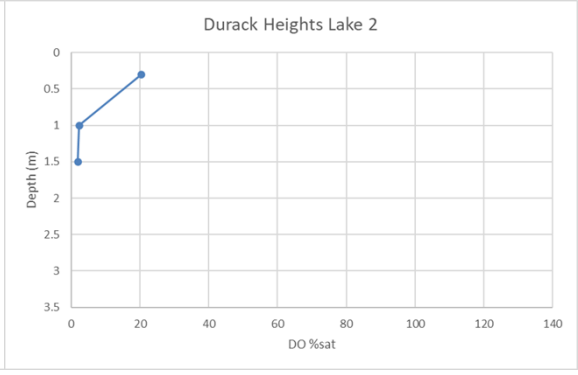



Sanctuary Lakes C
Depth (m)
DO %sat
am
pm


Sanctuary Lakes D
Depth (m)
DO %sat
am
pm


Marlow Lagoon - b - south basin
Depth (m)
DO %sat
am
pm


Durack Heights Lake 1
Depth (m)
DO %sat


Durack Heights Lake 2
Depth (m)
DO %sat

3 LAKE FUNCTIONS

All lakes were assessed on their current function, based on feedback from the CoP maintenance team. All lakes were observed to have the same functions and in the same order. The lake condition analysis and DO sampling identified that some of the lakes are under pressure with their various purposes. Desired primary and secondary functions were then derived in order to develop specific management targets for each lake.

Table 3-1 outlines the current functions of the lakes and the desired primary functions after the various investigations undertaken, upon which the lakes will have management targets derived.

Table 3-1. Current functions and desired priority functions for all lakes.

Lake	Current functions	Desired primary functions
Lake 1a	**Primary Function:** Stormwater management (retention and treatment) Ecological habitat **Secondary Functions:** Flood mitigation Visual amenity Irrigation water source^ Recreational fishing	Stormwater management Ecological habitat
Lake 1b		Stormwater management Ecological habitat
Lake 3		Stormwater management Ecological habitat
Lake 4		Stormwater management Ecological habitat
Lake 5		Visual amenity Ecological habitat
Lake 6		Visual amenity Ecological habitat
Lake 7 (a , b, c)		Visual amenity Ecological habitat
Lake 8		Irrigation water source (currently proposed) Visual amenity
Lake 9		Stormwater treatment (last point of treatment before discharge to Darwin harbour) Ecological habitat Irrigation water source
Lake 10 (a, b)		Stormwater treatment Ecological habitat Irrigation water source
Sanctuary Lake A		Visual amenity Stormwater management
Sanctuary Lake B		Visual amenity Stormwater management
Sanctuary Lake C		Visual amenity Stormwater management
Marlow Lagoon		Visual amenity Ecological habitat
Durack Heights Lake		Stormwater management Ecological habitat

^Excludes Lake 5, Marlow Lagoon and Durack Heights which are currently not used as an irrigation water source.

4 MANAGEMENT TARGETS

The following strategies have been developed specific to each lake and its desired function. Each strategy includes required management practices, performance indicators and a timeline for implementation. It is envisaged that each of the lake strategies will be adapted over time to align with changes to community expectations and improvements in knowledge regarding lake functioning and what management practices work best.

Sections 5 and 6 below provide details regarding the required maintenance and management practices. Corrective actions are detailed in Section 7.

Table 4-1. Lake 1a strategy.

Lake objective	To provide stormwater treatment for runoff entering the Durack Lakes system from Tiger Brennan Drive, whilst providing a good ecological habitat for aquatic life. This lake is located at the top of the catchment and is the first treatment asset for surface water treatment before passing under a culvert under Woodlake Boulevard and draining via grassed swale towards Lake 5.
Secondary functions	Secondary to stormwater management and providing a viable ecological habitat, Lake 1a is a visual amenity asset to the community, whilst also available for recreational fishing.
Current condition	Currently has low to poor water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of sediment load reducing measures Installation of aeration devices Active Salvinia management Desilting of lake (long term of plan) Community education about aquatic plants and impacts of human actions on the lakes
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-2. Lake 1b strategy.

Lake objective	To provide stormwater treatment for runoff entering the Durack Lakes system from Tiger Brennan Drive, whilst providing a good ecological habitat for aquatic life. This lake is located at the top of the catchment and is the first treatment asset for surface water treatment before entering Lake 3.
Secondary functions	Secondary to stormwater management and providing a viable ecological habitat, Lake 1b is a visual amenity asset to the community, whilst also available for recreational fishing.

Current condition	Currently has low to poor water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of sediment load reducing measures Installation of aeration devices Active Salvinia management Desilting of lake (long term of plan) Community education about aquatic plants and impacts of human actions on the lakes
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-3. Lake 3 strategy.

Lake objective	To provide stormwater treatment for runoff entering the Durack Lakes system whilst providing a good ecological habitat for aquatic life. This lake receives flows from Lake 1b and its own catchment.
Secondary functions	Secondary to stormwater management and providing a viable ecological habitat, Lake 3 is a visual amenity asset to the community, whilst also available for recreational fishing.
Current condition	Currently has low to poor water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of sediment load reducing measures Installation of aeration devices Active Salvinia management Desilting of lake (long term of plan) Community education about aquatic plants and impacts of human actions on the lakes
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 beloww Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-4. Lake 4 strategy

Lake objective	To provide stormwater treatment for runoff entering the Durack Lakes system whilst providing a good ecological habitat for aquatic life. This lake receives flows from Lake 3 and its own catchment.
Secondary functions	Secondary to stormwater management and providing a viable ecological habitat, Lake 4 is a visual amenity asset to the community, whilst also available for recreational fishing.
Current condition	Currently has low to poor water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of sediment load reducing measures Installation of aeration devices Active Salvinia management Desilting of lake (long term of plan) Community education about aquatic plants and impacts of human actions on the lakes
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-5. Lake 5 strategy

Lake objective	To enhance areas around the lake for visual amenity purposes and provide a good ecological habitat for aquatic life. This lake receives flows from Lake 1a (via a grassed swale) and its own catchment.
Secondary functions	Secondary to visual amenity and providing a viable ecological habitat, Lake 5 is a stormwater asset whilst also available for recreational fishing.
Current condition	Currently has good water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of aeration devices

Table 4-6. Lake 6 strategy

Lake objective	To rehabilitate the lake from previous use as a main irrigation source for the PGC, enhance areas around the lake for visual amenity purposes and provide a good ecological habitat for aquatic life.
Current condition	Currently has poor water quality, evidence of salvinia and microalgae
Required Maintenance/Management practices	Rehabilitation of lake from irrigation utilised pond to priority functions Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Desilting of lake (long term of plan) Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **March 2021** – Rehabilitation of lake **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-7. Lake 7a, 7b and 7c strategy

Lake objective	To enhance areas around the lake for visual amenity purposes and provide a good ecological habitat for aquatic life. This lake receives flows from its own catchment.
Secondary functions	Secondary to visual amenity and providing a viable ecological habitat, Lake 7a, b and c are stormwater assets whilst also available for recreational fishing.
Current condition	Currently has good water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of aeration devices

Table 4-8. Lake 8 strategy

Lake objective	To provide an irrigation resource for the PGC as well as enhance areas around the lake for visual amenity purposes. This lake receives overflows from Lake 5 (via a grassed swale) and its own catchment.
Secondary functions	Secondary to proving PCG with an irrigation source and providing a viable ecological habitat, Lake 8 is also available for recreational fishing.
Current condition	Currently has good water quality
Required Maintenance/Management practices	Development of an irrigation management plan (stipulating extraction volumes allowable from external parties) Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Water levels at a respectable height Large increase in EC concentrations (if too high, evident that lake is struggling with extraction) Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **February 2021 –** Irrigation management plan **April/May 2021** - Community education **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-9. Lake 9 strategy

Lake objective	To provide stormwater treatment for runoff entering and then exiting the Durack Lakes system whilst providing a good ecological habitat for aquatic life and an irrigation source for local parklands and reserves in the area. This lake receives flows from Lake 8 and its own catchment.
Secondary functions	Secondary to stormwater management, providing a viable ecological habitat and irrigation source, Lake 9 is a visual amenity asset to the community, whilst also available for recreational fishing.
Current condition	Currently has good water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of sediment load reducing measures Installation of aeration devices Active Salvinia management Desilting of lake (long term of plan) Community education about aquatic plants and impacts of human actions on the lakes
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events

Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices **2023 - 2025** - Desilting of lake (long term of plan)

Table 4-10. Lake 10a and 10b strategy

Lake objective	To provide stormwater treatment for runoff entering and then exiting the Durack Lakes system whilst providing a good ecological habitat for aquatic life and an irrigation source for local parklands and reserves in the area. This lake receives flows from Lake 5 and its own catchment.
Secondary functions	Secondary to stormwater management, providing a viable ecological habitat and irrigation source, Lake 10a and 10b is a visual amenity asset to the community, whilst also available for recreational fishing.
Current condition	Currently has good water quality
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of sediment load reducing measures Installation of aeration devices Active Salvinia management Community education about aquatic plants and impacts of human actions on the lakes
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices

Table 4-11. Sanctuary Lakes A, B and C strategy

Lake objective	To provide stormwater treatment for runoff entering and then exiting the Durack Lakes system whilst enhancing areas around the lake for visual amenity purposes
Secondary functions	Secondary to visual amenity and providing a viable ecological habitat, the Sanctuary Lakes is a stormwater assets whilst also available for recreational fishing
Current condition	Currently has poor water quality, evidence of salvinia and microalgae
Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake

Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices

Table 4-12. Marlow Lagoon strategy

Lake objective	To enhance areas around the lake for visual amenity purposes and provide a good ecological habitat for aquatic life.
Secondary functions	Secondary to visual amenity and providing a viable ecological habitat, Marlow lagoon is a stormwater asset whilst also available for recreational fishing.
Current condition	Currently has good water quality
Required Maintenance/Management practices	Management of collapsed causeway i.e. install box culverts to allow for water to flow through) Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2020** - Active Salvinia management **January 2021** - Quarterly water quality monitoring **April/May 2021** – Clean up the blockage where the old walkway used to be **April/May 2021** - Community education **December 2021** - Installation of sediment load reducing measures **December 2021** - Installation of aeration devices

Table 4-13. Durack Heights strategy

Lake objective	To provide stormwater treatment for runoff from the Durack Heights catchment, whilst enhancing areas around the lake for visual amenity purposes.
Secondary functions	Secondary to Stormwater management and visual amenity, the Durack Heights Lake provides an ecological habitat and is also available for recreational fishing.
Current condition	Currently has very poor water quality

Required Maintenance/Management practices	Water quality monitoring as per Section 6 below Regular and maintained weed harvesting Installation of aeration devices Active Salvinia management Community education about aquatic plants, impacts of human actions on the lakes and what makes a healthy lake
Performance indicators	Meeting assessment criteria for DO, turbidity etc as per Section 6.5 below Aquatic vegetation healthy and not showing signs of distress or disease No major fish kill events recorded
Timeline for implementation	**Ongoing -** Regular and maintained weed harvesting **November 2021** - Active Salvinia management **January 2022** - Quarterly water quality monitoring **April/May 2022** - Community education **December 2022** - Installation of aeration devices

5 MANAGEMENT MEASURES

Routine maintenance activities currently undertaken by CoP in and around the lakes includes frequent removal of aquatic plants and weeds from the lake beds, mowing and maintenance of lawn and parklands around the lakes, and the topping up of water levels in the lakes using groundwater from nearby bores.

New management targets were derived and are summarised as follows:

- An updated water quality monitoring plan is to be developed and implemented, which is targeted towards the water quality of the lakes rather than the overall Palmerston lakes system entering the Darwin Harbour. The plan is based on the most recent DO sampling that occurred in August 2020 and includes sampling for additional bacteriological parameters such as *E. coli.* Further information about this monitoring program is detailed in Section 6 of this document.
- The current harvesting regime is appropriate for the management of vegetation such as rooted aquatic plants (lilies) and fringing vegetation (bullrushes and typha). A more targeted approach to salvinia and algae management is required.
- Management of catchment related sediment inputs are crucial to reduce the nutrient load within the lakes.
- Recommendation to develop an irrigation management plan for lake water utilised for irrigation purposes (largely with Palmerston Golf Course).
- The importance of community education and engagement when it comes to looking after the lakes.

5.1 Vegetation management

The current harvesting regime conducted by the maintenance team at CoP is deemed adequate for the type of vegetation that is growing in and around the lakes. Aquatic plants will continue to grow in all the Palmerston Lakes, given their shallow depths and availability of nutrients entering the system. It is therefore recommended that CoP continue with the same harvesting program for vegetation, such as harvesting the rooted and floating aquatic plants and fringing vegetation, when growth reaches the thresholds as show below in Figure 5-1.

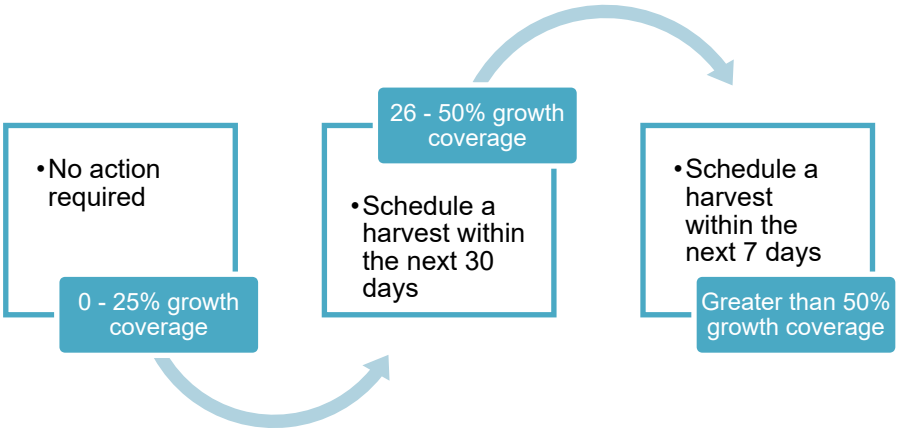


Figure 5-1. Management of rooted and floating aquatic and fringing vegetation

Improvements to the harvesting regime and identifying other means for managing the lake vegetation could come from commissioning a study (through CDU or similar) that specifically looks at how to achieve the optimal vegetation assemblage and minimise the rate of plant growth

5.2 Salvinia management

Salvinia (*Salvinia molesta*) is a 'Weed of National Significance' and is a free-floating perennial aquatic fern, which forms mats over water surfaces. In the Northern Territory, it's declared status is *Class B – growth and spread to be controlled*, which means in the case of its growth within the Palmerston lakes, it is the responsibility of CoP to manage its spread and prevent the public from spreading it into other water systems via fishing and other recreational activites.

Salvinia creates a mat on the surface of the water that blocks out light to the lower water column and alters the environment for aquatic organisms, fish and plants. Salvinia is spread by vegetative reproduction. Its stem fragments are distributed by water movement, and can be spread by water craft, fishing equipment such as lures and nets, and also by animals. Salvinia grows best when the water temperature is between 20°C and 30°C and tends to grow faster when nutrients are abundant or when there has been runoff from a recent rainfall event.

Salvinia can have the following impacts on the lakes:

- blocks light and reduces oxygen levels
- causes stagnation and pollution
- restricts water flow
- blocks access to water by animals
- creates favourable breeding conditions for mosquitoes.

Salvinia Management

There are four methods of control options for salvinia management and they are outlined in Table 5-1 below.

Table 5-1. Salvinia control methods (adapted from CRC Weed Management, 2003)

Type of infestation	Physical	Mechanical	Chemical	Biological
Small: Small area with a few plants	Manually remove by hand. Booms or nets can be used to prevent short-term spread.	Not suitable	Several chemicals are registered as suitable for salvinia destruction. The common herbicide (glysophate found in RoundUp) only attacks the top layer of growth and is therefore not effective in eradication. There are other chemcials that can be used however, not advisable for use in areas of public interaction (i.e. lakes used for irrigation)	Not suitable for smaller areas as it will not eradicate salvinia.
Medium: Medium area with medium density	Manually removing the salvinia is not suitable in medium to large growth areas. Fire is another physical method to be considered in integrated weed control, however it is not suitable in urban environments, such as that in Palmerston.	Aquatic weed harvesters can remove salvinia, however due to the rapid regeneration of salvinia, it will need to be harvested regularly.		The salvinia weevil (*Salvinia molesta*) has shown to be extremely effective in controlling salvinia. Generally, this method takes 1-3 years. Suitable and more effective in warmer climates.
Large: Large area (many ha) with high density of plants				

The key to controlling salvinia is to develop an integrated weed control program" which includes multiple methods of control. CoP currently use the mechanical method for salvinia management, and it is therefore

recommended that exploration into the biological method of salvinia control be explored in a selection of lakes whereby salvinia is a nuisance i.e. Sanctuary Lakes, given the effectiveness of control by the weevil in tropical climates.

5.2.1 Proposed salvinia management plan

It is proposed that the introduction of weevils as a method of control for salivina occur in lakes where the lakes are connected. The three Sanctuary Lakes are an ideal location for this type of treatment to be introduced due, to its position on the corner of Buscall Avenue and Lakeview Boulevard and its primary function as a visual amenity asset to the Palmerston community.

As there is such a wide spread of salvinia across all the lakes, total eradication is not possible, however with the introduction of weevils, this form of biological control means that there would be less use of mechanical inputs (such as the Truxor), saving time and cost of CoP maintenance staff.

On the 29th September, the Bureau of Meteorology has officially declared a La Niña event is currently underway, which means it is likely that the Northern Territory will have above average rainfall during the 2020-2021 wet season, and ideal conditions for introducing the salvinia weevil within the lakes. By the start of the 2021 dry season, the population will be established enough to reduce the bloom of salvinia that usually occurs during this time of the year.

The Palmerston lakes have a history of successful bio-control, followed by weevil numbers plummeting and the salvinia then returning. Applying the biological method of salvinia control is not a 'once off' permanent solution to the salvinia outbreak as the weevil population will need to be managed over time, even when the salvinia levels are low to ensure that the same situation does not recur in years to come.

It is therefore proposed that in the Sanctuary Lakes:

- An augmentative biological control method will be used, if weevils were to be introduced into the lakes. The augmentative method means that weevils are to be introduced in a large amount (in the late dry season/early wet season – October/November) and regularly topped up every month in order to sustain a weevil population.
    - Note a weevil's life cycle takes approximately 6 weeks from a juvenile weevil to an adult weevil.
- Weevils are to be introduced after the lakes have been mechanically harvested using the Truxor.
- Booms are to be put in place where there are areas of known salavina out breaks, in an attempt to control spread. The booms allow for closer management, as well as ease in checking for weevil efficiently and controlling salvinia movement across the whole of the lakes.
- By re-introducing small groups of weevils, each month we are establishing a population that will continuously grow and won't need another large re-introduction if there is a sudden reduction in population. Weevils will only reduce in population size when their food source is unavailable (which are dependent on the conditions of the lake and food sources available for them to eat), or following a large flushing event.
- Effects of the implementation of the salvinia weevil show within 3-4 months of regular releasing.
- The lakes will need to be monitored every fortnight, as part of the maintenance plan, to observe whether the weevils are performing.

Cost of weevils

If CoP were to proceed with the introduction of weevils within the Sanctuary Lakes, the Malak Malak Land Management Rangers located in Daly River under the Northern Land Council, would have the capacity to supply the weevils, which come at a cost of approximately 50 cents each. Note that this cost is a rough

estimate of the cost of adult weevils. It is recommended that CoP discuss with NT Weeds and the Malak Malak Rangers prices upon proceeding with this form of control.

Depending on CoP's budget, it will determine the volume of weevils to be introduced into the lakes. An ideal situation, upon which NT Weeds recommends includes the following:

- 2,000 weevils introduced during October or November of 2020, which would come to a cost of approximately $1,000.00.
- The risk of a population decline is unlikely, if the lake condition is established to ensure that there is enough young salvinia available for the weevils to eat. If this is the case, the population is likely to increase.
- Each month there would be a continuous addition of between 400-600 weevils.
- The total cost for the first year of utilising the salvinia weevil would be approximately $4,300.00, excluding transport, delivery and introduction. Negotiations with the Malak Malak Rangers and NT weeds would be required to discuss the exact costs associated with these services.

If CoP were to go ahead with the introduction of the salvinia weevil, an integrated weed management plan would need to be developed under a separate scope of works in conjunction NT Weeds regarding its implementation and monitoring regime.

A representative from CoP would be required to be responsible for the program, with the assistance of NT Weeds. A signage strategy would also be required for this program (see Appendix C for examples of the signs that can be implemented).

5.3 Algae management

The presence of algae within the lakes results from nutrient inputs from catchment runoff and the release of nutrients from the lake bed due to the breakdown of organic matter. Part of the management of algae will involve identifying areas within the lakes where the addition of more sediment controls can be implemented.

It is recommended that an algae specialist be engaged to survey the lakes to determine the types of algae that are present within the lakes. Once completed, the outcome of the survey will aid in determining specific algae treatment for the lakes.

Floating wetlands

A proposed option for the management of algae and general lake water quality, for lakes which have a desired lake function of stormwater management is the implementation of floating wetlands or floating treatment media (FTM). Floating wetlands and FTM are ideal for improving water quality in existing lakes or wetlands which have high nutrient loads, habitat restoration and natural beautification of lakes and their surrounds.

The floating treatment areas can be designed to fit any existing space or waterbody shape and can operate in fluctuating water levels. As the roots of the plants, which are attached to the filter media spread down through the water column, there is a larger activated space available for microbes and bacteria to take on the role of bio-remediation to remove pollutants and algae.

A system as such might be useful for the remediation of Lake 6, as well as be introduced into Lake 8, if that were to become the main lake used for irrigation by PGC. Lakes 1a, 1b, 3 and 4 might also benefit from a smaller FTM system, increasing the potential for these lakes to meet the MUSIC water quality objectives, as specified in the CoP Lake Construction Guidelines.

5.4 Sediment management

Sediment removal, in established waterbodies, is a difficult undertaking and requires extensive planning to ensure that the condition of the lake and its surrounds are not severely impacted. Proposed approaches for managing incoming sediment inputs include:

- Cleanout and re-installation of pre-existing sediment traps currently within the lakes. It is noted that these sediment assets have not been operating effectively.
- Cleanout of Gross Pollutant Traps (GPT) within the lakes drainage network.
- Installation of primary treatment assets upstream of the lakes within the stormwater drainage systems. These types of systems require less space than the traditional sediment pond used in Water Sensitive Urban Design (WSUD), as they are installed within the drainage network, rather than developing a piece of land. As land acquisition will prove to be a difficult undertaking given the heavily developed extent of the lakes catchments, a proprietary system (as seen below in Figure 5-2), might be a feasible option for some upstream lakes (such as lakes 1a, 1b and 6).

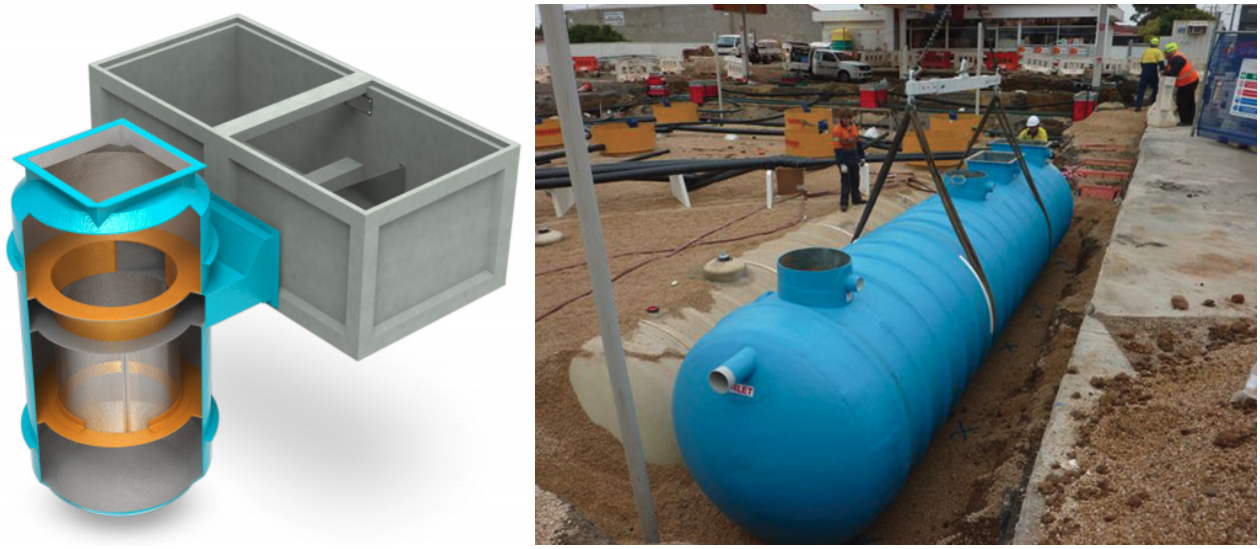


Figure 5-2. SPEL Vortceptor (left) and SPEL Stormceptor (right) (SPEL Environment, 2020)

- Developing a long term plan to dredge the lakes in order to clean out the current sediment that sits at the bottom of the lakes, which includes a cost benefit analysis for social, economic and environmental impacts.

It is recommended that CoP review the abovementioned options in regards to their own visions for the Palmerston community, as all options will have a cost associated within them, whether it be financial or space/land acquisition related.

In the future, it may be warranted to dredge the lakes, remove the built-up sediment and thereby deepen the lakes which could assist in reducing the rate of aquatic plant growth.

5.5 Aeration devices

Maintaining higher DO levels throughout the water column, preventing stratification, and preventing hypoxic conditions close to the lakebed, should decrease the internal loading of nutrients (in particular phosphorus) from the lakebed sediments back into the water column to fuel plant growth. An aeration system however, will not assist in reducing the external loading of nutrients from the catchment. Therefore, if external nutrient loads are high enough, the rate of plant/algae growth may not decrease.

In the very least, the aeration system should mean there is always oxygenated habitat available for fish to move into, even if some parts of the lake become hypoxic. None of the Palmerston lakes currently have aeration fountains or diffusers, except for Lake 7b, which has a small surface fountain.

Table 5-2 provides the proposed locations and recommended aeration systems provided to CoP in an advice letter in July 2020. CoP have begun installing the lake diffusers in Lakes 9 and 10.

Table 5-2. Recommended size and number of aeration systems for Palmerston lakes taken from EcOz advice letter, July 2020.

Lakes considered of high priority for aeration are highlighted in pink. The Durack Heights lake was not included in this advice.

Lake	Recommended aeration system
Lake 1a	2 x half HP fountains
Lake 1b	2 x half HP fountains
Lake 3	1 x 2 HP fountain
Lake 4	1 x 2 HP fountain
Lake 5	4 x lake bed diffusers
Lake 6	4 x lake bed diffusers
Lake 7a	2 x half HP fountains
Lake 7b	Already has fountain
Lake 7c	1 x half HP fountain
Lake 8	5 x lake bed diffusers
Lake 9	4 x lake bed diffusers
Lake 10	3 x lake bed diffusers
Sanctuary Lake A	2 x lake bed diffusers
Sanctuary Lake B	2 x lake bed diffusers 1 x half HP fountain on SW side of island
Sanctuary Lake C	2 x lake bed diffusers

5.6 Irrigation management plan

As the lakes are used for irrigation for the surrounding parklands, open space and the golf course, it is recommended that an irrigation management plan be developed. It is understood that CoP are currently undergoing an irrigation audit, therefore an irrigation management plan would complement the outcome of the audit with respect to the audit outcomes.

Generally, an irrigation management plan would include some of the following objectives:

- Provide context regarding the landscape where the CoP irrigation system operates (topography, soils, climate and historical irrigation use)
- Provide details on the operational instructions and requirements of the irrigation system (including maps where the system is located)
- Identify triggers from the WQMP (i.e. *E. coli* levels, low DO, etc.) that will assess whether the water from the lakes is of a sufficient quality for irrigation purposes
- Outline reporting protocols for activities relating to the irrigation system operations, maintenance and monitoring
- Outline a procedure for recording volumes extracted from lakes for irrigation and bores for lake filling.

5.7 Community education and engagement

An important component of the LMP is to ensure that the local Palmerston community, visitors to the lakes and those that manage the lakes and their surrounds, have the necessary knowledge, awareness, motivation and behaviours to assist in protecting these areas.

Effective management of these lakes cannot be achieved by CoP alone, as the community can have a positive impact in raising awareness and participating in environmental management. Raising community awareness regarding the status of the lakes, the importance of their role for stormwater management, ecological habitat, irrigation and weed hygiene is crucial as some individuals may not be aware of these functions.

Ways the community can be informed to the abovementioned include:

- Implementation of a 'Signage Strategy', whereby a series of wayfinding and interpretive signs about the lakes are installed including, what their specific function is, what aquatic animals can be found, types of vegetation etc. The signs could also include content for natural areas suggesting people use designated pathways, clean up after their dogs minimise disrupting any vegetation or weeds they might come across.
- Educating local residents about the impact of backwashing their swimming pools can have on the water quality of the lakes through flyers, signs and/or education days at the lakes.
- Involving the community in clean up days.
- Educating local residents and the general public about the importance of weed hygiene practices to aid in the prevention of weed (particularly salvinia) spread. Minimising public access and disturbance in areas where there is prominent growth of salvinia.
- Holding an education session at the lakes when the salvinia weevils are being introduced, allowing local residents and the general public to look at the weevils and understand the process of their introduction. This would also be a good opportunity for the local Ranger group supplying the weevils to get involved within the community.

Schools are also an important avenue for raising awareness and interest in environmental issues and creating future community members that are aware of, and actively participate in local environmental management.

6 WATER QUALITY MONITORING PROGRAM

6.1 Monitoring objectives

The primary objective of water quality monitoring of the Palmerston lakes is to monitor the environmental condition of the lakes and inform their management so as to maintain 'good' water quality; with 'good' being defined as:

- Maintaining a well oxygenated water column throughout the day and night
- Having a desirable mix of aquatic plant types (e.g. submerged rooted plants and lilies)
- No algal blooms, excessive aquatic plant growth across most of the lake
- No fish kills
- Clear water, i.e. not turbid from fine sediment washed in or green and murky from microalgae
- No odours from rotting vegetation etc

Dissolved oxygen

DO is focused on in the proposed monitoring program given aquatic plant growth is currently the most problematic issue facing the lakes. The measurement of DO in the morning and afternoon, and throughout the water column, provides a measure of plant biomass, organic matter breakdown and risks to fish and other aquatic organisms.

The water quality monitoring program proposed here is modelled on the DO survey undertaken in August 2020 (see Section 2.4.2 above). This survey provided a snapshot of lake environmental condition during the late dry season. Conditions are expected to be different at different times of the year i.e. seasonal, and may also change in response to specific maintenance activities being undertaken e.g. aquatic plant harvesting, installation of oxygen diffusers, increases/decreases in the volume of water extracted for irrigation, clean-out/installation of sediment traps at lake inlets.

Sediment

Sediment inputs into the lakes from catchment runoff is of concern, given high inputs bring in attached nutrients (in particular phosphorus), which can remain within the lakes rather than being flushed through. The build-up of sediment also reduces the depth and volume of the lakes, which reduces their capacity to treat nutrients. Plant growth appears to be more rapid in the smaller lakes e.g. Lakes 3 and 4 as compared to the deep Lake 8. To monitor sediment inputs, the water quality monitoring program includes the measurement of turbidity and water depth.

Bacteriological and bore water quality

Secondary objectives of this monitoring program are to fill some knowledge gaps identified above in Section 2.4 regarding bacteriological indicators and the quality of groundwater used to fill the lakes. Bacteriological indicators have to date only been sampled on an annual basis and always during the wet season. Testing for these indicators during the dry season would provide a better indicator of any potential bacteriological risks of using this water for irrigation.

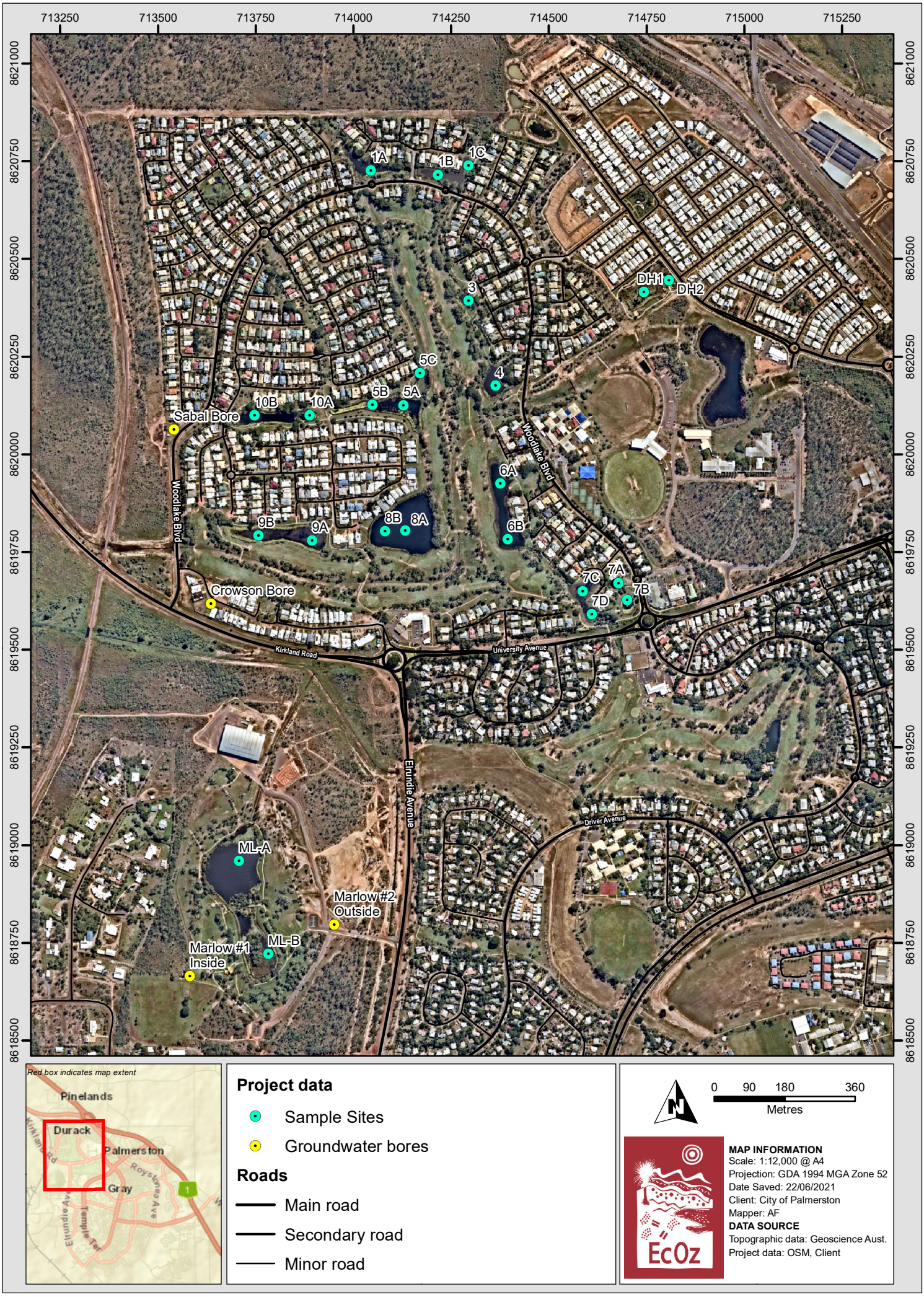
Sampling the water from the Sabal, Crowson and Sanctuary bores on a six-monthly basis would determine if this water contains a level of nutrients or bacteriological contamination. The increasing salinity of these bores due to high extraction volumes and saline intrusion is also a concern and regular sampling would assist in tracking this.

6.2 Monitoring sites

Monitoring site locations are listed in Table 6-1 and shown in Table 6-1. Monitoring site location details Figure 6-1 and Figure 6-2. Lake monitoring sites are the same as those sampled during the DO survey discussed in Section 2.4.2 above.

Table 6-1. Monitoring site location details.

Site ID	Latitude	Longitude	Location details
Surface water sites			
1A	-12.46957	130.96937	Centre of Lake 1a
1B	-12.46966	130.97095	Centre of Lake 1b
1C	-12.46944	130.97167	North eastern arm of Lake 1b
3	-12.47257	130.97170	Centre of Lake 3
4	-12.47453	130.97235	Centre of Lake 4
5A	-12.47500	130.97018	Eastern open water zone of Lake 5
5B	-12.47500	130.96945	Central open water zone of Lake 5
5C	-12.47425	130.97057	North eastern arm of Lake 5, after the boardwalk
6A	-12.47679	130.97247	Northern open water zone of Lake 6
6B	-12.47808	130.97266	Southern open water zone of Lake 6
7A	-12.47907	130.97527	Centre of Lake 7a
7B	-12.47946	130.97548	Centre of lake &b
7C	-12.47926	130.97443	Northern open water zone of Lake 7c
7D	-12.47980	130.97465	Southern open water zone of Lake 7c
8A	-12.47789	130.97025	Centre of Lake 8
8B	-12.47791	130.96978	Western open water zone of Lake 8
9A	-12.47814	130.96806	Eastern open water zone of Lake 9
9B	-12.47803	130.96679	Western open water zone of Lake 9
10A	-12.47525	130.96798	Centre of Lake 10a
10B	-12.47525	130.96668	Western open water zone of Lake 10b
SA	-12.48915	130.99566	Centre of Sanctuary Lake A
SB	-12.48928	130.99664	Centre of Sanctuary Lake B
SC	-12.49001	130.99731	Centre of Sanctuary Lake C
SD	-12.48970	130.99626	South west of Sanctuary Lake B, on the other side of the island
ML-A	-12.48556	130.96639	Northern area of Marlow Lagoon
ML-B	-12.48771	130.96710	Southern area of Marlow Lagoon
DH1	-12.47234	130.97582	Centre of Durack Heights Lake 1
DH2	-12.47206	130.97641	Centre of Durack Heights Lake 2
Groundwater bore sites			
Sabal Bore RN035414	-12.47560	130.96478	Located off Woodlake Boulevard, south of Sabal Place
Crowson Bore RN031124	-12.47962	130.96568	Located at 10 Crowson Close
Sanctuary Bore RN032101	-12.48976	-130.99958	Located downstream of the Sanctuary Lakes, access from Lakeview boulevard
Marlow #1 RN023582	-12.48824	130.96525	Inside of the Marlow Lagoon reserve
Marlow #2 RN022721	-12.48703	130.96865	Outside of the Marlow Lagoon reserve



Path: Z:\01 EcOz_Documents\04 EcOz Vantage GIS\EZ19022 - Palmerston Lakes Water Quality and Maintenance Review\01 Project Files\Sampling map 1.mxd

Figure 6-1. Sampling plan map (Durack Lakes, Durack Heights and Marlow Lagoon).

Path: Z:\01 EcOz_Documents\04 EcOz Vantage GIS\EZ19022 - Palmerston Lakes Water Quality and Maintenance Review\01 Project Files\Sampling map 2.mxd

Figure 6-2. Sampling plan map (Sanctuary Lakes).

6.3 Frequency of sampling and sampling parameters

The 29 lake sampling sites are sampled four times over the year to represent changing seasonal conditions. The groundwater bores are sampled 6-monthly to represent both wet and dry seasons.

Parameters to be measured during each lake monitoring round include field parameters (temperature, pH, DO, EC, turbidity), lake depth and observations of aquatic plant assemblage and coverage and any other observations relevant for lake water quality (pollutants etc). Laboratory parameters will only include bacteriological indicators *E. Coli* and enterococci.

Parameters to be measured when sampling the groundwater bores include field parameters, as well as the groundwater level (if possible). Laboratory parameters will include bacteriological indicators and nutrients (total nitrogen and total phosphorus).

The frequency of sampling and parameters to be measured are summarised in Table 6-2.

Table 6-2. Monitoring program sampling frequency and parameters.

Month	Groundwater Sampling		Lake Sampling	
	Frequency	Parameters	Frequency	Parameters
January		**Field:** • Temp • DO • EC • pH • ORP • Groundwater level (if possible) **Laboratory:** • *E. Coli* • Enterococci • TN, TP		**Field:** • Temp • DO • EC • pH • Turbidity • Lake depth • Observations of aquatic plant assemblage and coverage **Laboratory:** • *E. Coli* • Enterococci
February			X	
March				
April	X			
May				
June				
July			X	
August				
September			X	
October	X			
November			X	
December				

6.4 Sampling methodology

The proposed sampling program involves the following:

- Measuring in-situ DO (and other field parameters) using a hand-held field meter at each of the sampling sites during the early morning, between 6.30 am and 8.30 am, and in the afternoon, between 12 noon and 4 pm.
- At each sampling site, field parameters will be measured at the surface, and at depth intervals of 0.25 m through the water column to the lake bottom.
- A sample for bacteriological analysis will also be taken from the surface at each sampling site.
- Sites will be accessed by paddling an un-motorised boat; either a small tinnie or canoe depending on the lake.
- Lake depths will be recorded at each site using a tape measure and an extendable pole and/or a weighted tape measure.
- Other relevant observations will also be recorded at the time of sampling including wind strength and direction, cloud cover, water clarity, plant/algae coverage, any visual signs of pollution etc.

- The sampling will be undertaken by two personnel as a safety precaution and for manual handling, given the work will be undertaken using a boat.

Bore sampling will need the assistance of CoP operations staff to gain access to the bore compound and turn on the bore pump so as to collect a bucket of water for field parameter measurements and to collect samples for laboratory analysis.

6.5 Assessment criteria

The following is proposed as the main assessment criteria for applying to quarterly lake monitoring results:

- Maintain DO concentrations greater than 80% throughout the majority of the water column during both the morning and afternoon
- Turbidity to remain below 20 NTU.

Also, where relevant, results will be assessed against the local Water Quality Objectives (WQO's) developed by the NT Government for Darwin Harbour; specifically, those for the 'upper estuary' and 'freshwater rivers and streams' as outlined in the document *Water Quality Objectives for the Darwin Harbour Region – Background Document* (NRETAS 2010).

The criteria for assessing bacteriological results is yet to be developed in the context of using the lake water for irrigation. The criteria will depend on an assessment of the potential risks.

Bore water quality will be monitored for long-term trends in salinity increases, presence/absence of bacteriological indicators and a comparison of TN and TP to the Darwin Harbour WQO's.

6.6 Reporting

To provide a more engaged and simplified approach to reporting, results from water quality monitoring is proposed to be structured similar to the Darwin Harbour Report Cards. A simplified reporting structure allows a score to be determined per lake, based on the water quality assessment criteria and the desired lake targets, whilst also being engaging for the community. Key performance indicators that are observed will be in line with the assessment criteria listed in Section 6.5 above.

The report cards could be uploaded on the CoP website, making it easy and accessible for the local community to be kept up to date on what is happening at their local lake.

An annual report, will also be developed based on the results of the quarterly report cards for internal use at CoP. An example developed as the annual report card for 2020 can be found in Appendix B.

6.7 Documentation

Documentation is crucial in regards to monitoring of the lakes. It is understood that CoP currently have some documentation in place to monitor the lakes. It is recommended that the documentation system be reviewed to align with the LMP. All documentation, plans, procedures, registers, reports, databases and records should be uploaded to CoP's internal system and be made available to all who are maintaining and managing the lakes. A summary of the documents recommended to be reviewed and made available is provided in Table 6-3.

Table 6-3. Documents and records summary

Document/Record	Summary	Frequency of updates
Minutes and actions of site meetings relating to specific actions for the lakes	Staff scheduled meetings to discuss any issues within the lakes. It provides opportunity to provide feedback and concerns. Meeting minutes are documented and kept within the CoP internal system.	As required
Lake inspection checklist	The Lake Inspection Checklist (Appendix B) is a general site inspection checklists used as a tool to ensure compliance with the CoP lakes maintenance plan	As required
Action register	Where there is an inspection or audit, which identifies non-conformances, corrective or preventative actions that need to be addressed, these are recorded within CoP's internal management system.	As required
Non-conformance register	All environmental incidents, near-misses or non-compliances are reported to the head of the CoP maintenance team as soon as practicable.	As required
Maintenance plan review	The maintenance plan is required to be reviewed at least annually to ensure the content remains current and up to date with practices at the CoP.	Annually

6.8 Site inspection checklists

In the past, CoP have used various spreadsheets and word documents to record lake inspection data. However multiple sheets and documents being taken out on site can become a nuisance and difficult to manage.

It is recommended that all lake inspection data is consolidated and recorded in one location. For example, the maintenance crew undertaking the lake inspection and maintenance could take out an iPad with a pre-filled template loaded in it, to make recording of the inspections easier. Once back at the office, the inspections could be easily loaded up onto CoP's database.

The pre-filled template could be in the form of a spreadsheet or an online form, such as Google Forms or Survey Monkey, which upon completion is automatically uploaded into CoP's internal system.

An example of the type of questions that would be in the form is provided in Appendix A.

7 NON-CONFORMANCE AND CORRECTIVE ACTIONS

Any non-conformance will be documented through site inspections/audits, using the tables provided in this section, stating the nature of the non-conformance and the mechanisms implemented to correct the incident.

A CoP representative should be notified of any non-conformance within 24 hours of an environmental incident occurring. Corrective/preventative action should be completed within a timely manner (e.g. within a maximum of seven days of the event occurring) to ensure that the incident is addressed. Records will be kept of all environmental incidents that occur, and corrective actions implemented throughout the duration of the project. If management controls are not implemented and completed in the designated manner, additional training may be required for the Company Project Manager, works crews and/or subcontractors.

Corrective actions for each environmental safeguard category are provided in Table 7-7-1.

Table 7-7-1. Corrective actions for continual improvement.

Category	Target	Corrective Action
Inductions and training	• All Company staff and subcontractors have received a site induction that covers all environmental responsibilities.	• Review induction records and procedures. • Revise induction procedures.
Community liaison	• No complaints from nearby residents or general public.	• Review community engagement efforts and undertake additional methods. • Respond to all complaints and implement specific corrective actions.
Water quality	• If water quality objectives are not being met over a series of two monitoring events, the following corrective actions are to be implemented	• Investigation into the likely source linked to the poor water quality being observed • Determining if the source driving the poor water quality have any 'high risk' parameters (i.e. extremely low DO, visual observation of the water quality is murky and full of marco/micro algae) • Ensuring that no sewer overflows have occur in the area • Increase community awareness and ensure warning signs re put in place until compliance is met (i.e no fishing). • Ensure that erosion and sediment controls are in place and consistent with CoP's Erosion and Sediment Control standards. • If faecal coliform results are non-compliant, additional testing must occur and access to the lake for secondary uses or functions should be restricted. Seek professional advice on rectification options • If pH changes, fish kills can occur, therefore an investigation must be initiated to determine if pH was the cause. Professional advice must be sought on rectification options.

Category	Target	Corrective Action
Vegetation and fauna	• The presence of threatened fauna is identified within works areas prior to operations commencing. • No threatened flora or fauna species harmed during the works. • All vegetation clearing has prior approval from the relevant authority (i.e. DIPL, DENR).	• Ensure experienced and knowledgeable personnel are available to assist with the removal of any native fauna. • Delineate and clearly mark out areas for clearing or maintenance and ensure all workers and subcontractors are made aware. • Vegetation should be trimmed as required • Where a risk to safety is identified, vegetation should be removed
Weeds management	• No new weeds or pests introduced to site, and/or spread of existing weeds and pests. • Existing weeds (salvinia) to be managed more regularly.	• Review weed management procedures. • Establish exclusion areas for existing weed infestations. • Implement weed management practices as per the NT Weed Management Handbook. • Remove or contain all pest attractants. • Ensure vehicles are cleaned for weeds and pests prior to entry to site.

8 REFERENCES

ABC News (2020), *BOM declares a La Nina, signalling wet springs and summer likely for northern, eastern Australia*. [online] Available at https://www.abc.net.au/news/2020-09-29/bom-declares-la-nina-wet-conditions-likely-for-eastern-australia/12617528#:~:text=During%20a%20La%20Nina%20phase,the%20south%2Deast%20misses%20out [Accessed 29 September 2020]

City of Palmerston (2017*). Lakes in the City of Palmerston: Minimum requirements for the design and construction of Lakes in Palmerston*. Version 1. City of Palmerston, Palmerston, Northern Territory.

Department of Environment and Natural Resource (2019), Darwin Harbour Report Card 2019 at a Glance. [online] Available at https://denr.nt.gov.au/__data/assets/pdf_file/0010/795079/darwin-report-card-at-a-glance-2019.pdf [Accessed 25 September 2020]

Lamche G (2007). *The Lagoons of the Outer Darwin Area.* Milestone Report 1 – DNA8 Affiliation: National Land & Water Resources Audit, NT Department of Natural Resources, Environment and the Arts

Louis A. Helfrich, James Parkhurst and Richard Neves, Department of Fisheries and Wildlife Sciences (2009), Guide to Understanding and Managing Lakes: Part 1 (Physical Measurements). [online] Available at https://www.pubs.ext.vt.edu/420/420-538/420-538.html [Accessed 22 September 2020]

National Heritage Trust (2003), *Salvinia (Salvinia molesta)*. [online] Available at https://www.environment.gov.au/biodiversity/invasive/weeds/publications/guidelines/wons/pubs/s-molesta.pdf [Accessed 29 September 2020]

NRETAS (2010), *Water Quality Objectives for the Darwin Harbour Region – Background Document*, Department of Natural Resources, Environment, the Arts and Sport (NRETAS), Northern Territory Government, Palmerston.

NSW Department of Primary Industries (2006), Salvinia control manual – Management and control options for salvinia (Salvinina molesta) in Australia. [online] Available at https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/89554/salvinia-control-manual.pdf [Accessed 25 September 2020]

SPEL Stormwater (2020), *Floating Wetlands – Stormwater.* [online] Available at http://spel.com.au/products/spel-wetlands/stormwater/ [Accessed 29 September 2020]

SPEL Stormwater (2020), *Stormceptor*. [online] Available at http://spel.com.au/products/stormceptor/stormceptor-gallery/ [Accessed 29 September 2020]

SPEL Stormwater (2020), *Vortceptor*. [online] Available at http://spel.com.au/products/vortceptor/ [Accessed 29 September 2020]

APPENDIX A SITE INSPECTION REPORT

Palmerston Lakes:
Monthly Maintenance Checklist

INSPECTION TYPE: **MONTHLY LAKES INSPECTION AND MAINTENANCE RECORD**

INSPECTION DATE: **INSPECTED BY:**

Monthly maintenance inspections to be undertaken as per the following checklist

Category	Inspection Checklist	Comments/Notes	Tick
Lake ID	Note lake ID number		☐
Visual appearance	Water clarity – is water clear? If not, note colour.		Y ☐ N ☐
	Does water have a sheen or surface scum?		Y ☐ N ☐
	Does water have an odour?		Y ☐ N ☐
	Is there algae visible in the water?		Y ☐ N ☐
Vegetation harvesting	Are there weeds present? If yes, name weeds		Y ☐ N ☐
	Vegetation coverage - % of water covered by vegetation Note type of vegetation covering lake (e.g. salvinia, lilies)		<25% ☐ 25% ☐ 50% ☐ >75% ☐
	Bank coverage - % of bank covered by vegetation		<25% ☐ 25% ☐ 50% ☐ >75% ☐
	Harvesting required? If yes - note date to be harvested		Y ☐ N ☐
	Weed spraying required (aquatic plants)? If yes - note date to be sprayed		Y ☐ N ☐
Park / grass maintenance	Has mowing been undertaken within past month? If yes – note date of mowing operations.		Y ☐ N ☐
	Has fertilizing been undertaken within the past month? If yes – note date of fertilizing, and area fertilized (spot fertilizing or large area? Estimate m^2).		Y ☐ N ☐
	Has weed spraying been undertaken within the past month? If yes – note date of spraying and area sprayed (spot spraying or large area? Estimate m^2).		Y ☐ N ☐
Sediment	Has there been soil disturbance within lake catchment within the past month? Note any known sources of sediment upstream (e.g. active construction works)		Y ☐ N ☐
	Is there noticeable sediment in water (based on water colour – e.g. red or brown water)?		Y ☐ N ☐
Water volumes	Has the lake been topped up with groundwater within the past month?		Y ☐ N ☐
	Has water been extracted from the lake within the past month?		Y ☐ N ☐

Palmerston Lakes:
Monthly Maintenance Checklist

	Have grounds surrounding the lake been irrigated within the past month?		Y ☐ N ☐
Dissolved oxygen	Is lake being aerated (e.g. with aerator or fountain)?		Y ☐ N ☐
	Is lake flowing at outlet and inlet?		Y ☐ N ☐
	Have there been any fish kills within the past month?		Y ☐ N ☐
Pollution	Are there signs of lake pollution? (e.g. rubbish, foams/scums/surface sheens)		Y ☐ N ☐
	Are there signs of illegal dumping of domestic plants/fish tank contents into lake?		Y ☐ N ☐
Golf course	Note any known golf course maintenance activities within the past month (e.g. fertilizing)		
Other	Note any other comments/observations		
ACTIONS REQUIRED:	E.g. vegetation harvesting, mowing		
ADDITIONAL COMMENTS:			
DATE OF NEXT INSPECTION:			

Signed:

…….

Name:

Date:

APPENDIX B PALMERSTON LAKES WATER QUALITY REPORT CARD

Palmerston Lakes Water Quality Report Card

AT A GLANCE

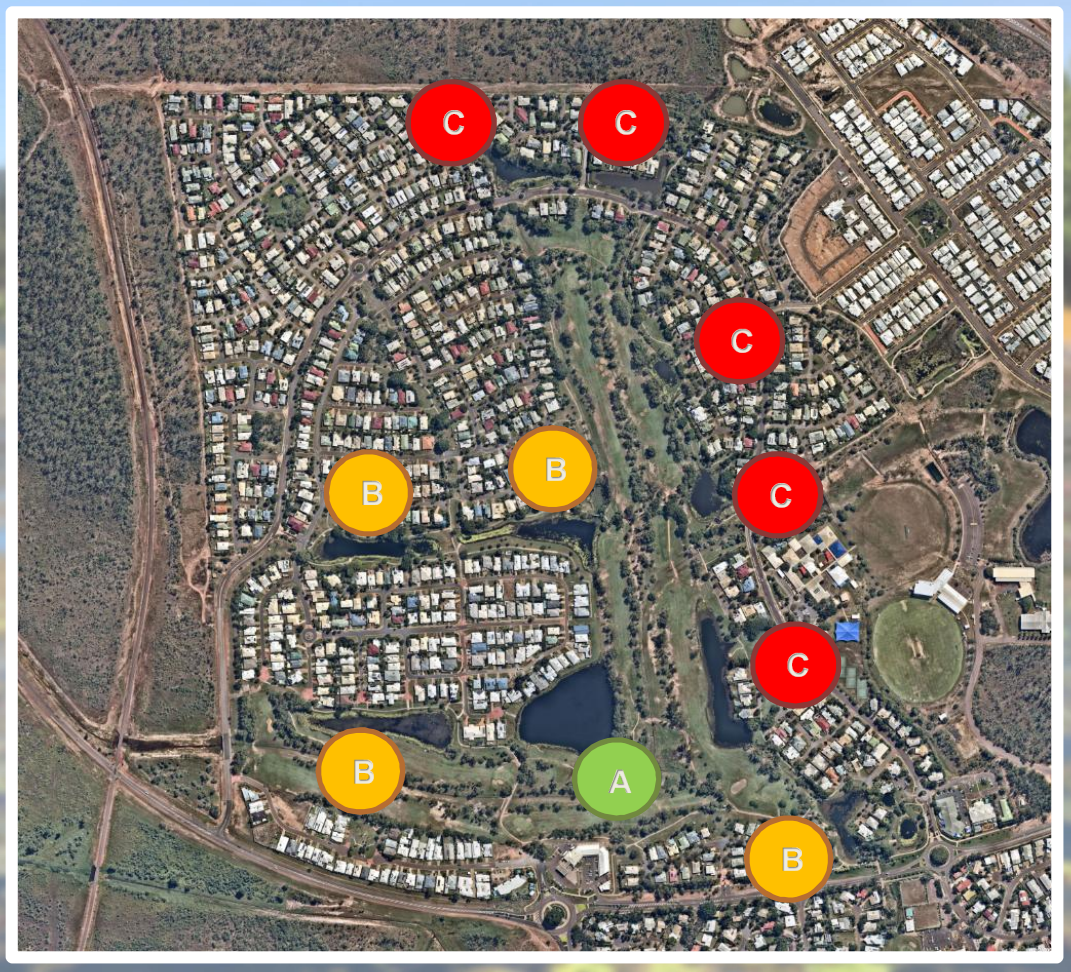
✗ Two Large fish kill events were recorded

✓ Installation of aeration devices at lakes 9 & 10

In 2020, water quality in the Durack Lakes, Sanctuary Lakes and Marlow Lagoon received a combined FAIR rating.

Lake 8 was the standout lake, recording excellent dissolved oxygen concentrations and provided a great habitat for local aquatic wildlife.

Durack Lakes 1a, 1b, 3, 4, and 6 and all three Sanctuary Lakes received a POOR rating, due to low dissolved oxygen readings, excessive plant and algae growth, as well as large amounts of *Salvinia molesta* (Salvinia), a Weed of National Significance.



RATINGS

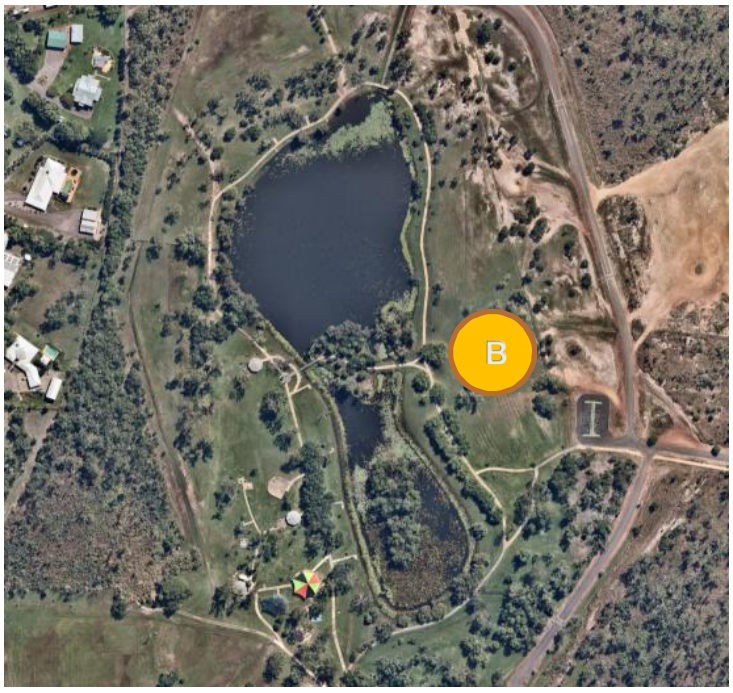
A — GOOD

B — FAIR

C — POOR

D — VERY POOR

Palmerston Lakes
Water Quality Report Card



2020 Individual Lake Grading														
Lake	Lake 1a	Lake 1b	Lake 3	Lake 4	Lake 5	Lake 6	Lake 7	Lake 8	Lake 9	Lake 10	Sanctuary lake A	Sanctuary Lake B	Sanctuary Lake C	Marlow Lagoon
Grade														

How does this report card work?

Water quality analysis was conducted by EcOz Environmental Consultants. Each lake was assessed for water quality and assigned a grade against the following five water quality objectives; water clarity, dissolved oxygen, abundance of wildlife, vegetation (including weeds and algae) and fish kills.

APPENDIX C SALVINIA SIGNAGE

SALVINIA FREE AREA

Salvinia is not known to be in the Mary or Adelaide River systems.

Check your boat, trailer and fishing gear for salvinia before launching.

Salvinia is a free-floating aquatic weed that can cover and choke out freshwater billabongs and rivers. It can destroy habitat for fish, birds and other aquatic life, and prevent fishing and recreational boating.

DO NOT INTRODUCE SALVINIA TO THIS AREA

If you see salvinia in this river system, report it immediately to the Weed Management Branch 08 8999 4567

www.nt.gov.au/salvinia

NORTHERN TERRITORY GOVERNMENT

BIOSECURITY ALERT: SALVINIA OCCURS IN THIS RIVER SYSTEM

Check your boat, trailer and fishing gear for salvinia before leaving this area.

Salvinia is a free-floating aquatic weed that can cover and choke out freshwater billabongs and rivers. It can destroy habitat for fish, birds and other aquatic life, and prevent fishing and recreational boating.

DO NOT SPREAD SALVINIA FROM THIS AREA

For more information see our website or call the Weed Management Branch on 08 8999 4567

www.nt.gov.au/salvinia

NORTHERN TERRITORY GOVERNMENT