Lake Ainsworth Coastal Management Program

Stage 2 – Vulnerabilities and Opportunities Study

Final Report

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Front cover photo: Ecosystem components at Lake Ainsworth, clockwise from top left: Fringing vegetation; Rainbowfish (*Melanotaenia duboulayi)* captured during fish survey, Swordtail (*Xiphophorus helleri*) captured during fish survey; two main sediment types (organic rich-muds and medium-grained sands); and Redclaw crayfish (*Cherax quadricarinatus*) captured during fish survey.

Hydrosphere Consulting Pty Ltd
Suite 6, 26-54 River Street
PO Box 7059, BALLINA NSW 2478
www.hydrosphere.com.au

18-009 LAKE AINSWORTH COASTAL MANAGEMENT PROGRAM
STAGE 2: VULNERABILITIES AND OPPORTUNITIES STUDY

REV	DESCRIPTION	AUTHORS	REVIEW	APPROVAL	DATE
0	Draft for Client Review	K. Pratt, M. Howland, U.Makings	M. Howland	M. Howland	22 Apr 2019
1	Draft for Steering Committee Review	K. Pratt, M. Howland, U.Makings	M. Howland	M. Howland	10 May 2019
2	Final Report for Public Release	K. Pratt, M. Howland, U.Makings	M. Howland	M. Howland	20 June 2019

EXECUTIVE SUMMARY

This report documents Stage 2 of the Lake Ainsworth Coastal Management Program (CMP). It comprises detailed studies to support decision-making in later stages of the planning process. The scope of detailed studies was identified during Stage 1 and was designed to reflect the scale and complexity of local issues as well as community and stakeholder perceptions of risks and vulnerabilities. The additional information will assist Council and the community to better understand coastal management issues and to analyse and evaluate risks and opportunities. A key outcome of Stage 2 is the identification of opportunities to reduce risks and enhance the environmental, social and economic values of Lake Ainsworth (presented in Section 7).

Detailed studies were carried out between June 2018 and April 2019. A summary of each aspect is provided below.

Coastal Hazards

- Ocean shoreline recession is a key risk for the management of Lake Ainsworth. Coastal hazard predictions show the potential for ocean breakthrough to the lake within a 50-year timeframe. Any connection with the ocean is likely to have significant implications for the ecology and public usage of the lake.
- The coastline CZMP advocates ‘protection’ utilising rock sea walls rather than ‘retreat’. Current defences against shoreline recession are inadequate in the vicinity of Lake Ainsworth;
- The risk of significant wave run-up and over-wash of salt water to Lake Ainsworth during heavy seas is currently low, but will increase with continued sea level rise. The highest risk site is at the Surf Club, where risks can be mitigated by temporary minor works as required.
- Foreshore erosion - Field surveys were undertaken for all banks of Lake Ainsworth in December 2018. Banks were divided into sites and categorised in terms of erosion severity. Erosion sites were prioritised for management action by combining three key factors: observed erosion severity; foreshore access safety; and potential of erosion to impact built assets around the lake.
- Freshwater flooding - Considering the information currently available, a range of future flooding scenarios are possible. An average increase in mean sea level coupled with an increase in extreme rainfall and sea-level events, suggests average lake levels may rise in the future and the risk of future flooding events (both in frequency and magnitude) will also increase. Conversely, increasingly dry winters with increased temperatures may result in occasional periods of lower lake levels during the latter half of the year than previously seen.

Hydrology/Groundwater

- Detailed hydrographic survey of the lake was undertaken in July 2018 documenting the current status of the lake’s bathymetry.
- The updated water balance model has indicated that groundwater outflows vary significantly from year to year and are governed by the balance of inputs (rainfall, runoff, groundwater inflows) and outputs (evaporation) as well as sea level conditions. There is some indication that groundwater outflows have reduced in recent years and recent sediment sampling indicates expansion of organic-rich muds since 1996, which may account for reduced outflows. Climate change is also expected to lead to an increase in average water levels in the lake and increased flooding due to sea level rise and a predicted increase in extreme rainfall and sea level events.

Water Quality

- A detailed review of water quality data collected from 2015 to 2018 was completed.

- Water quality is typically acidic (pH ~5.8), with elevated nutrient levels, and is prone to blooms of blue green algae (cyanobacteria) which impacts lake health and recreational use.
- Comparison to ANZECC guidelines for aquatic ecosystem health showed a significant exceedance of nutrient and Chlorophyll *a* indicators indicating eutrophic conditions. Other physical parameters (temperature, turbidity and DO) were within suitable levels for aquatic ecosystem protection.
- Nutrient levels persist in the water column and appear to have increased over time. Current average total phosphorus concentrations (measured from 2015-2018) are almost double the levels measured in 1995 and current dissolved inorganic phosphorus levels are up to four times the levels measured in 1998/99.
- Nutrient inputs to the lake can come from atmospheric sources, the catchment via surface runoff, eroded soils and groundwater, fauna and recreational users, as well as internal cycling of nutrients between sediments and biota. The organic-rich muds located in the deeper sections of the lake are still considered to be the primary source of nutrients within the water column.
- Sunscreen has been identified as a potentially significant pollutant source, not only contributing to oily slicks on the water surface and chemical compounds known to effect ecological health but also as a potential nutrient source. Initial estimations of potential sunscreen load to the lake equated to approximately 192L of sunscreen per year. Estimation of potential average annual contribution of phosphate equated to approximately 10% of the current average PO_4-P levels measured in the lake.
- Over the last 16 years, levels of blue-green algae (cyanobacteria) have fluctuated substantially in the lake with no overall trends observed through time. The alert levels have been frequently exceeded with impacts on recreational use and public health risks and this is regarded as the highest priority for management by the community.
- Review of the current aerator program indicated that despite artificial aeration, a low dissolved oxygen zone was still detected at the sediment/water interface creating conditions suitable for P-release from sediments to the overlying water;
- Artificial aeration is very effective at mixing and oxygenating the entire water column, however this is also believed to be a mechanism for transport of nutrients released from sediment to surface layers where algal growth occurs in the presence of sunlight. It is believed that this continued cycling of nutrients contributes to algal blooms.
- There is also some evidence to suggest that phosphorus -release from sediments increases as pH increases. From current water quality monitoring it is known that pH levels in the lake are slightly increased from levels monitored in 1996 and this may be facilitating increased P-release from sediments. Increased algal productivity may be the cause of increases in pH which in turn increases P-release, thus stimulating further algal growth.
- In 2018, Beachwatch graded three of the four lake swimming sites as ‘poor’ in terms of contamination with faecal material from animal and human sources (Lake Ainsworth North, Lake Ainsworth East and Lake Ainsworth West). The majority of faecal matter is believed to be washed into the lake from land surfaces during rainfall. Swimming should be avoided during and for up to three days following rainfall or if there are signs of stormwater pollution such as turbid/murky water or floating debris.

Sediment Quality

- Field survey of benthic sediments in November 2018 revealed expansion of the organic-rich mud layer further northwards and towards the south-east in the lake compared to 1996 mapping.

- The organic-rich muds were acidic (pH range 5.7 - 6.01), high in organic carbon, high in nutrients and were in a reducing-state (oxygen-deficient). These sediments also exceeded ANZECC sediment guidelines for Lead and Mercury at several sites, although high carbon content is likely to assist in binding these contaminants to sediment and prevent release to the water column. The results of sediment sampling were generally consistent with previous sampling conduced in 1996 indicating very little change in sediment nutrient and heavy metal content in the last 22 years.

Flora and Fauna

- Flora and fauna assessments were focussed on the assessment of riparian vegetation extent and condition; aquatic fauna survey; and assessment of aquatic weed management options.
- A total of six fish species were captured in Lake Ainsworth during the fish survey including two exotic species and four native species. Incidental captures included Cane toad (*Rhinella marina*) tadpoles (exotic) and the non-endemic and invasive Redclaw Crayfish (*Cherax quadricarinatus).*
- A summary of fish and cane toad eradication techniques and their potential applicability to Lake Ainsworth is provided.
- Exotic weeds present within Lake Ainsworth include Mexican Waterlily (*Nymphaea mexicana*), *Salvinia sp*., Water Primrose (*Ludwigia spp*.) and Water Hyacinth (*Eichhornia crassipes*). A variety of management techniques are and have been implemented to address exotic weeds infestations within the lake to date, many with a high level of success and are ongoing. A summary of potential weed management options and their potential applicability to Lake Ainsworth is provided.
- A field survey was undertaken for all riparian zones surrounding Lake Ainsworth in December 2018. Riparian zones were categorised in terms of the extent of riparian vegetation, degree of shading of the water and overall disturbance rating. A number of factors were noted as contributing to riparian vegetation disturbance including clearing, exotic species, a high level of pedestrian traffic, bank erosion, disturbed areas adjacent (e.g., mown exotic grassed areas or roads).

Community uses

- Lake Ainsworth is an important asset utilised by the community and tourists for recreational, commercial and educational purposes. The lake is bordered by, or is in close proximity to, commercial and recreational facilities and businesses. The catchment area and these associated facilities and businesses provide a key destination for visitors to the region which in turn has a positive impact on the local economy.
- A detailed program of community and stakeholder consultation was undertaken to document community uses, priority issues, opinions and aspirations for the lake. Consultation activities included: community online and paper-based survey; project webpage; media and advertising; targeted stakeholder consultation with key stakeholder groups; community drop-in session; meetings with the Project Steering Committee; and consultation with the local Aboriginal Community.
- A high level of community response was generated through engagement activities demonstrating the significance of this much-loved lake in the everyday lives of the community. The results of the survey provide a good snapshot of community opinion about the lake including: popular activities and locations of access; current issues; perceptions about lake health; management priorities; and the community's vision for the future of the lake.
- A public access safety risk assessment was completed in December 2018. Where safety risks were regarded as high or very high, recommended measures to address these risks are to be developed as part of the CMP.

CONTENTS

FIGURES

PLATES

TABLES

1. COASTAL HAZARDS

The following coastal hazards were identified in the Scoping Study as having potential to affect Lake Ainsworth:

- Ocean shoreline recession, breakthrough and saline intrusion;
- Wave run-up and dune overtopping;
- Foreshore erosion of the lake; and
- Localised freshwater flooding.

The sections below describe the outcomes of tasks recommended in the Scoping Study to examine issues relating to these hazards.

1.1 Coastal Recession and Oceanic Break-through

The continued recession of Seven Mile Beach and increased risk of erosion as a consequence of climate change (i.e. sea-level rise and storm events) has the potential to result in periodic or permanent opening of Lake Ainsworth to the sea. This has been identified as a key issue in the CZMP (GeoLINK, 2016). Oceanic breakthrough to the lake would substantially alter the ecosystem functions of the waterbody and surrounding habitats by changing the salinity, water chemistry and water level regime of the waterbody.

1.1.1 Shoreline Recession

WBM (2003) assessed the potential for shoreline retreat based on volumetric change (storm bite) in relation to the dune scarp position in 1999 and with application of the Bruun rule (Bruun 1962) for 50 and 100 year timeframes. The result of this work led to the definition of best estimates, as well as minimum and maximum extents of hazard lines for the ‘immediate’, ’50 year’ and ‘100 year’ timeframes. These figures were updated by BMT WBM in 2011 (Figure 1).

The ‘immediate’ hazard line developed at the time indicated that there was a risk of the dune scarp retreating as far as the Surf Club building, but not intersecting the foreshore of Lake Ainsworth. The best estimate for the 50-year timeframe (i.e. ~2050) shows that an unprotected shoreline would be likely to intersect the lake boundary, whereas the 100-year predictions are well within the current lake foreshores, almost to the deepest part of the lake.

In defining hazard lines, the WBM (2003) study did not take into account the protective effect of any existing coastal protection infrastructure, although it was clearly acknowledged that this will have a significant influence on coastal retreat. Figure 1 shows the location of existing erosion defences which are currently buried within the sand dunes of Seven Mile Beach. To the south of Lake Ainsworth, a rock wall constructed in 1977-1980 exists with a northward extent at around the Surf Club. At the northern end a rock wall is located along the eastern side of the Sport and Recreation Centre, with an upgraded, substantial wall immediately east of the main buildings at this location.

Between the two sets of buried walls, there are no documented coastal defences, although some rock work of unknown extent does exist within the dunes. The northward extent of the 1967 ‘ti-tree’ fence is unclear but is not known to extend beyond the Surf Club. Similarly, the northward extent of the historical boulder rock wall is not known and was the subject of a ground penetrating radar survey in 2013 (GBG, 2013). This survey indicated that some form of structure was evident between the Surf Club and the dog track, however subsequent excavation just north of the Surf Club concluded that the sea wall probably didn’t extend beyond that point (BMT WBM, 2016).

The status of the coastal protection between the Surf Club and the dog track remains uncertain. In any case, any structure that is present is not likely to offer any substantial protection, leaving this section exposed to erosion and long-term coastal recession risks.

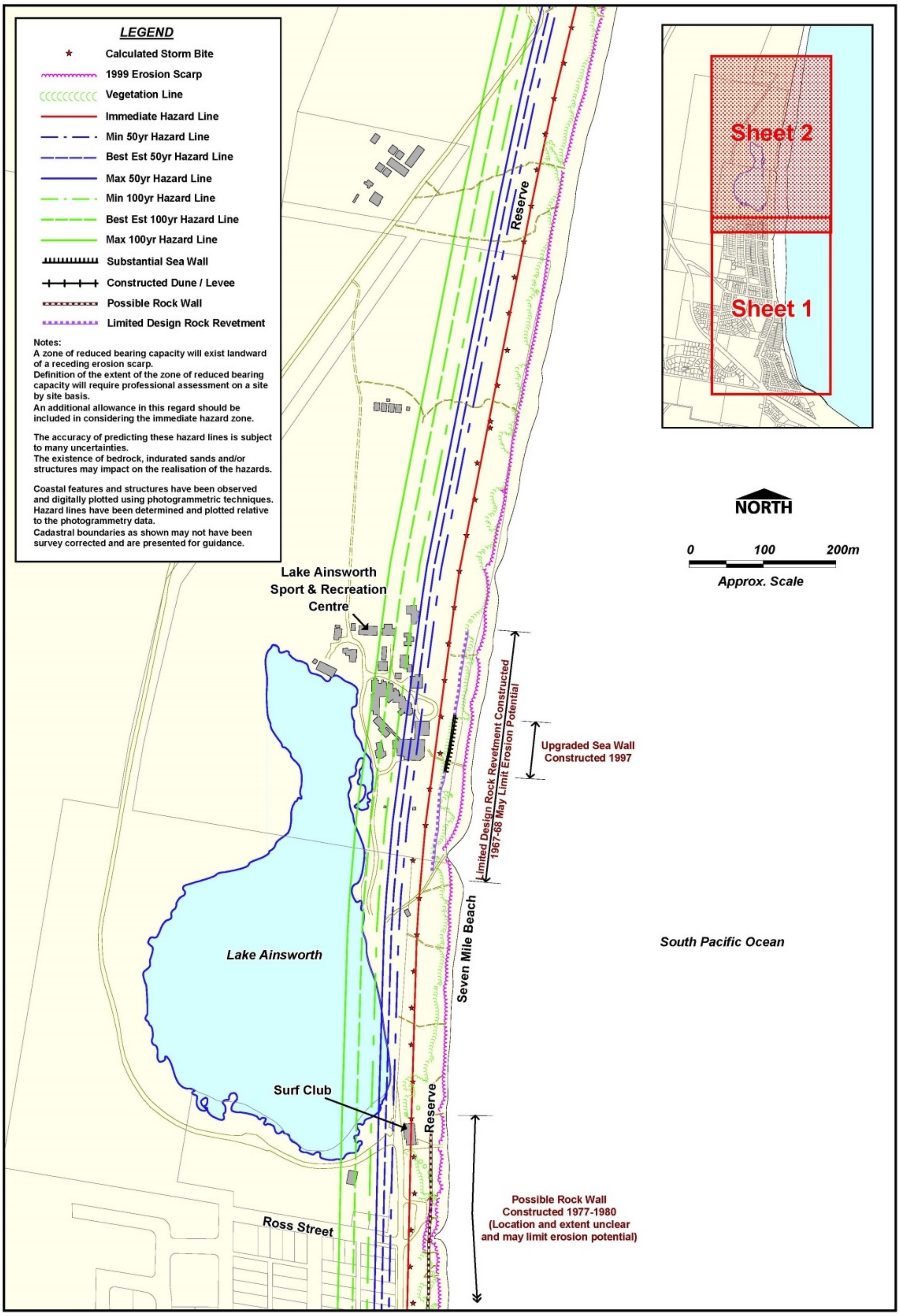


Figure 1: Coastal retreat hazard lines in the vicinity of Lake Ainsworth (Source: WBM 2011)

1.1.2 Oceanic Break-through

With continued sea level rise and associated risk of coastal recession there is a significant risk that breakthrough (connection between Lake Ainsworth and the ocean) will occur in the future if there is no management intervention. The area immediately north of the Surf Club is considered to be the most likely location for break-through as the width of the dune/beach barrier is the least at this point and has the least sand volume to satisfy multiple erosive events. During a period of active erosion, this location may also experience significant scour at the end of the southern sea wall, if this becomes exposed, which may locally exacerbate erosion at this point.

Break-through is most likely to occur during a period of heavy seas where significant coastal erosion has depleted the protective dune field and the beach face is at its lowest. Once this level of erosion occurs, there would be a very high probability of a 'breakout' of the lake to the ocean, as average water levels at around +2m AHD in the lake would have sufficient hydraulic head to make this happen. This would be likely before the dune scarp (as predicted by the hazard lines) actually intersects the lake boundary and could be exacerbated by sub-surface water flow from the lake through the beach face, as well as wave over-wash effects. The location of break-though would depend on the state of Seven Mile Beach at the time, but it is considered most likely to occur just north of the Surf Club.

Once breakout occurs, the lake would drain rapidly to approximately mean sea level (~0m AHD) within a number of days. The resulting breakout channel would scour down to at least mean sea level and expose the lake to tidal ingress. Although the connection would likely temporarily close again with low swell conditions and associated beach building activity, subsequent breakouts would become more common, with the waterbody taking on the characteristics of an ICOLL (Intermittently Closed and Open Lake and Lagoon).

Lake Ainsworth has a relatively small hydrological catchment and hence sustained freshwater flows from the lake to the ocean would typically be low. The lack of freshwater flow would not be sufficient to maintain an open entrance for long after breakouts, and hence it would be expected that the ICOLL would remain closed more often than not. Groundwater levels in the immediate vicinity of the lake would mirror lake levels. As an ICOLL, the minimum water level of the lake during breakout conditions would be controlled by the elevation of the breakout channel and would be expected to be lower than current average water levels. This would result in reduced local groundwater levels and it is likely that rapid draining of groundwater during a breakout event would have significant ecosystem impacts and exacerbate bank erosion around the lake. During periods of closure, the water level in the lake would be controlled by a combination of groundwater inflow /outflow, rainfall and evaporation (as occurs now), as well as the level of the beach berm. Aside from the impacts of sea level rise, which will act to increase groundwater levels generally, it is expected that the effect of connection of Lake Ainsworth to the ocean would not increase lake or groundwater levels and is more likely to lead to reduced water levels.

With connection to the ocean, the lake would act as a sand sink and infilling of marine sands near the entrance would be likely. The eastern shoreline of the Lake would gradually migrate westwards along with the retreat of unprotected sections of Seven Mile Beach. In the long term it is not known whether the shoreline would experience a major readjustment at this location or whether there would be sufficient coastal sand supply to significantly infill the lake and maintain the shoreline between sea walls to the south and north.

Aside from geomorphological changes, there would be significant changes in water quality and ecological functioning of the lake following break-through. It is likely that several aspects considered important by the community for public amenity would be lost. Access along the eastern shoreline would be hampered during breakout events and emergency access to the Sport and Recreation Centre could not be guaranteed, water in the lake would become more saline and there would be changes in riparian vegetation, including potential dieback of salt-influenced Melaleuca trees.

1.1.3 Wave Run-up and Dune Overtopping

Weather events resulting in storm surges and abnormal waves have the potential to overtop the bordering dune system along Seven Mile Beach at points of low elevation (i.e. beach access tracks). This could result in saline input into Lake Ainsworth, localised flooding along the eastern side of the catchment, localised erosion along the dune system and lake foreshore, and disruption of public use via impeded access.

Wave run-up is greater for steep, low-porosity shorelines and is reduced for wide beaches that absorb the wave's energy. As a general estimate, a barrier height of 5.5m AHD is currently considered sufficient to resist wave run-up and over-topping in all but the most extreme events.

1.1.4 Evaluation of Dune Barrier Condition

To assist in assessing the risks to Lake Ainsworth posed by shoreline recession, ocean break-through and wave run-up an examination of dune volume utilising available LiDAR data was undertaken. LiDAR uses a similar concept to radar, but utilises a plane-mounted laser to scan the ground surface. Data were available from a survey in 2010 and again in 2017. A field survey utilising a survey-grade GPS was also undertaken in critical locations during December 2018 to verify elevations derived from the LiDAR data.

The LiDAR data from 2017 was found to be poorly classified, leading to the intermittent inclusion of vegetation in the 'ground' strikes utilised for topographic mapping. Sectional views of the 2010 and 2017 data sets indicated that the 2017 data consistently under-estimated the elevation of fixed features (e.g. the eastern road surface) compared to the 2018 high-accuracy GPS survey data. The 2017 data also appeared to under-estimate ground levels within the dunes, sometimes significantly, but not consistently. As a result there was low confidence in the 2017 data generally. Despite this, there was sufficient evidence to show that there was a significant difference in the volume of the upper beach face and position of the fore-dune scarp, with 2017 being significantly depleted compared to 2010.

WBM (2003) discuss the concept of storm bite (the volume of sand likely to be eroded during a design storm event) and consider a likely storm demand of 200m^3/m appropriate when Seven Mile Beach is in an accreted state and less for eroded profiles. In 2017, when the state of Seven Mile Beach was somewhat depleted there was still significant volume of sand above 0m AHD to combat multiple successive storms, with an average of ~600m^3/m available between the Surf Club and the dog track and ~450m^3/m within the flat, relatively dune-less area immediately north of the Surf Club. Spot elevations from the 2018 GPS survey indicate significantly more sand on the beach since 2017, more comparable to the 2010 LiDAR survey. In this case, the sand volumes above 0m AHD were calculated to be 615m^3/m on average and 480m^3/m just north of the Surf Club.

Notwithstanding the long-term risk of shoreline recession, it is concluded that there are significant sand reserves in place, even in the highest risk location immediately north of the Surf Club, to combat coastal erosion in the short term.

With respect to the risk of wave run-up and over-wash into Lake Ainsworth, the 2010 LiDAR data were utilised to identify potential low-elevation pathways through which run-up could overtop the dunes. Five such pathways were identified (Figure 2) considering the current dune topography with potential wave run-up heights exceeding 5.0m AHD:

1. The access ramp and driveway immediately south of the Surf Club, with a crest elevation of ~5.5m AHD less than 40m from the current dune scarp. Although narrow, the steep, smooth ramp and limited overland distance increases the risk of wave over-wash through this corridor.

2. The flat area immediately north of the Surf Club also appears vulnerable to wave over-wash, but has a crest elevation at around 5.7m AHD. This is marginally higher than some of the other areas but has some degree of vulnerability due to the limited vegetation and relatively short distance between the current beach scarp and 'dune' crest (40m).

3. A narrow gully running approximately SE-NW through the dunes approximately 2/3 of the distance northward towards the dog track. There are two narrow ridges of dune at elevations of around ~5.5m across this gully with the final barrier at around 80m from the beach dune scarp. The narrowness the gully (between 5 and 10m) and convoluted pathway for over-wash significantly reduces the risk of any issue at this location.

4. The dog track. This track crests at around 5.3m AHD about 50m from the current dune scarp. In this case, the orientation of the track (ENE-WSW) is not aligned with the dominant SE swell direction and the pathway for overland flow of water is narrow and through a relatively heavily vegetated area. There is minimal risk of high volumes of over-wash through this route.

5. The most northward vulnerability is through a low spot in the dunes south of the Sport and Recreation Centre. The crest of the gaps in the dunes is once again at around 5.3m AHD. The distance between the current dune scarp and the dune crest is also around 50m.

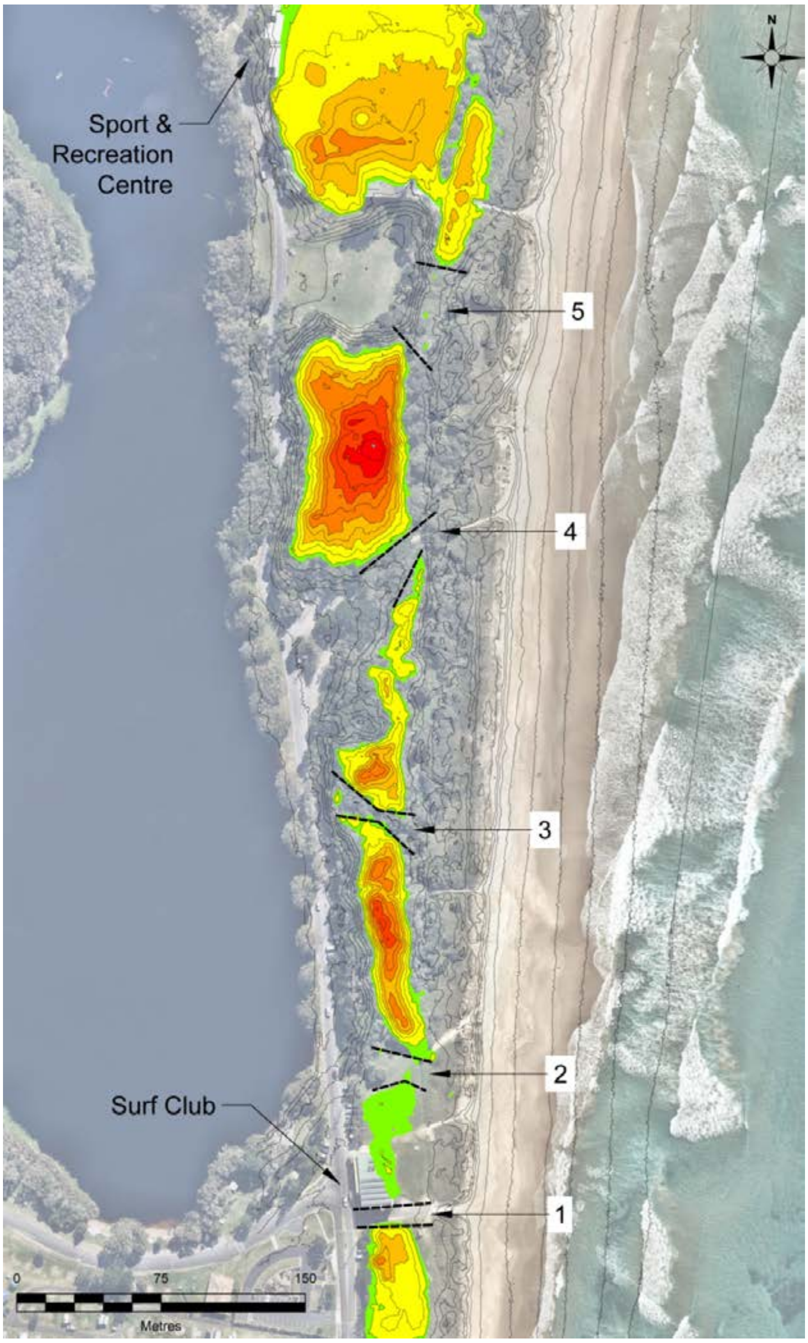


Figure 2: Potential over-wash locations. Coloured regions indicate elevations above +5.75m AHD.

Inspection of these locations indicates that the potential for wave over-wash is generally low, with the greatest risk at the Surf Club access ramp. Given the good accessibility and the proximity to the Surf Club (Plate 1) which itself would also warrant protective measures, a strategy to deploy short-term defences such as sand bags would likely do much to mitigate any current risk associated with wave run-up. Even if over-wash of salt water to the lake did occur, it is likely that this would be for a short period of time, corresponding with high tide. The actual volume of salt water would consequently be low and any negative impacts (e.g. dead grass, minor erosion) likely to be short-term or repairable.

There has been no detailed evaluation of future wave run-up risk associated with sea level rise. The risk will increase, however further work will be required to evaluate critical elevation thresholds and should consider potential shoreline position at that time.

Plate 1: Aerial view of Surf Club and potential over-wash areas 1 and 2.

1.1.5 Coastal Zone Management Plan

The Coastal Zone Management Plan (CZMP) for the Ballina Shire coast between Patches Beach in the south to Seven Mile Beach in the north was certified in 2016. This CZMP (GeoLINK 2016) provides guidance for the management of coastline and focuses on maintaining or improving the ecological, cultural, recreational, and economic values that are exposed to the following coastal hazards:

- Beach erosion, due to offshore movement of sand from the sub-aerial beach during storms or an extreme or irregular event;
- Shoreline recession due to sediment budget deficits (i.e. more sand leaving a beach than entering it) and sea level rise; and
- Coastal inundation, resulting from extreme ocean storm events, overtopping dunes and inundating land behind the dunes.

Lake Ainsworth is not a specific focus of the CZMP, although the CZMP identifies risks to the lake associated with coastal hazards and makes recommendations regarding investigation of the status of the current buried sea walls, sea wall upgrades and beach nourishment. The CZMP recommends protection of landward assets (rather than a 'retreat' option) for the section of coast between Byron Street and the Sport and Recreation Centre.

1.1.6 Additional Measures to the Ballina Coastline CZMP Required to Protect the lake

The coastline CZMP protection strategy is regarded as sound and fully compatible with the on-going management requirements for Lake Ainsworth. Additional measures which should be considered as part of the current CMP are:

1. A response strategy to extreme swell/high water conditions should be formulated to combat the potential for wave run-up and marine over-wash into the Lake Ainsworth basin. It is considered that the only notable risk at current is the Surf Club access ramp area and that a short-term emergency response in this area would be feasible and effective.
2. The coastline CZMP suggests that any sea wall option protecting Lake Ainsworth could be located further landward than in other areas, however it would be advantageous to protect as much of the dune system as practical, for ecological, aesthetic and risk mitigation purposes. Therefore a more easterly alignment is advocated.
3. Further analysis and correction of discrepancies in recent LiDAR data to ensure an accurate monitoring of coastline sand reserves to the east of Lake Ainsworth. For future acquisition, particular focus should be placed on proper discrimination and classification of LiDAR returns to ensure appropriate analysis can be undertaken.

1.2 Flood Hazard Assessment

Localised flooding has previously occurred within the catchment as a result of extreme wet weather events, resulting in elevated lake levels that impede access and recreational activities, impact water quality, inundates surrounding infrastructure, and hinders access to the Sport and Recreational Centre. Such events are likely to continue into the future and may be exacerbated by factors such as increased storminess, sea level rise or changes in hydraulic conductivity of the lake sediments. The Lake Ainsworth Management Plan (GeoLINK, 2002) outlines management actions which aim to mitigate the effects of flooding which involves the placement or replacement of new/ existing recreational facilities above prolonged inundation levels. The Lake Ainsworth Foreshore Improvements Review of Environmental Factors (REF) (DAC Planning, 2016), is consistent with the recommended management actions outlined in the current management plan (GeoLINK, 2002).

To assist in future management of flooding the following tasks were completed:

- Review of previous water level data;
- Determine historical water level maxima in relation to rainfall and flooding events, considering historical stakeholder recollection of events; and
- Field assessment of lakeside infrastructure within potential impact levels.

1.2.1 Review of lake water levels

Manly Hydraulics Laboratory (MHL) has collected water level and rainfall data continuously (every 15 minutes) at Lake Ainsworth since 30th September 1994 as part of the NSW Coastal Data Network Program managed by OEH. In April 2018, temperature and conductivity probes were added to the logger. The data logger is located at the northern end of the lake. Figure 4 shows water level data from Lake Ainsworth against rainfall from 1994 to 2018. Lake water levels are controlled by the balance between inflows (e.g. direct rainfall, surface runoff and groundwater flows) and outflows (e.g. evaporation and groundwater flow predominantly to the east, through dunes to the sea). Figure 4 suggests that rainfall has a large influence on water level, with higher water level in the lake experienced during wetter years and lower levels during drier years. The relationship between average annual lake levels and annual rainfall is graphed in Figure 5, showing a positive correlation. Between 2009 and 2018 there has been a period of consistently higher water levels in the lake than what was experienced in the 15 years prior and this has raised concerns in the community that lake outflows have reduced. This is explored further through the water balance model presented in Section 2.2.

Plate 2: Water level logger deployed at northern end of Lake Ainsworth managed by MHL/OEH

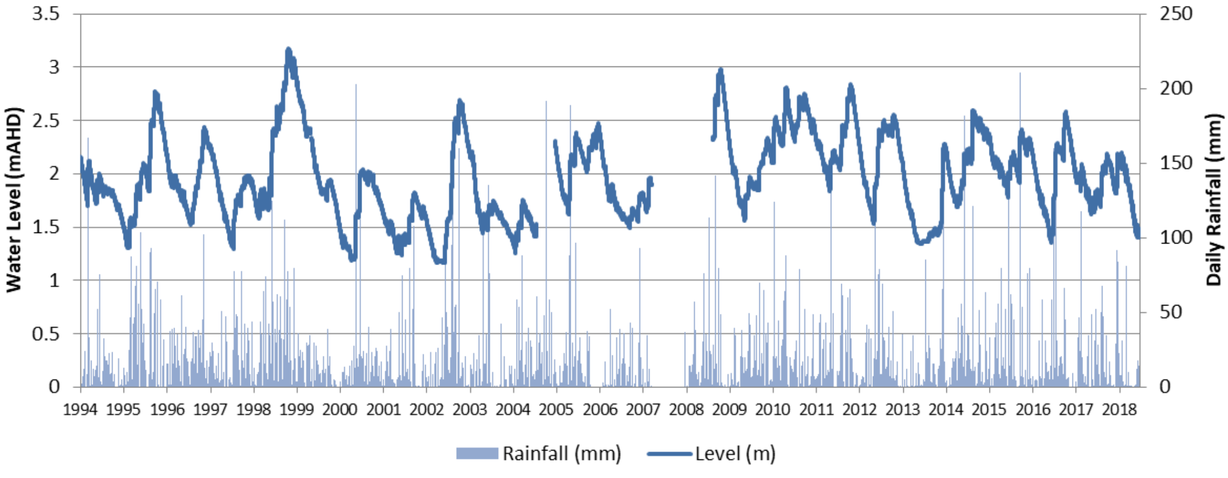


Figure 3: Lake Ainsworth water level data, recorded every 15mins against daily rainfall 1994-2018.

*Note: There was no logger data recorded from May - August 2005 and from December 2007 to May 2009.

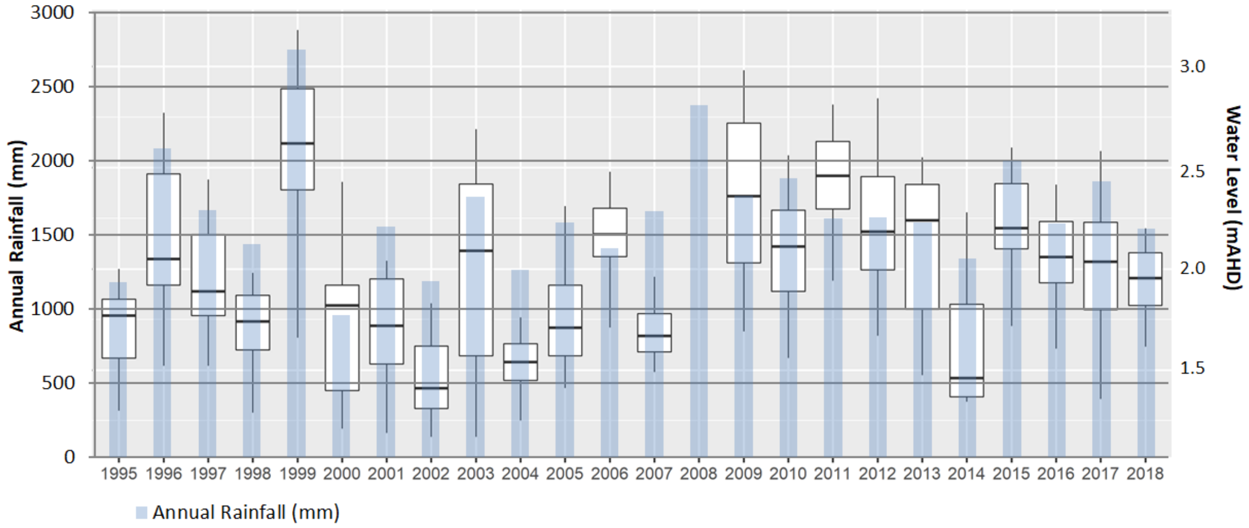


Figure 4: Lake Ainsworth annual water level variation. Box plots show the range of water level each year, the line in the middle of the box equates to the most frequently experienced water level.

*Note: No logger data was recorded between 6/12/2007 and 7/5/2009. Rainfall data substituted from BOM during this time.

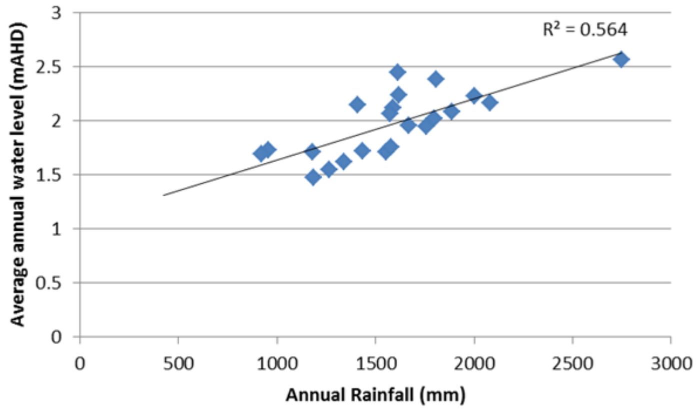


Figure 5: The relationship between water level and rainfall at Lake Ainsworth

Seasonal Variation

By comparing the monthly range of water levels across the period of record (Figure 6), it was possible to see very clear seasonal patterns emerging. Water level is generally lowest in the summer months (median level of approx. 1.7m AHD in January), steadily increasing to maximum levels in winter (median level of approx. 2.3m AHD in August). Reducing levels in the last half of the year can be largely explained by reducing inflows (lower rainfall) occurring from July to December and increasing outflows (increased evaporation) as the weather warms through spring and summer. Lake levels begin to increase again as higher rainfall occurs from January to June (Figure 7).

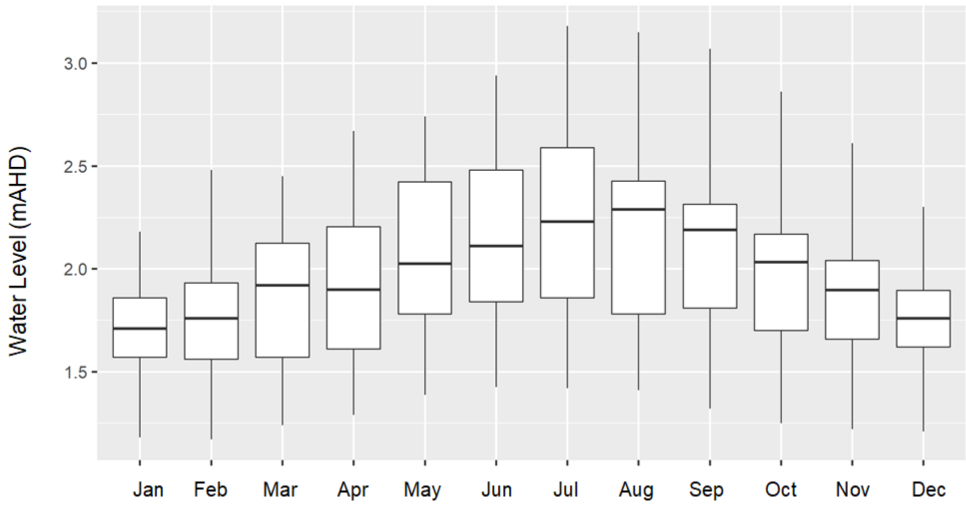
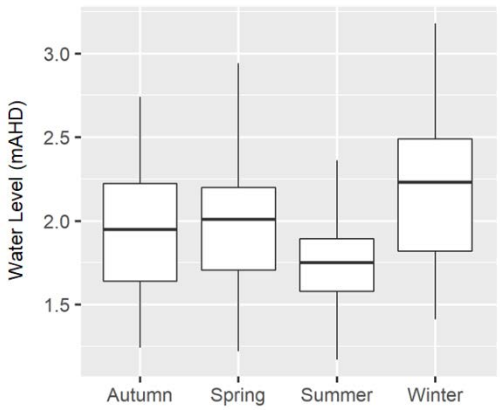


Figure 6: Lake Ainsworth inter-annual water level variation (all data from 1994-2018)



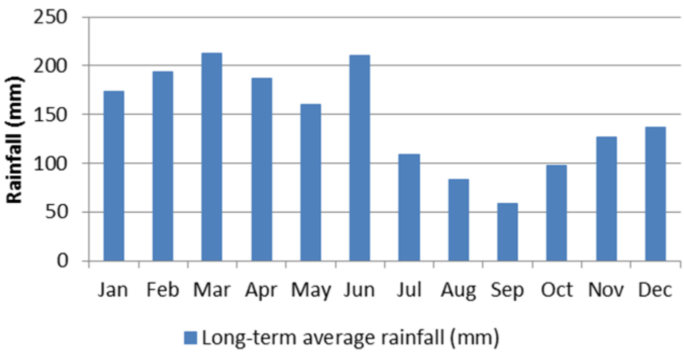


Figure 7: Left - Lake Ainsworth seasonal water level variation (all data from 1994-2018); Right: Average monthly rainfall totals (1993-2018) (Source: BOM, 2018).

1.2.2 Historical maximum water levels

The highest water level on record occurred in 1999, when the lake reached a peak of 3.18m AHD in July of that year (Figure 8). This coincided with the highest recorded annual rainfall total of 2749mm (Figure 4), well above the long-term average of 1842mm for Ballina (BOM, 2018). Figure 9 plots 1999 monthly rainfall against long-term average and median monthly rainfall at Ballina Airport AWS, showing a particularly wet year, and especially high rainfall in June and July. Flooding occurred around the lake in July 1999, resulting in closure of the Eastern Road, flooding of the boat shed at the Sport and Recreation Centre and foreshore picnic areas (Plate 3). Flooding events will continue to occur in response to extreme weather and may be exacerbated by climate change including factors such as increased storminess, sea level rise or changes in lake hydrology such hydraulic conductivity of the lake sediments.

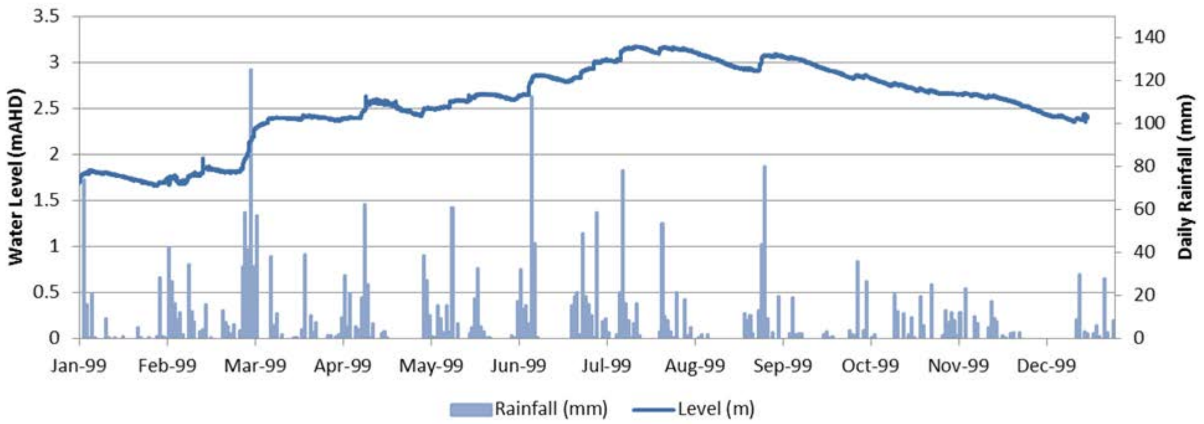


Figure 8: Lake Ainsworth water level variation over 1 year (Jan-Dec 1999) against daily rainfall, showing gradual increase to a peak water level in July at 3.18m AHD (highest level recorded to date).

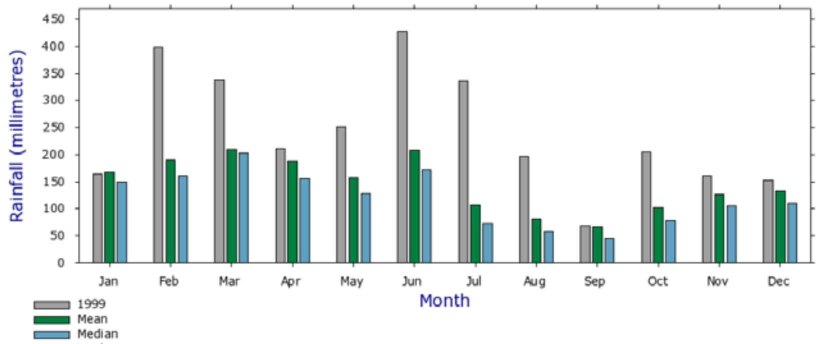


Figure 9: Monthly rainfall data for 1999 plotted against long-term average and median rainfall at Ballina Airport AWS (Source: BOM, 2019)

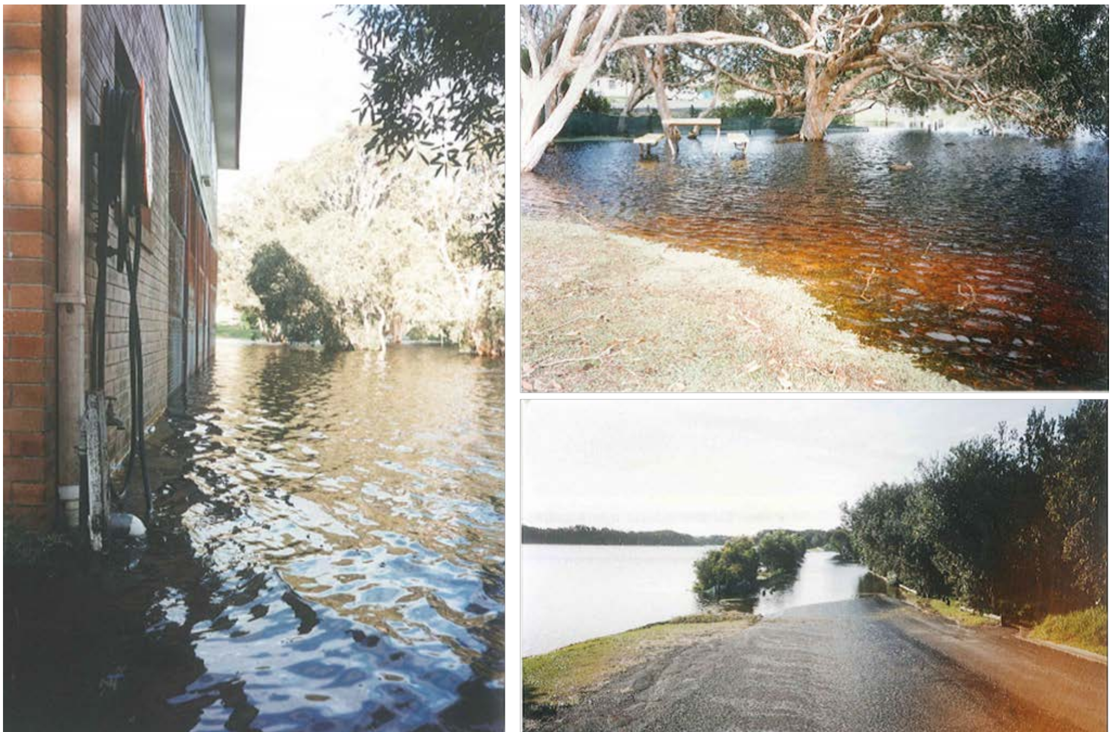


Plate 3: Flooding around the lake in June/July 1999 – Left: Sport and Recreation Boat Shed; Top Right: picnic area in south east corner; Bottom Right: Eastern Road (Source: BSC, 1999)

1.2.3 Potential for hydrological changes due to climate change

The key projected impacts of climate change for the East Coast of Australia (southern district) are presented in Table 1. All aspects have the potential to impact on both the mean water level and extreme water level events in the lake.

One of the main losses of water from the lake is through groundwater flow towards the ocean (AWACS 1996, estimated an average of 39% of losses were through groundwater outflow through the dunes with the remaining 61% through evaporation). This outflow is dependent on sea levels being low enough to create adequate hydraulic gradient and allow for net groundwater outflow from lake to sea. AWACS (1996) monitored a series of groundwater bores through the dunes between the lake and sea in 1995 and noted that the hydraulic gradient from the lake to the ocean can temporarily reverse during high tides and storms, thus confirming this link. Sea level rise therefore, has the potential to increasingly restrict the volume of outflow via groundwater from the lake and therefore increase average lake water levels into the future.

Increases in average temperatures and extreme temperature events are also predicted with very high confidence and this has potential to increase losses via evaporation, thus reducing lake levels.

Rainfall projections are less clear, with the CSIRO predicting drier winters, but potential for either drier or wetter overall rainfall conditions in the local area (refer Table 1). An increase in the intensity of extreme rainfall events is predicted with high confidence which could increase the potential for flooding events.

Considering the information currently available, a range of scenarios are possible. An average increase in mean sea level coupled with an increase in extreme rainfall and sea-level events, suggests average lake levels may rise in the future and the risk of future flooding events (both in frequency and magnitude) will also increase. Conversely, increasingly dry winters with increased temperatures may result in occasional periods of low lake levels during the latter half of the year than previously seen. The CMP will therefore need to consider the range of potential future climate scenarios across all management actions.

Table 1: East Coast (Southern) Projection Summary (Source: Adapted from CSIRO, 2019)

Climate factor	Projection	Confidence level
Mean Sea Level	Mean sea level will continue to rise	Very high confidence
Extreme Sea level Events	Height of extreme sea-level events will increase	Very high confidence
Average Temperatures	Average temperatures will continue to increase in all seasons	Very high confidence
Extreme Temperature Events	More hot days and warm spells are projected	Very high confidence
Average Rainfall	Decreases in winter rainfall	Medium confidence
	Other changes are possible but unclear and CSIRO notes this region should consider the risk of both a drier and wetter climate.	
Extreme Rainfall and Drought	Increased intensity of extreme rainfall events is projected	High confidence
	Time spent in drought to increase over the course of the century.	Medium confidence

1.2.4 Assessment of lakeside infrastructure within potential impact levels

The statistical range of historical water levels from 1994-2018 is provided in Table 2. Average lake levels are at approximately 2m AHD. The lowest lake levels on record were experienced during the 2001/2002 drought when levels reached as low as 1.17m AHD. As discussed above, a maximum level of 3.18m AHD was reached during the July 1999 flood.

Table 2: Statistical range of historical water levels (1994-2018)

Water level (m AHD)	%ile	Notes
1.17	0	Coinciding with 2001/2002 drought
1.66	25	
1.92	50	Most frequently occurring levels around 2m AHD
2.26	75	
2.50	90	
2.95	99	
3.18	100	1999 Flood coinciding with above average rainfall

While the exact influence of sea level on the levels in Lake Ainsworth is not known, the current IPCC predictions of sea level rise by 2100 relative to 1986-2005 provide a guide for potential future flood risk due to sea level rise. The predictions comprise increases of up to 0.44m (low emission scenario); 0.54m (medium emission scenario); and 0.74m (high emission scenario) above mean sea level (IPCC, 2013; Figure 10). Figure 11 shows the 1999 flood area and potential flood areas for 2100 generated using Coastal Risk Australia Interactive Map Tool (Coastal Risk Australia, 2019) and provides an overview of the potential future flooding risk. As an initial assessment, the potential maximum flood risk for 2100 Lake Ainsworth has been approximated by adding the potential high emission sea level rise scenario to the maximum observed water level from 1999 flooding (3.18m AHD) and Figure 11 illustrates the potential flooding impacts that would occur in 2100 under the different sea level rise scenarios if the lake experienced the same weather conditions experienced in 1999. All lakeside infrastructure at or below the flood risk contours are at risk of future lake flooding and are detailed in Table 3 and mapped in Figure 12 and Figure 13.

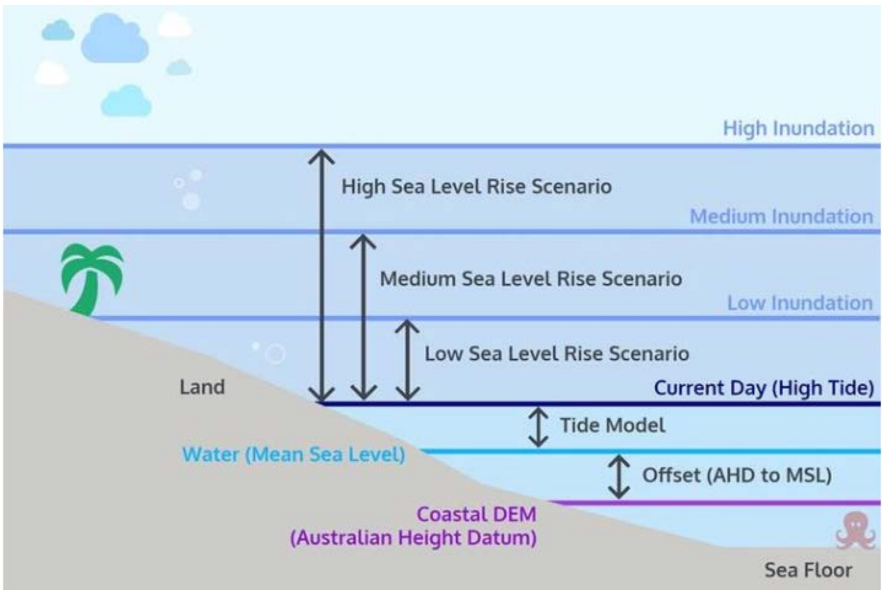
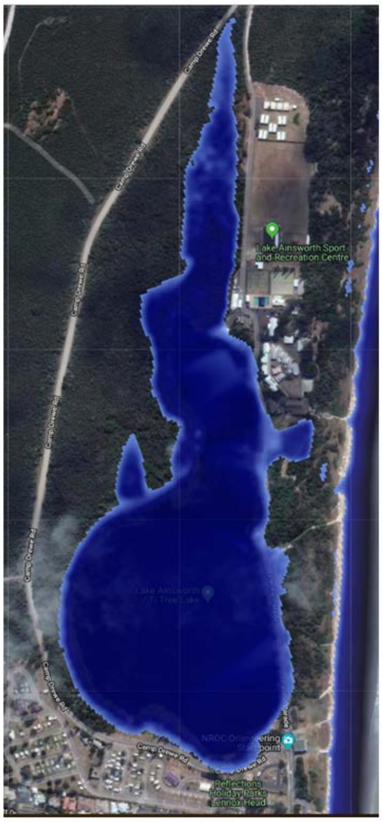


Figure 10: Coastal Risk Australia Interactive Map Tool methods for estimating inundation height – not to scale (Coastal Risk Australia, 2019).

a) 1999 flood (3.2m AHD)

b) Potential 2100 flood – Low SLR (3.6mAHD)



c) Potential 2100 flood – Med SLR (3.7mAHD)

d) Potential 2100 flood – High SLR (3.9m AHD)

Figure 11: a) 1999 actual flood area; and potential 2100 flood risk for b) Low; c) Medium; and d) High sea level rise scenarios (Source: Generated manually using Coastal Risk Australia Interactive Map Tool, March 2019).

Table 3: Lakeside infrastructure currently at or below the projected 2100 flood risk area.

Map ref.	Infrastructure	Location	Land Manager	Mitigating design elements
1	Lake View Conference Room and Aquatic Storage Shed	Northern end	NSW Office of Sport	Raised floor level
2	Covered BBQ area with picnic tables	Northern end	NSW Office of Sport	Outdoor facility
3	Internal roads within Sport and Recreation Centre	Northern end	NSW Office of Sport	Able to withstand short-term flooding – road closure probable, surface damage possible
4	Sewerage Pump Station	Northern end	BSC	none
5	Eastern Road	Eastern Foreshore	BSC	Able to withstand short-term flooding – road closure probable, surface damage possible
6	Electricity poles/lines	Eastern Foreshore	BSC	Able to withstand short-term flooding
7	BBQ Shelter, picnic tables	Southeast	BSC	Outdoor facility
8	Small section of Camp Drewe Road	Southeast	BSC	Able to withstand short-term flooding – road closure probable, surface damage possible
9	Covered picnic tables	Southern end	BSC	Outdoor facility

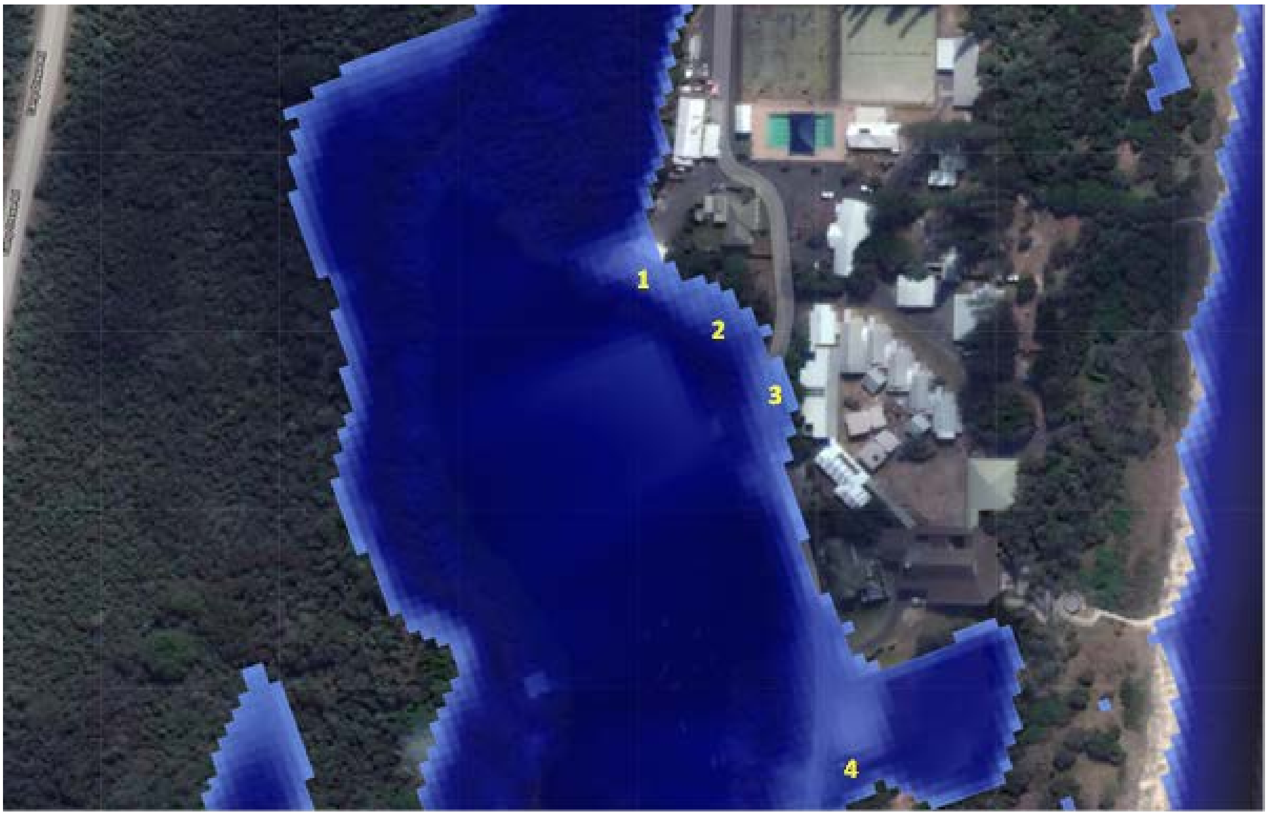


Figure 12: Infrastructure currently at or below the potential 2100 flood risk area (high emissions scenario), northern end of the lake (Source: Generated using Coastal Risk Australia Interactive Map Tool, March 2019).

Figure 13: Infrastructure currently at or below the 2100 potential flood risk area (high emissions scenario), southern end of the lake (Source: Generated using Coastal Risk Australia Interactive Map Tool, March 2019).

1.3 Foreshore erosion hazard assessment

Foreshore erosion is evident along large sections of the Lake Ainsworth foreshore. The Lake Ainsworth Community Survey identified that bank erosion was the 2nd most important issue after algal blooms with 62% of respondents concerned about this issue (refer Section 6.4), The major factors affecting bank stability are: historical clearing of riparian vegetation; changes in lake water level; waves generated by wind and boats; human access; and overland flows/ run-off /stormwater particularly from hard surfaces such as roads and parking areas in close proximity to the lake foreshores. Bank erosion is linked to several other issues that have been identified including water quality, aesthetics, public amenity and safety, and biodiversity.

1.3.1 Desktop Assessment

The aim of the desktop assessment was to identify built assets such as buildings or roads that are currently or may be potentially threatened by areas of existing bank instability. This was be done by evaluating the proximity of built features to existing areas of bank instability. No prediction of future areas of instability (e.g. due to sea level rise) was undertaken, as key factors such as future lake levels, sediment budget and future riparian condition are not known at this time. Areas of erosion mapped from field survey work were then compared to:

- Aerial photo identification of built assets (e.g. roads, parking, public facilities, water and sewer pipelines, buildings etc. (within 5m of current bank);
- Land tenure and land use; and
- Field notes and photographs;

Details for each section were noted and added to the Foreshore Condition Database (Appendix 1).

1.3.2 Field surveys

Longitudinal field surveys were undertaken for all banks of Lake Ainsworth in December 2018. Banks were divided into sites and categorised in terms of erosion severity according to the classes described in Table 4. Site locations are provided in Figure 16.

Table 4: Erosion categories assigned during field investigation

Erosion Category	Description
Controlled	Erosion controls have stabilised erosion
Stable	No visible evidence of erosion, intact riparian vegetation
Minor	Some evidence of minor erosion (e.g. exposed roots or trees undercut less than 25% of total) Erosion face is approximately <0.1m in height
Moderate	Greater level of erosion than ‘minor’ (e.g. exposed roots or trees undercut 25% to 75% of total); Erosion face is between approximately 0.1 and 0.5m in height
Severe	Greater level of erosion than ‘moderate’ (e.g. exposed roots or trees undercut more than 75% or riparian vegetation absent); Riparian vegetation absent or many trees are destabilised (falling into water); Erosion face is ≥ 0.5m in height Erosion face in generally exposed soil/sand with no vegetative or hard (artificial) cover and actively eroding.

Information for each site was recorded including:

- The major causes of erosion (e.g. stormwater runoff, bank clearing, human access etc.);
- A description of each site (e.g. bank shape, slope, length, height of erosion scarp, tree root exposure/undercutting etc.);
- Riparian vegetation condition, extent and degree of shading of water;
- Any existing physical controls/mitigation measures;
- Adequacy of existing control measures;
- Any significant natural or built assets potentially affected by bank instability currently or in the near future if erosion continues;
- Community access points affected by bank instability;
- An assessment of public safety risk; and
- Photographs were taken of each section for later verification of characteristics.

Note that this was undertaken as a rapid visual assessment and does not include any detailed analysis of the mechanisms of instability, sediment budgets, rates of erosion, etc.

Following the field investigation, foreshore erosion categories were mapped on GIS and all observations and notes recorded in the Foreshore Condition Database (Appendix 1).

1.3.3 Observed erosion

A number of factors were noted as contributing to bank erosion at Lake Ainsworth. Natural erosion processes are the key driving forces which are accelerated in many places by human impacts. Water level changes and wind driven wave action are primary natural causes of erosion at the lake but this is exacerbated by pedestrian access and stormwater runoff, particularly from the southern and eastern roads and parking areas. Much of the severe erosion observed at the lake occurred along the southern and eastern extents at heavily utilised access points, with little or no riparian vegetation and evidence of stormwater runoff scouring the banks (Plate 4). One of the most heavily trafficked access points in the south-eastern corner of the lake, is somewhat protected by mature Broad-leaved paperbark trees holding the banks together, although the trees have been severely undermined by erosion, with a high level of root exposure and many showing signs of poor health most likely as a result of excessive root exposure (Plate 5). Erosion issues are less prominent along the western shoreline, where riparian vegetation is largely intact, stormwater is not an issue and numbers of people accessing the foreshore is generally less.

Plate 4: Left - Carpark areas in south-east corner opposite Lennox SLSC showing areas of scour due to stormwater runoff from hard surfaces; Right - Erosion Site 7, downslope of the carpark.

The location and classification of observed erosion for each site is shown in Figure 16. Corresponding details for each labelled section can found in the Foreshore Condition Database (Appendix 1). Table 5 presents a summary of the results as total length of bank and percentage of bank classified in each erosion category. Figure 14 presents the results graphically.

Of the total length surveyed, approximately 2% (54m) of the lake's banks were classified as having severe erosion, comprising two sites: Site 1 at the south-west corner; and Site 7 in the south-east corner. Both sites experience heavy foot traffic, are largely devoid of riparian vegetation and experience impacts from stormwater runoff from adjacent roads and parking areas. Moderate erosion accounted for 9% (238m) of banks, the majority of which was located along the eastern foreshore as a series of small inlets with no riparian vegetation and subject to high pedestrian use and stormwater runoff from the eastern road. Site 22 located at the Sport and Recreation Centre boat launching area, and Site 6 in the south-east corner were also classified as having moderate erosion. Mature trees along the shoreline at both sites provide some mitigation against ongoing erosion, however a high degree of root exposure due to erosion and trampling is compromising tree health at both locations. Minor erosion was present along 22% (559m) of the foreshore and these sites were generally vegetated foreshores where access was restricted along the eastern side of the lake. Several sites with minor erosion were located between the moderately eroded inlets and demonstrate the effectiveness of past revegetation works on controlling erosion, compared to the inlets with no vegetation. Vegetated areas preclude pedestrian access but also lead to a concentration of trampling impact in adjacent areas.

Approximately 65% (1.6kms) of the lake's banks were considered to be stable, comprising the majority of the western foreshore, northern section and vegetated sections of the southern foreshore. These sites experience much less foot traffic than other sites, are well-vegetated (often with aquatic macrophytes extending into the water providing further protection from wave action) and generally have only minor stormwater impacts, if any. At the time of the field assessment, erosion at Site 3 and Site 5 on the southern foreshore had recently been controlled with a trial of sand nourishment and small-scale geofabric sills. This comprised 1% (32m) of the lake's foreshores.

Table 5: Bank condition summary for Lake Ainsworth

	Total length surveyed (m)	Stable (m)	Controlled (m)	Minor (m)	Moderate (m)	Severe (m)
Lake Ainsworth	2,521	1637 (65%)	32 (1%)	559 (22%)	238 (9%)	54 (2%)

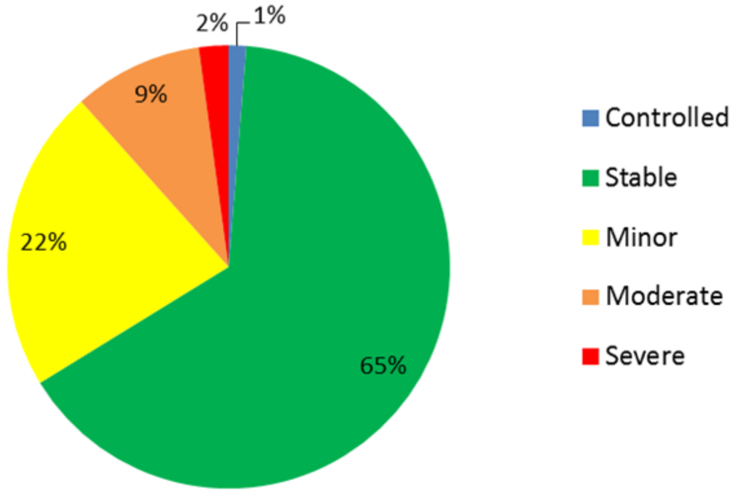


Figure 14: Proportion of bank condition for Lake Ainsworth

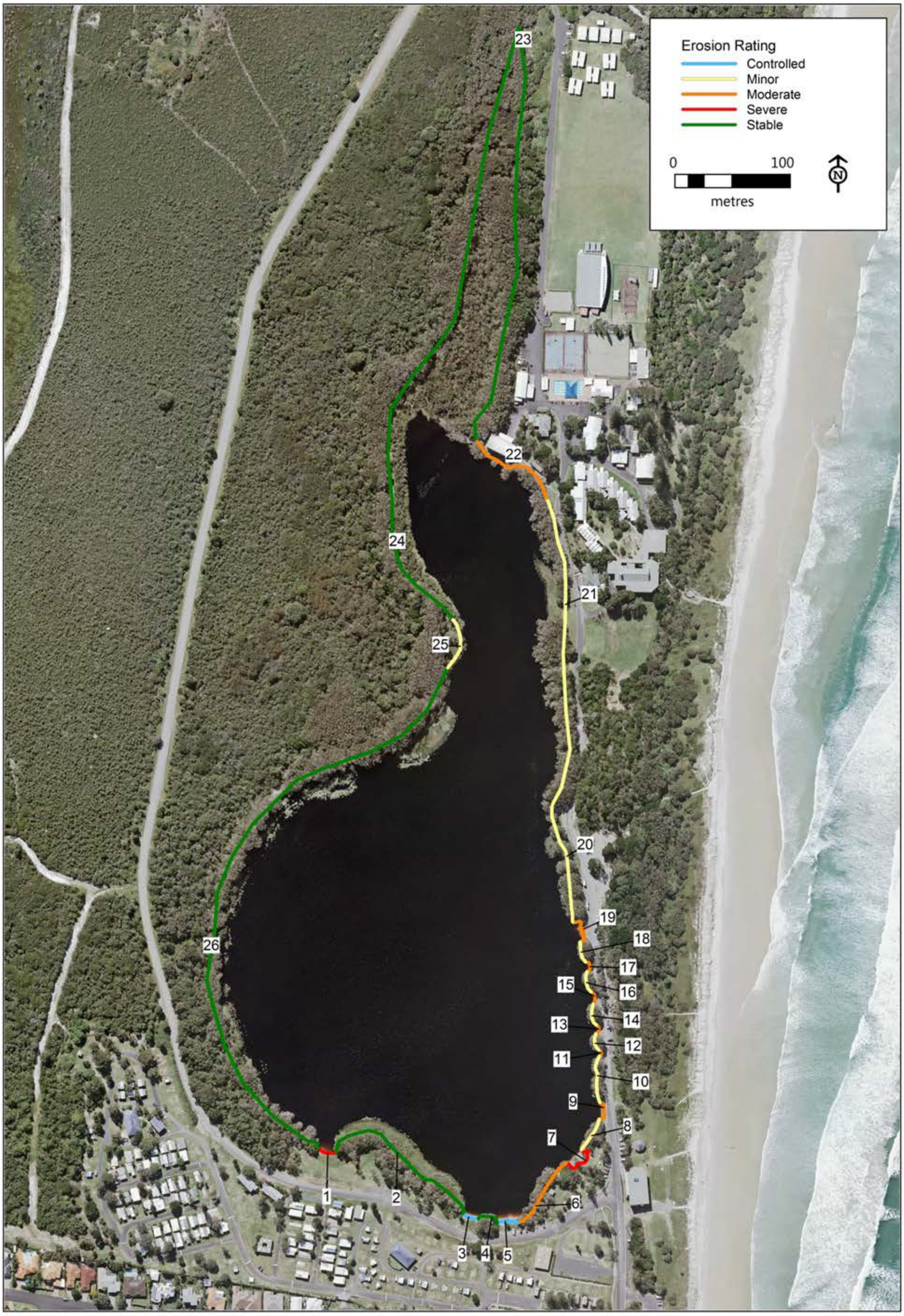


Figure 15: Bank erosion ratings assigned during field assessment December 2018

1.3.4 Priority erosion sites

Erosion sites were prioritised for management action by combining three key factors:

- Observed erosion severity;
- Foreshore access safety risk (results presented in Section 6.6, Public Safety Assessment); and
- Potential of erosion to impact built assets around the lake.

Table 6 shows the resultant priority rank for all sites and their locations are mapped in Figure 16. The highest priority sites (Priority 1) comprised a series of small inlets all located along the eastern shoreline and constrained by the eastern road. These all displayed moderate erosion ratings and very high public safety risk due to proximity to the road (refer Section 6.6) and were within close proximity to built assets that could be impacted by continued erosion (the road, water mains etc.). Priority 2 sites were all located at access points with high frequency pedestrian use on the south-west foreshore, south-east corner and along the northern shoreline at the Sport and Recreation Centre. These displayed moderate to severe erosion with high safety risk and some within close proximity of built assets. Priority 3 sites were generally vegetated foreshores along the eastern and southern extents where access was restricted, safety risk was low and erosion was minor or controlled. These sites were all in close proximity to built assets, but the potential for these assets to be impacted was reduced due to the minor erosion observed. Priority 4 and 5 sites had minor, stable or controlled erosion, low or medium safety risk and no built assets under immediate threat from erosion. These sites were located along the relatively undisturbed northern arm and western foreshores and also vegetated foreshores along the south and south-east foreshores.

Plate 5: a) Priority 1 erosion at site 9, in close proximity to the eastern road; b) Priority 2 erosion at site 6 showing Broad-leaved paperbark trees severely undermined by erosion leading to root exposure; c) Priority 2 erosion at site 7 showing vertical erosion scarp at south-east corner access point. Broad-leaved paperbark trees showing signs of poor health due to root exposure; d) Priority 4 erosion at site 26 showing stable, vegetated banks and aquatic macrophytes.

Table 6: Erosion Priority Ranking (ranked in order of priority from highest to lowest)

Erosion Site Priority Ranking	Site	Erosion Rating	Foreshore Access Safety Risk	Built assets within 5m
1	9	Moderate	Very High	Yes
1	11	Moderate	Very High	Yes
1	13	Moderate	Very High	Yes
1	15	Moderate	Very High	Yes
1	17	Moderate	Very High	Yes
1	19	Moderate	Very High	Yes
2	6	Moderate	High	Yes
2	22	Moderate	High	Yes
2	1	Severe	High	No
2	7	Severe	High	No
3	10	Minor	Low	Yes
3	12	Minor	Low	Yes
3	14	Minor	Low	Yes
3	16	Minor	Low	Yes
3	18	Minor	Low	Yes
3	20	Minor	Low	Yes
3	21	Minor	Low	Yes
3	5	Controlled	Medium	Yes
4	26	Stable	Medium	No
4	8	Minor	Low	No
4	25	Minor	Low	No
4	3	Controlled	Medium	No
5	2	Stable	Low	No
5	4	Stable	Low	No
5	23	Stable	Low	No
5	24	Stable	Low	No

Figure 16: Location of priority erosion sites at Lake Ainsworth, assessed December 2018

1.3.5 Future bank recession due to climate change

Climate change impacts including sea level rise, increasing temperatures and an increase in extreme rainfall and sea-level events has the potential to increase the rate of lake water level variation into the future (refer Section 1.2.3). This will expose more of the lakes' banks to erosive forces, thereby potentially exacerbating the erosion of susceptible banks resulting in shoreline retreat. Management actions will therefore need to be adaptive to the changing shoreline.

1.3.6 Management options

Past and present management techniques

Various techniques have been used to manage foreshore erosion at the lake over the years including:

- Retaining walls placed along the shoreline including: large square-cut timber logs shown in Plate 6 (a) from 1953 along the eastern foreshore (some are still present and visible today when water levels are low); and a timber retaining wall installed in 2000 which is no longer at this location (Plate 6, b).
- Dredging of sand from the eastern side of the lake to nourish beaches along the lake's foreshore in the early 1990's (Plate 6, c). Some areas were turfed to stabilise the sand and control erosion.
- Riparian plantings and fencing in mid-90's, which are still present and have been shown to be effective in controlling erosion (Plate 6, d).

Plate 6: a) Log revetment in 1953 along eastern shoreline; b) timber retaining wall installed in 2000; c) eastern shoreline following dredging and beach nourishment 1992; d) Revegetation and fencing of eastern shoreline early to mid-1990's.(Source: Images courtesy of the Lennox Head Heritage Committee)

The Lake Ainsworth Management Plan (2002) recommended the following actions with regard to addressing erosion:

- Restrict vehicular and pedestrian movements to specific areas to minimise damage to riparian vegetation;

- Prohibit foreshore parking and provide designated parking areas;
- Continue and enhance current riparian flora management strategies;
- Treatment/redirection of runoff from road/parking areas through filter swales to slow flow velocities and reduce erosion.

Some of these actions have been implemented, or are planned to be addressed as part of the Foreshore Improvement Works currently underway at the lake. This includes restriction and formalisation of traffic and parking and stormwater management. However, due to the severity of erosion observed at some sites, and identified safety risks, further ameliorative management action is required to reinstate safe access points and protect banks from ongoing erosion.

Assessment of potential foreshore erosion management options

A range of management options can be employed to address erosion. Table 7 summarises bank erosion management options identified from the literature giving an overview of the range of erosion management options available.

Table 7: Summary of bank erosion management options identified

Strategy	Definition
Engineering approaches	
Armouring	Placement of a structure designed to maintain the slope or protect it from erosion
Battering	Involves removing vertical sections of eroded banks and reducing the slope where possible
Renourishment	Involves replacing foreshore sediment (usually sand) lost through erosion
Reshaping	Smoothing eroded banks without cutting material or disturbing existing native vegetation
Managed retreat	Permits bank erosion to continue, while managing any safety or environmental concerns
Complimentary works:	
Revegetation	Re-establishing local native vegetation to stabilise bank sediments by generating a network of roots and partially absorbing wave and current forces
Manage access	Involves rationalising and formalising pedestrian access to control access to banks. May involve fencing or other structures
Stormwater control	Direct stormwater to treatment areas to slow water flow and reduce erosive potential

Based on the foreshore erosion and public safety risk assessment and considering feedback from the community (refer Section 6.4), potential management options for Lake Ainsworth should aim to:

- Provide safe access points to the lake;
- Provide sandy recreational beaches, focussing on the high-use areas in the south-east corner, eastern and southern foreshore; and
- Minimise the frequency of repeat sand management works wherever possible.

Table 35 in Section 7 presents a preliminary assessment of the potential effectiveness of various management options at Lake Ainsworth. Options recommended for further consideration will be assessed in detail as part of Stage 3 of the CMP: Response Indication and Evaluation.

2. HYDROLOGY/GROUNDWATER

2.1 Hydrographic survey

Detailed hydrographic survey of the lake was undertaken in July 2018 (Figure 17). The central southern section of the lake is approximately 300m wide, and currently has a maximum depth of around 7.5m below AHD, which equates to approximately 9m water depth at average lake levels. The northern section of the lake is narrower (50-100m wide) with a central channel of around 2m below AHD (approx. 4m depth) at the deepest point getting progressively shallower to the north. Around the perimeter of the lake sandy beaches grade with varying slopes into deeper water. Shallow sandy shoals are evident extending from the north and south shorelines at the midpoint of the deep central basin, while steep drop-off points are present along the eastern foreshore.

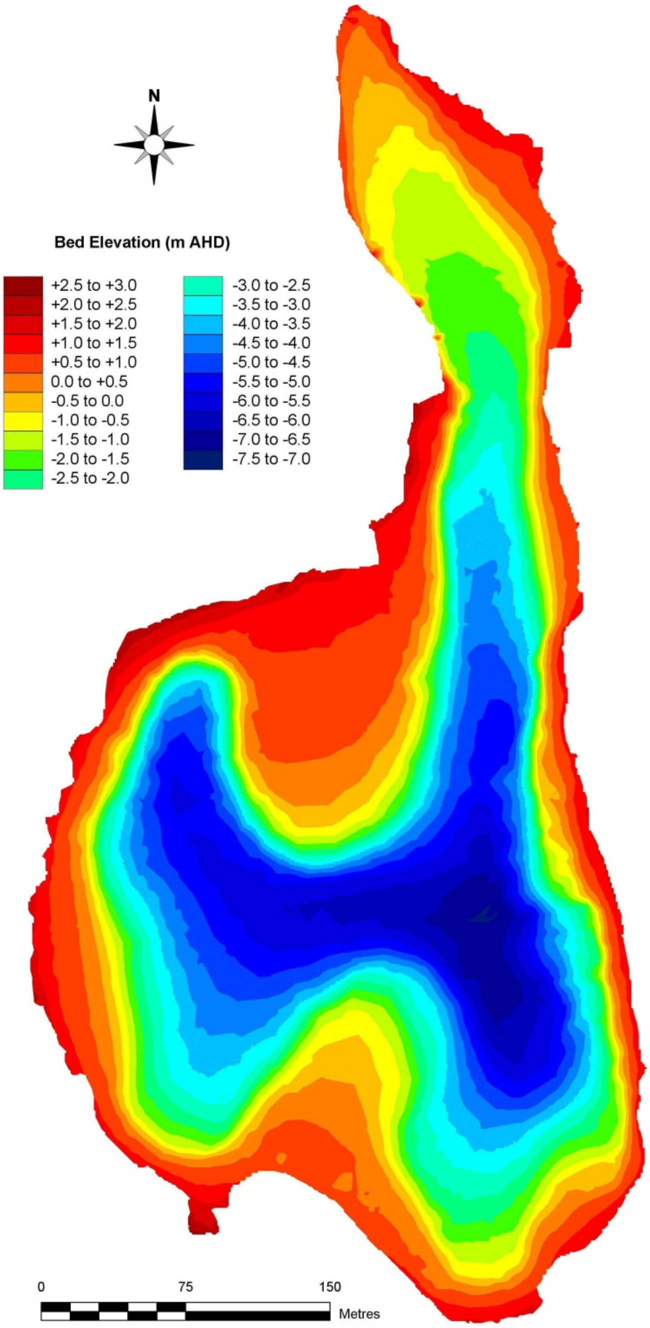


Figure 17: Hydrographic survey showing bed elevation relative to AHD.

2.2 Water balance model

A detailed assessment of the lake's water balance was completed as part of the 1996 Processes Study (AWACS, 1996). The lake water volume and water level are determined by a balance between inflows to the lake (direct rainfall, surface runoff and groundwater flows) and outflows (evaporation and groundwater discharge eastward through the dunes to the ocean). These elements are shown in Figure 18 below.

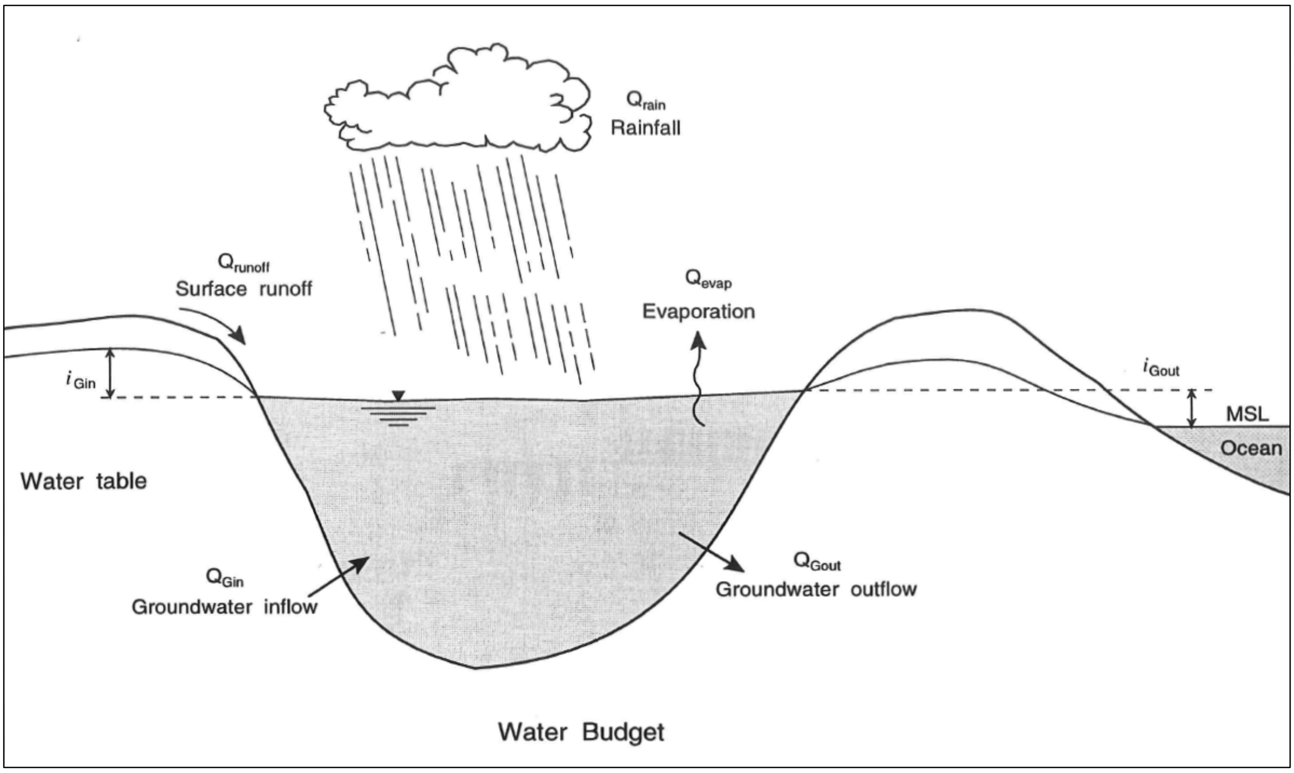


Figure 18: Water Budget schematic diagram (Source: AWACS, 1996)

Figure 19 provides a geological cross-section (from west to east) of Lake Ainsworth showing the local geology and sediments. AWACS (1996) determined that below a level of about -4 m AHD the benthic sand becomes indurated with humic matter that significantly reduces groundwater flows. The majority of groundwater flow therefore occurs in the Woodburn sand aquifer above the level of -4m AHD and generally from west to east towards the ocean, allowing flushing of lake water through the dunes when sea levels are sufficiently low.

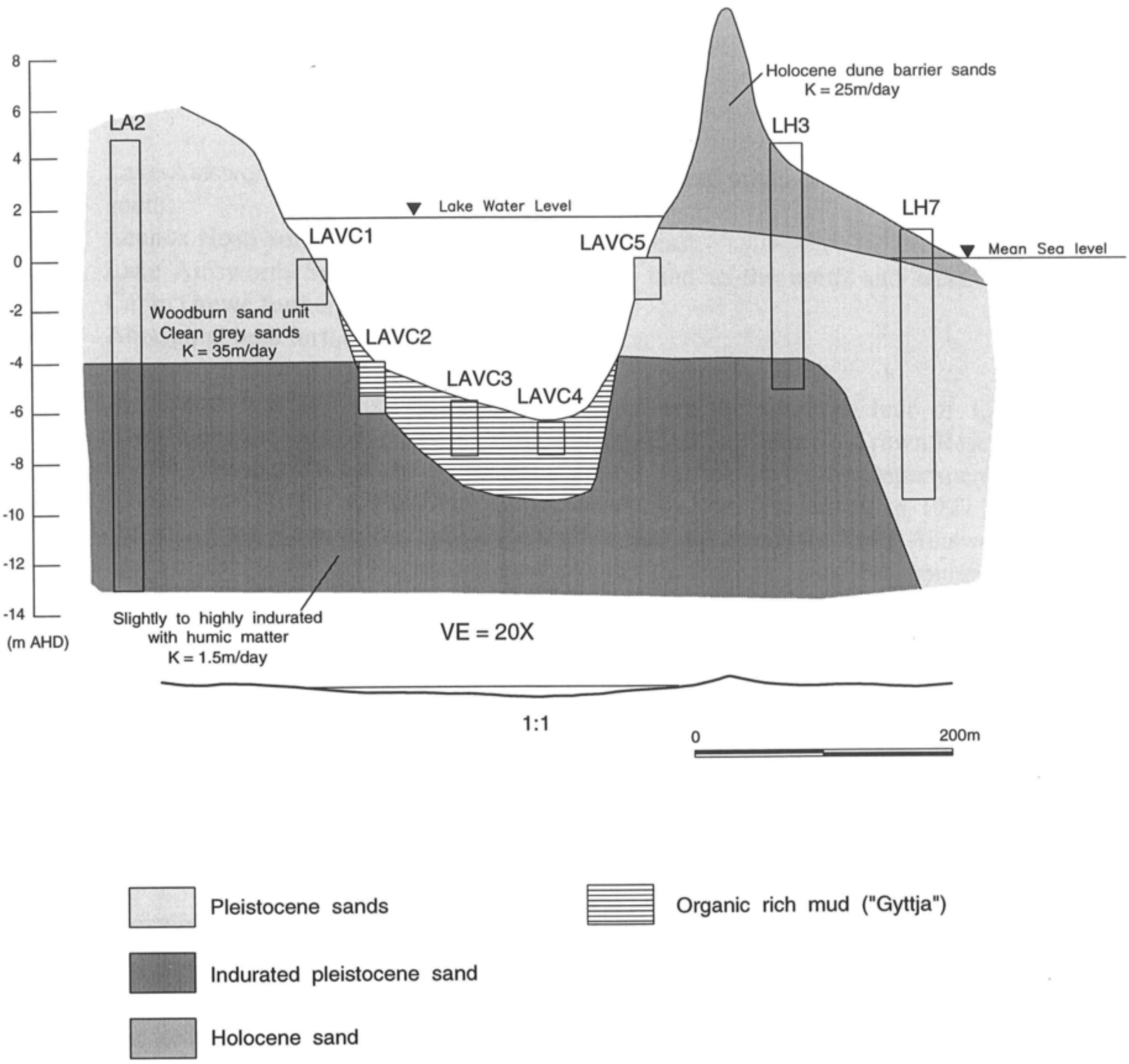


Figure 19: Geological cross section of Lake Ainsworth (Source: AWACS, 1996). Note that the vertical scale has been exaggerated 20x to clearly show the geological features.

More recently, Milner (2017) applied a modification of the AWACS methodology to periods of water level draw down in 1995/1996 and 2015/2016 and compared results to assess changes in outflow from the lake between the two time periods. Milner (2017) concluded that in 2015/2016 there was a significantly lower flow through the dunes than in 1995/1996 and attributed this to reduced hydraulic conductivity resulting from a build-up of clay and silt sediments along the eastern side of the lake.

2.2.1 Updated water balance model

In order to further assess changes to lake outflow, the AWACS methodology was applied to all years with available water level information to estimate groundwater losses for each year from 1996-2017 (note water level data was not available for whole years in 2005, 2007, 2008 and 2009 and these could not be included in the assessment).

Methods

All years of water level data were examined and the water level drawdown period in each year was selected for analysis. Generally, water level drawdown was observed during the last half of each year from around June to December, but this varied from year to year. Evaporation and rainfall data were obtained using the Silo Data Drill service which provides daily interpolated data for a given location based on nearby BOM weather station observations. The updated water balance model was based on calculations derived from AWACS (1996), however because no groundwater monitoring has been undertaken since 1996, it was necessary to simplify the model as per the Milner (2017) study. These estimations should therefore be interpreted as indicative only.

Results

Figure 20 presents the modelled average daily groundwater outflows plotted with annual rainfall totals and observed evaporation. Table 8 provides the key water balance components. The results indicate a high degree of variability in groundwater outflow for the period examined. Groundwater outflow was greatest in 1999 which coincided with above average rainfall and high lake levels which resulted in flooding during July that year (refer Section 1.2.2). High water levels provide a greater capacity for outflow due to increased volumes and a greater differential between lake level and sea levels generating positive eastward flow. Lowest groundwater outflows were experienced during drought conditions from 2000-2002, coinciding with record low water levels in the lake (Figure 4). When water levels are low, there is less capacity for outflow to the sea due to reduced lake volumes and because a larger proportion of water is below -4m AHD where indurated sands geology and organic-rich mud benthic sediments significantly restrict hydraulic conductivity. Since 2012, the estimated groundwater outflow is reduced compared to previous years with similar rainfall (2006-2012). While increased evaporation rates during this time may account for some of the decrease in groundwater flow in some years (more water is lost through evaporation than groundwater), it does not account for changes in outflow for all years (e.g. compare 2011 with 2016).

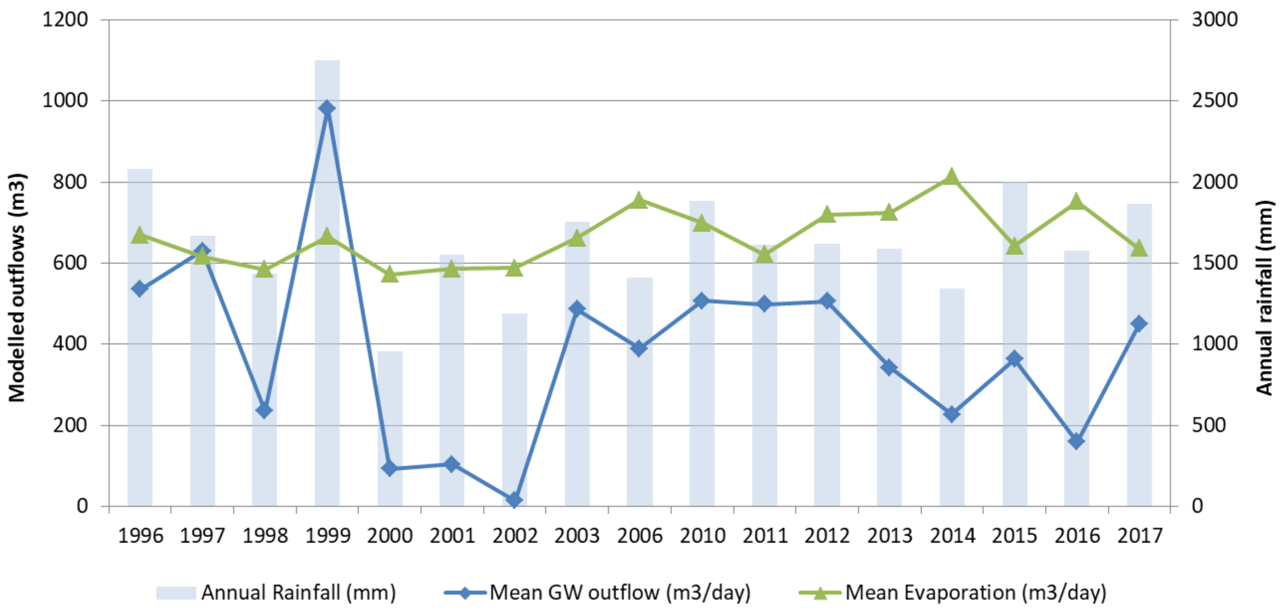


Figure 20: Modelled groundwater outflow from 1996-2017 and observed mean evaporation and annual rainfall totals

Sediment sampling was carried out in November 2018 to confirm the current extent and composition of lake sediments in comparison to the previous AWACS (1996) mapping. As discussed in Section 4.4, the results indicate that the organic-rich mud layer appears to have extended in area from previous assessment in 1996. The muds are now present above the impervious indurated sands geology (at approx. 4m below AHD) and may be impacting on groundwater outflows from the lake.

Table 8: Water balance components

Year	Highest day	Highest day level (mAHD)	Lowest day	Lowest day level (mAHD)	Drawdown period (days)	Total drawdown (m)	Mean daily drawdown (mm/day)	Mean daily rainfall (mm/day)	Mean daily evaporation (mm/day)	Mean daily evaporation (m^3/day)	Mean water level (mAHD)	Lake surface area (m2)	Volume water loss (m3)	Estimated Mean GW outflow ($m^{3/day}$)
1996	28/06/1996	2.72	25/12/1996	1.88	180	0.84	4.67	3.33	4.45	669.74	2.30	150624	1205	535
1997	9/08/1997	2.44	24/12/1997	1.76	137	0.68	4.96	3.70	4.29	616.83	2.10	143874	1247	630
1998	20/08/1998	1.96	12/11/1998	1.60	84	0.36	4.29	1.85	4.37	583.97	1.78	133577	819	235
1999	16/07/1999	3.17	20/12/1999	2.38	157	0.79	5.03	4.79	3.97	665.57	2.78	167665	1647	981
2000	5/07/2000	1.94	29/12/2000	1.24	177	0.70	3.95	1.25	4.48	572.14	1.59	127747	665	92
2001	23/05/2001	2.01	29/12/2001	1.37	220	0.64	2.91	2.37	4.48	586.25	1.69	130790	691	104
2002	14/06/2002	1.80	28/12/2002	1.19	197	0.61	3.10	1.73	4.71	588.84	1.50	124909	603	14
2003	3/07/2003	2.68	13/01/2004	1.44	194	1.24	6.39	1.66	4.64	661.92	2.06	142554	1149	487
2006	22/09/2006	2.40	16/12/2006	1.77	85	0.63	7.41	0.56	5.27	754.90	2.09	143378	1144	389
2010	14/10/2010	2.51	22/12/2010	2.27	69	0.24	3.48	4.36	4.54	698.43	2.39	153742	1206	507
2011	17/06/2011	2.75	13/01/2012	1.85	210	0.90	4.29	3.15	4.12	620.91	2.30	150624	1120	499
2012	8/07/2012	2.84	23/01/2013	1.55	199	1.29	6.48	1.85	4.90	719.81	2.20	147050	1226	506
2013	18/07/2013	2.52	1/02/2014	1.35	198	1.17	5.91	1.79	5.23	724.60	1.94	138489	1067	342
2014	18/09/2014	2.25	31/12/2014	1.75	104	0.50	4.81	2.59	5.78	812.75	2.00	140591	1039	227
2015	5/05/2015	2.58	24/12/2015	1.82	233	0.76	3.27	3.56	4.36	641.97	2.20	147168	1006	364
2016	25/06/2016	2.39	25/02/2017	1.37	245	1.02	4.16	2.50	5.50	752.13	1.88	136730	911	159
2017	5/07/2017	2.53	30/09/2017	1.93	87	0.60	6.90	0.43	4.30	636.73	2.23	148234	1085	449

Conclusions

The updated water balance model has indicated that groundwater outflows vary significantly from year to year and are governed by the balance of inputs (rainfall, runoff, groundwater inflows) and outputs (evaporation) as well as sea level conditions. There is some indication that groundwater outflows have reduced in recent years and recent sediment sampling indicates expansion of organic-rich muds since 1996, which may account for reduced outflows. This is consistent with the findings of previous study by Milner (2017).

Looking to the future, further build-up of organic-rich muds extending above the indurated sands geology (at approx. 4m below AHD) could further restrict outflows and lead to an increase in lake water levels. Sediment accretion is a naturally occurring process as waterbodies age, however eutrophication can accelerate this process through the repeat bloom and die off of aquatic plants and algae and subsequent deposition of organic material on the lake floor. Additionally, as discussed in Section 1.2.3, climate change is also expected to lead to an increase in average water levels in the lake and increased flooding due to sea level rise and a predicted increase in extreme rainfall and sea level events. The CMP will need to consider the impact of increasing lake levels in all management actions.

3. WATER QUALITY

Lake Ainsworth is a freshwater coastal dune window lake characterised by 'tea' coloured water resulting from the natural leaching of humic acids and tannins from surrounding heath and wetland areas. Water quality is typically acidic (pH ~5.8), with elevated nutrient levels, and is prone to blooms of blue green algae (cyanobacteria) which impacts lake health and recreational use. Cyanobacteria blooms in the lake have occurred periodically for many years, with records of serious outbreaks dating back to the 1980's (Lennox Head Landcare, 2018). A key driver of the CMP is the ongoing concern of increasing nutrient levels and resulting cyanobacteria outbreaks in the lake.

3.1 Lake Ainsworth Water Quality Monitoring

The Lake Ainsworth water quality monitoring program involves *in situ* monitoring and collection of surface water samples for laboratory analysis. There are a total of 5 regular water quality sampling sites within the lake (Figure 23).

Local rainfall data is obtained from the Lake Ainsworth data logger, located in the vicinity of site LA1-North. Figure 21 shows the daily rainfall totals for Lake Ainsworth from Dec 2015 – June 2018. There was considerable variation with maximum daily rainfall typically falling in autumn and early winter up to 210mm per day. Figure 22 shows the total annual rainfall and average monthly rainfall for 2015, 2016 and 2017 as compared to the long-term average at Ballina AWS. Minor variation in annual rainfall is apparent over the water quality period with 2015 recording above average rainfall and 2016 and 2017 recording below average rainfall. Average monthly rainfall for 2015-2017 showed some deviation from long-term averages with higher rainfall in March and June and drier July and August compared with long-term averages. The majority of rain falls in the first half of the year from summer to early winter with the driest months in late winter and early spring.

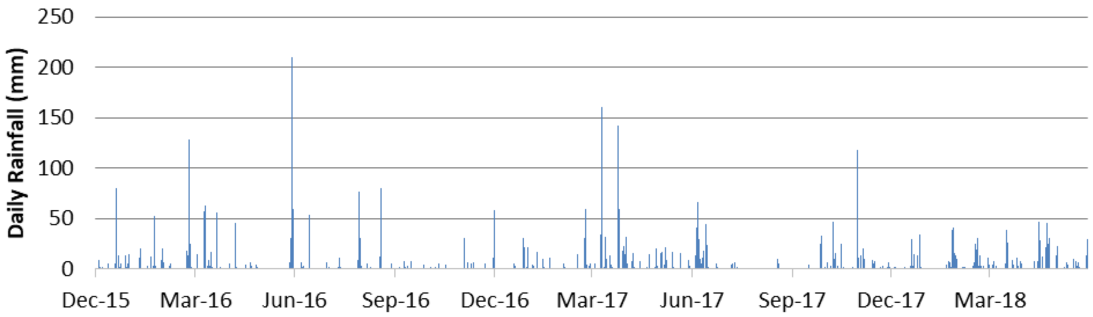


Figure 21: Daily Rainfall Dec 2015-June 2018

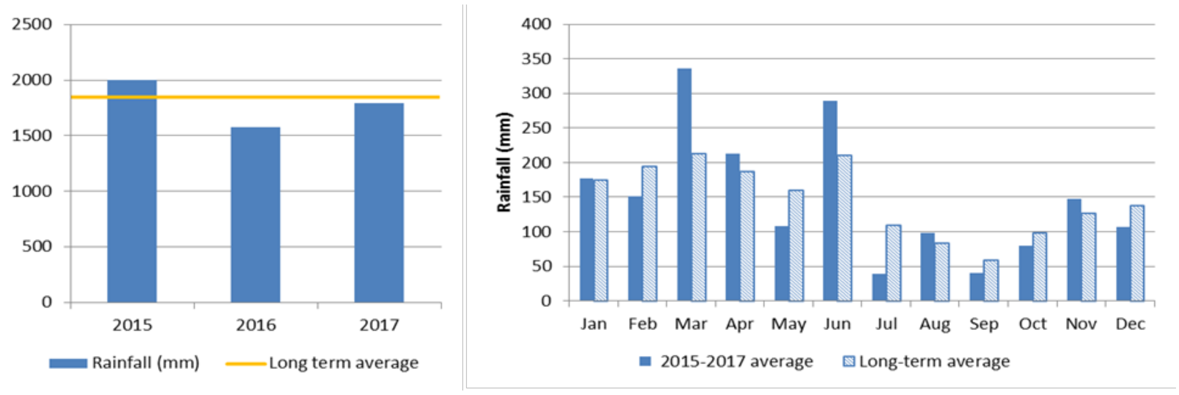


Figure 22: Annual rainfall and monthly average rainfall for Lake Ainsworth 2015-2017 compared to the long-term average at Ballina AWS (Source: BOM, 2018)

3.2 Rainfall classification

Rainfall information was assigned to the Lake Ainsworth water quality dataset retrospectively by calculating three-day rainfall totals leading up to each sampling event. Three-day rainfall prior to sampling is considered to be a good indicator of the occurrence of runoff generation. The samples were then categorised using the following method:

- Low: <10mL of rainfall in three days prior to sampling;
- Moderate: between 10mL and 50mL of rainfall in three days prior to sampling; and
- High: >50mL of rainfall in three days prior to sampling.

Table 9 shows the percentage of samples in each rainfall category based on this classification. Also included in the table is the percentage breakdown of rainfall conditions over the entire sampling period (2015-2018). Most samples (69%) were collected during low rainfall conditions, with 24% collected during moderate rainfall conditions. High rainfall or ‘event’ samples comprise approximately 7% of the dataset. Based on this classification, it appears that overall the program has sampled water quality under a range of rainfall conditions that aligns well with the ratio of rainfall conditions experienced over the whole period.

Table 9: Sample counts at each site classified by rainfall condition compared to all days from Dec 2015- July 2018.

Rainfall category	Rainfall condition	Number of samples	%	Total of all days 2015-2018
High	>50mm over 3 days	46	8%	8%
Moderate	Between 10 and 50mm over 3 days	127	21%	17%
Low	<10mm over 3 days	430	71%	75%
Total no. samples		603	100%	100%

*Note: temperature sample counts were used for this analysis

Figure 23: Lake Ainsworth water quality sampling sites from Dec 2015 – 2018

3.3 Water Quality Compliance

Compliance was measured against water quality objectives for aquatic ecosystem protection and primary contact recreation and is presented in Table 10. Compliance was assessed for a key range of indicators against the objectives for aquatic ecosystem health (DO, Turbidity, pH, TN, NOx, TP, PO_4-P and Chlorophyll *a*) and human health (enterococci, refer Section 3.6).

The lake is naturally acidic due to natural leaching of humic acids and tannins from surrounding heath and wetland areas and this is reflected in a median pH value of 5.89. While this lies outside of the ANZECC guidelines for freshwater ecosystems it is considered a natural attribute of the system. Other physical parameters (temperature, turbidity and DO) were within suitable levels for aquatic ecosystem protection.

All nutrient parameters showed a significant exceedance of the ANZECC guidelines and indicate eutrophic conditions. Correspondingly high Chlorophyll *a* levels also exceeded the guidelines, reflecting an ecosystem with high levels of primary productivity.

Table 10: Compliance with ANZECC default trigger values for freshwater lakes in south-east Australia collected from all sites 2015-2018.

Parameter	Units	median	mean	min	max	n	ANZECC trigger
Temp	ºC	25.4	24.5	14.9	32.4	603	-
Wind Velocity	km/hr	15	16	0	43	705	-
DO	mg/L	7.18	7.26	2.00	13.10	597	90-110%sat (approx. 7 – 9 mg/L at 25ºC)
EC	mS/cm	221	228	181	511	1028	-
pH	pH units	5.89*	5.99	4.54	8.89	874	6.5 - 8.0
Turbidity	NTU	2.0	2.8	0.0	18.0	599	1 - 20
Chlorophyll *a*	mg/L	0.011	0.014	0.002	0.120	219	0.005
TN	mg/L	0.763	0.779	0.124	2.797	559	0.35
NO_x-N	mg/L	0.050	0.039	0.005	0.290	559	0.01
TP	mg/L	0.120	0.120	0.020	0.350	600	0.01
PO_4-P	mg/L	0.118	0.115	0.020	0.343	530	0.005

*Note: Red highlighted levels show non-compliance with guidelines

Further analysis of the available water quality data is provided in the following sections to highlight the key water quality risks; any mitigating factors; spatial and temporal trends; and the influence of natural factors such as rainfall and water levels.

3.4 Physico-chemical parameters

3.4.1 Temperature

Water temperature regulates ecosystem functioning both directly through physiological effects on organisms, and indirectly, as a consequence of habitat loss. Many ecosystem processes are affected by temperature including photosynthesis, aerobic respiration, nutrient cycling, and the growth, reproduction, metabolism and the mobility of organisms. Water is more likely to become anoxic or hypoxic under warmer conditions because of increased bacterial respiration and a decreased ability of water to hold dissolved oxygen.

Lake Ainsworth surface water temperatures showed a strong seasonal pattern with summer maximum water temperatures reaching 32ºC and winter minimum temperatures reaching 15ºC (Figure 24). Temperature did not vary greatly between sites with a median concentration of approximately 26 ºC across all sites from 2015-2018. There were no statistically significant differences in temperature between any sites over the sample period (Appendix 2). There was also very little variation in temperature due to rainfall and this was likely due to the overriding influence of solar heating of surface waters particularly during summer and autumn months coinciding with the wet season.

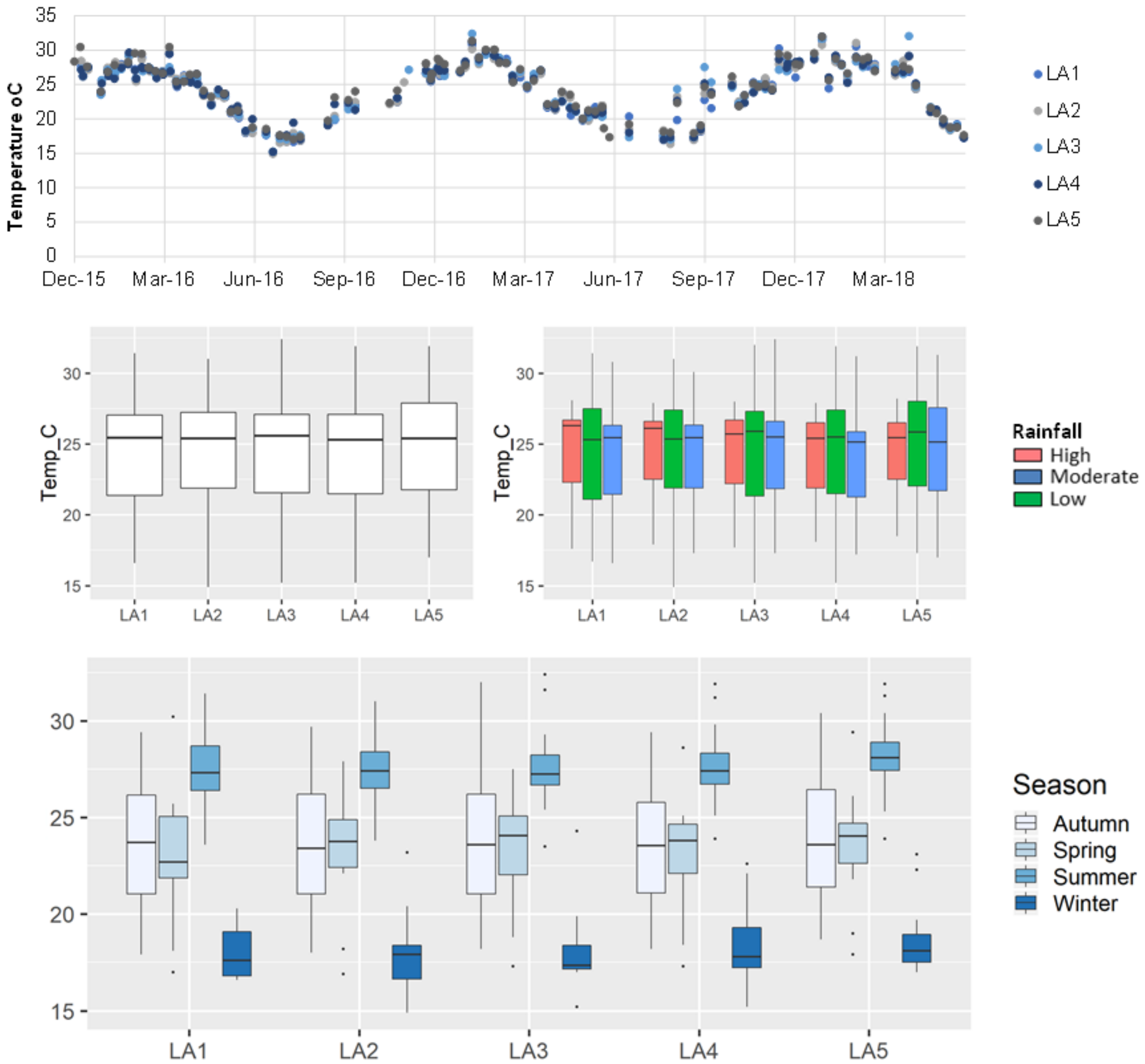


Figure 24: Lake Ainsworth temperature Dec 2015-June 2018: Top - temporal variation; Middle left - Box plot showing range of all data; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.

3.4.2 Electrical Conductivity

Electrical Conductivity (EC) is a measure of water's capability to pass an electrical current and is an indicator of salinity. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds (Wetzel, 2001). EC is an important ecological parameter with most aquatic organisms functioning optimally within a narrow range. Typically freshwater systems have a range of EC from 100-2000 µS/cm.

Lake Ainsworth EC levels range from 181-511 µS/cm with an average EC of 228 µS/cm, well within the classification of a freshwater system (Figure 25). Summer tended to show a higher range of EC which is likely due to increased evaporation rates and lower summer water level/lake volume (Figure 7) leading to a higher concentration of dissolved ions. Site LA5 on the western side displayed slightly higher EC levels than the other sites and there was a statistically significant difference in EC between LA1 and LA5 (Appendix 2). This result may reflect the greater influence of mineral-rich catchment inputs on the west side of the lake (LA5). Rainfall was generally associated with lower EC values, most likely due to dilution. However, at site LA3 in the south-east corner some elevated readings of EC were recorded in association with rainfall, potentially indicating stormwater impacts at this site, however, this was not a statistically significant result (Appendix 2) suggesting the higher readings were a once off event rather than an ongoing issue.

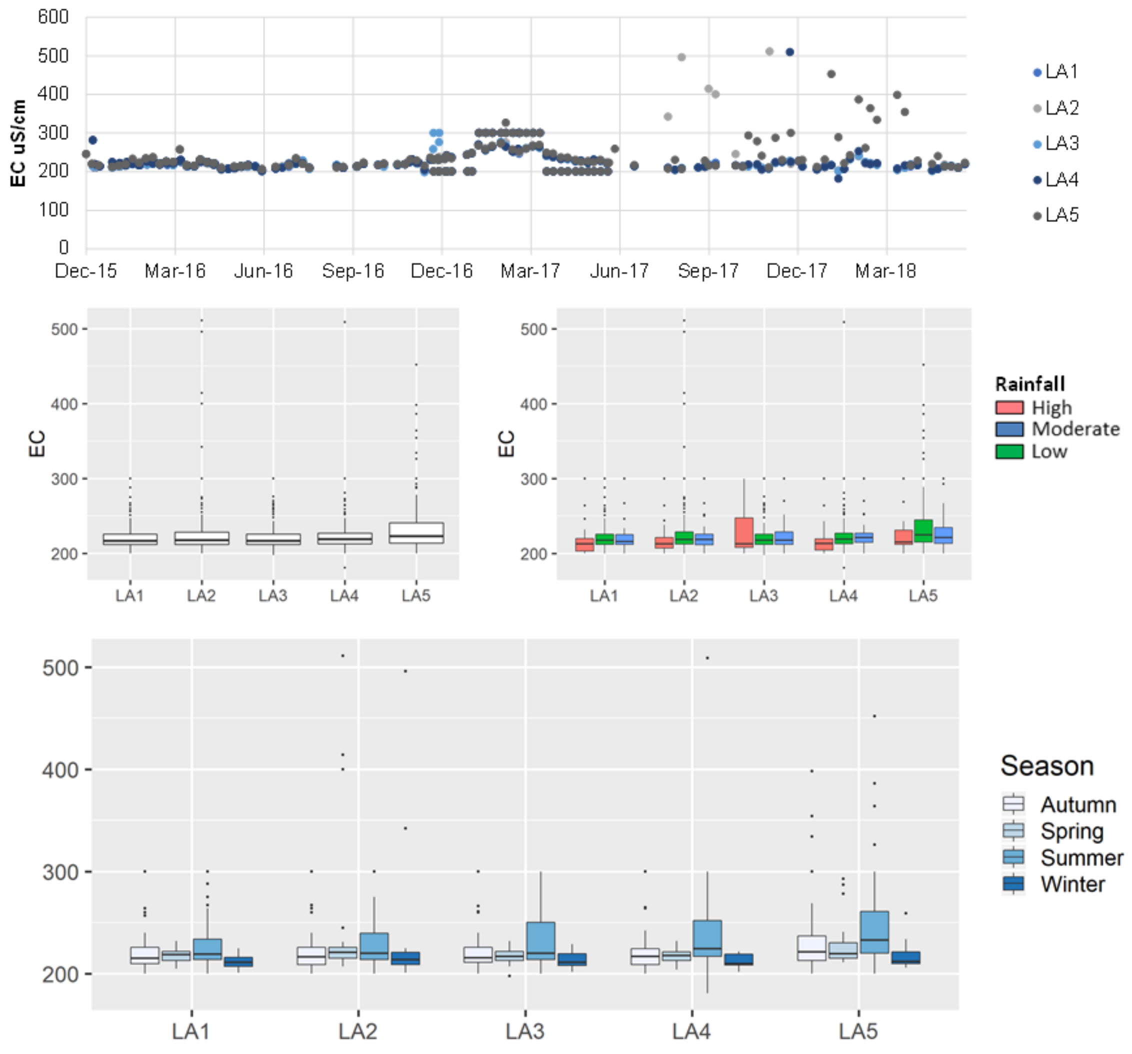


Figure 25: Lake Ainsworth electrical conductivity (EC) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.

3.4.3 pH

pH is a measure of how acid or alkaline a water body is on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline). The pH of most natural freshwaters have pH values in the range from 6.5 to 8.0, however humic lakes such as Lake Ainsworth are naturally acidic with levels as low as pH 4.5, due to the leaching of humic acids (tannins) from decaying vegetation. Most aquatic organisms and some bacterial processes require that pH be in a specified range. If pH changes above or below the preferred range of an organism (including microbes), physiological processes may be adversely affected.

Lake Ainsworth showed a range of pH between pH 4.5-8.1, and a median value of pH 5.89 across all sites (Figure 26). There were no statistically significant differences in pH between any sites over the sample period (Appendix 2). It is likely that some of the higher pH results (e.g. Sep/Oct 2017) are associated with algal blooms as CO_2 utilised during photosynthesis decreases water acidity. The current pH levels are somewhat higher than the levels reported previously by Timms (1982) (pH range 4.9 - 5.1); and AWACS (1996) (pH range 5 – 6), and appear to indicate an increasing pH trend over time (implications of increasing pH are discussed further in Section 3.10.2).

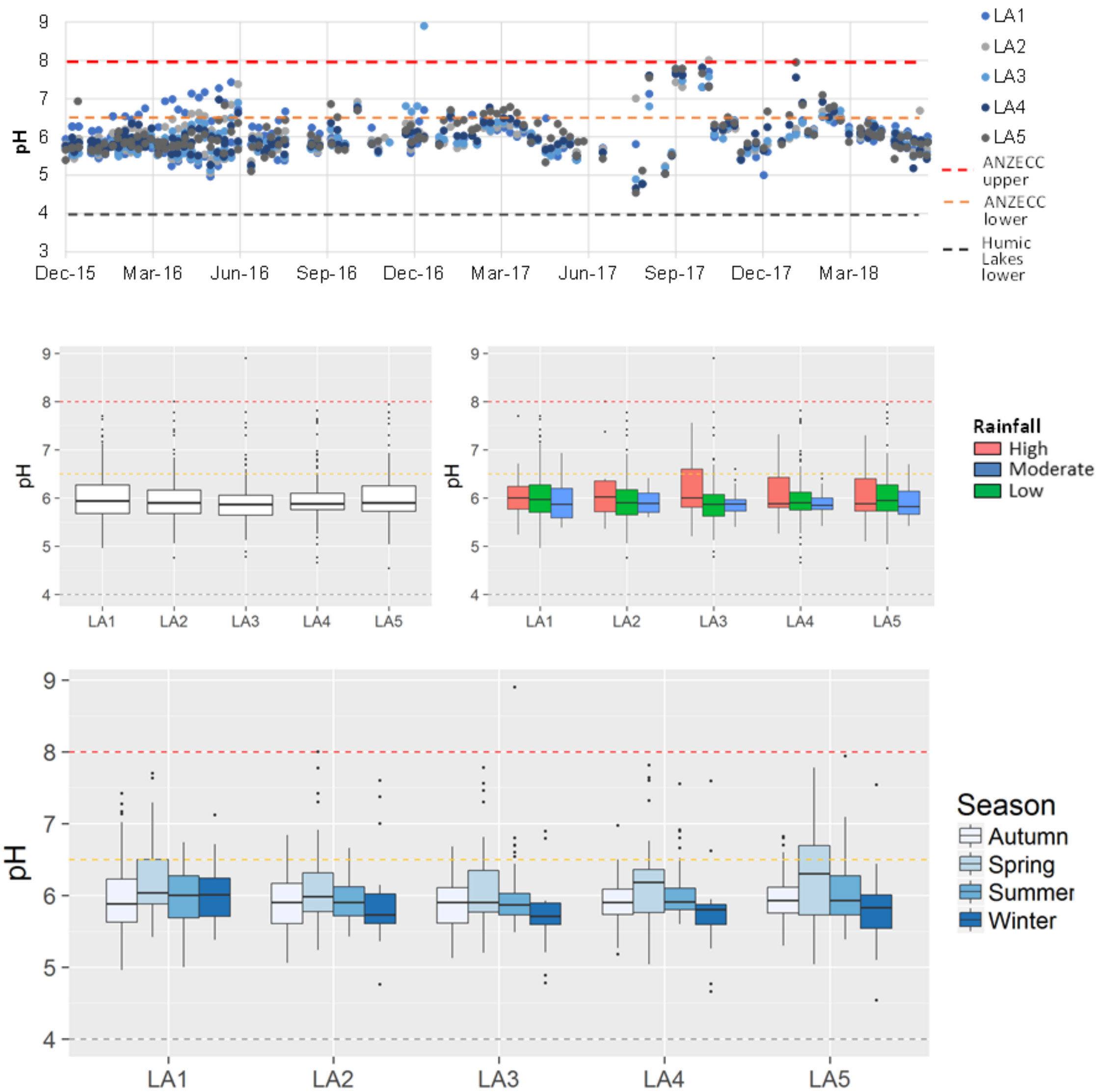


Figure 26: Lake Ainsworth pH Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.

pH tended to increase slightly with rainfall particularly at sites LA1, LA2 and LA3 which are all located along the eastern side of the lake. It is not immediately clear why this occurs as generally pH would be expected to decrease with rainfall due to rainwater (typically pH 5.3 - SA EPA, 2004) and runoff/groundwater flows from the surrounding catchment expected to be slightly acidic. It could be related to runoff from asphalt and concrete areas which are typically alkaline and have been shown to elevate pH in runoff waters (Kuang and Sansalone, 2011). However, when comparing pH across all sites during high rainfall conditions, there was no statistically significant difference in results (Appendix 2), indicating that the observed increases in pH did not come from any specific location and possibly internal lake processes are the overriding factor. The lowest pH was recorded in winter across most sites except LA1 and this may be due to the end of the wet season and switch to dominant inflows from the humic rich (and lower pH) catchment groundwater.

3.4.4 Dissolved Oxygen

Dissolved oxygen (DO) levels refer to the amount of oxygen contained in water, and define the living conditions for oxygen-requiring (aerobic) aquatic organisms. Any deviations from 100% saturation are largely due to biological or chemical processes in the water body which consume or produce oxygen. Oxygen consuming processes include aerobic respiration by phytoplankton, and the biological breakdown of organic matter. Oxygen producing processes include photosynthesis by phytoplankton, aquatic plants and benthic algae. Most aquatic organisms require oxygen in specified concentration ranges, and DO concentration changes above or below this range can have adverse physiological effects. In extreme prolonged low DO events (e.g.DO <3mg/L or <~30% saturation), major kills of aquatic life can occur. Other effects of low DO include increased toxicity of many toxicants (e.g. lead, zinc, ammonia etc.), immune suppression in fish, and changes to nutrient cycling between sediment and water which can lead to algal blooms (refer Section 0 for further detailed discussion of lake stratification and assessment of the aerator program).

Overall, daytime surface DO levels in Lake Ainsworth are considered suitable for a healthy functioning ecosystem. Over the 2015 -2018 sampling period a range of 2-13mg/L and a median value of approximately 7mg/L was recorded across all sites. There were no statistically significant differences in DO between any sites over the sample period (Appendix 2). Seasonal trends in DO were apparent, with winter coinciding with higher DO levels and the summer-autumn wet season consistently producing lower DO levels in the lake. This seasonal trend is likely to be linked to both increased water temperatures (DO solubility decreases with warmer temperature) and increased primary production during the warmer months (DO consumed by algae). Aerator function during the spring and summer months also impacts on DO levels and this is investigated further in Section 0. Rainfall also appeared to be having some effect on DO, with high rainfall associated with lower DO at all sites except for LA3. The input of low DO water from the catchment could account for reduced overall DO during runoff events. When comparing DO across all sites during high rainfall conditions there was no statistically significant difference in results (Appendix 2), indicating that the observed decreases in DO occurred equally across the lake, with no particular sources indicated.

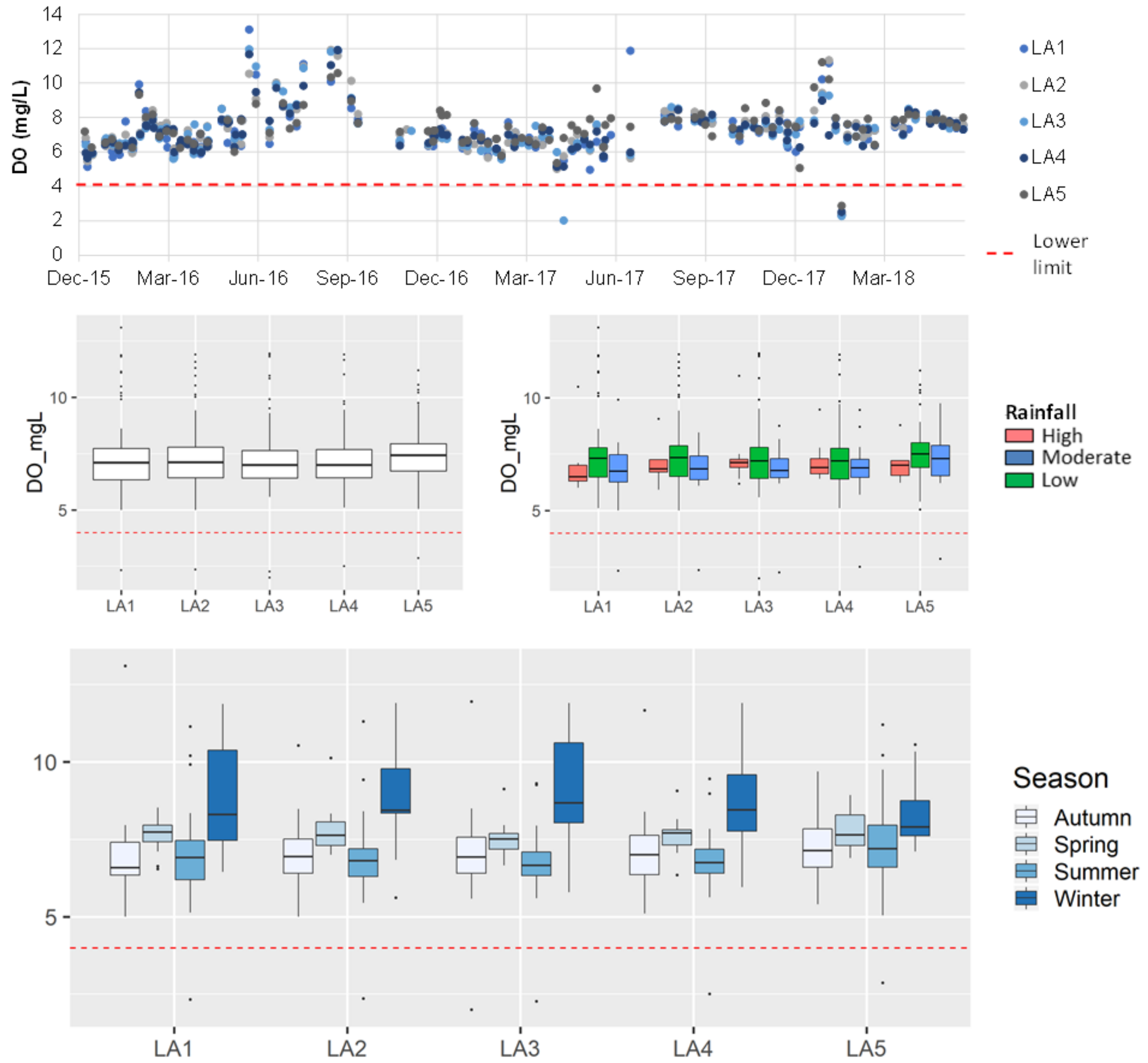


Figure 27: Lake Ainsworth Dissolved Oxygen (DO) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.

3.4.5 Turbidity

Turbidity is a measurement of the suspended particulate matter or coloured dissolved organic matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, detritus and organisms (algae and zooplankton). High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress overall ecosystem productivity.

In general, turbidity was low at Lake Ainsworth across the study period, with a range of 0.2-18 NTU and a median value of approximately 2 NTU across all sites. There were no statistically significant differences in turbidity between any sites over the sample period or when examining high rainfall events in isolation (Appendix 2). This suggests there is no relationship between turbidity and rainfall events, indicating that sediment runoff is not a key contributor. As water quality sites were located adjacent to areas of varying degrees of bank erosion, this result also suggests bank erosion is not contributing significantly to turbidity at adjacent sites. In fact, higher turbidity levels were experienced at some sites (LA1, LA2 and LA4) during low rainfall conditions, indicating that turbidity may be more greatly affected by factors other than rainfall (e.g.

human/animal disturbance of bottom sediments). Another key factor with relevance at Lake Ainsworth is light scattering by algae which can affect measured turbidity levels.

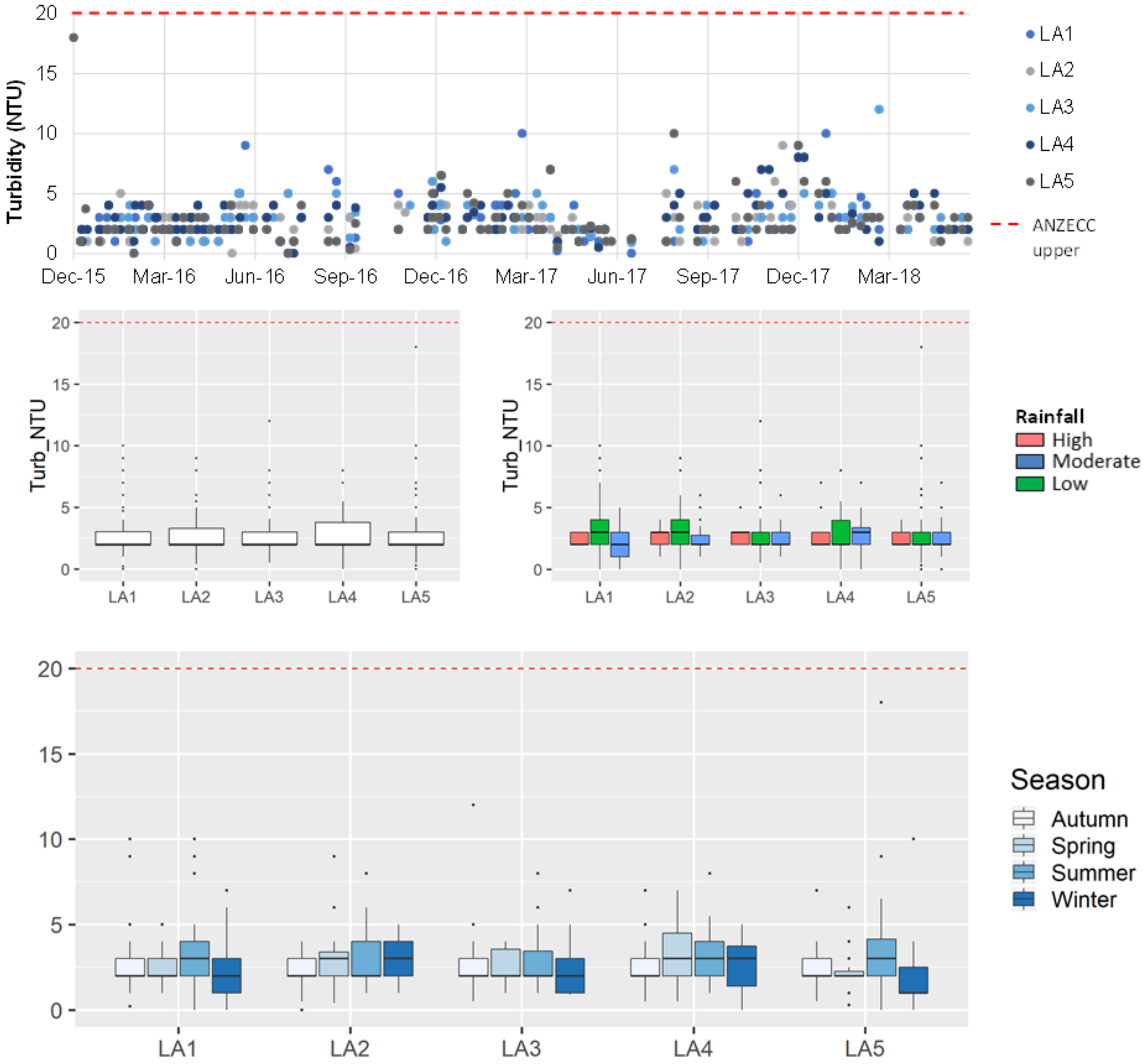


Figure 28: Lake Ainsworth Turbidity Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.

3.5 Nutrients and Chlorophyll *a*

The nutrients nitrogen and phosphorus are essential building blocks for plant and animal growth. Over enrichment with nitrogen and phosphorus in aquatic ecosystems can lead to excessive algae and plant growth, eutrophication and subsequent deterioration of water quality conditions affecting the balance of key ecosystem requirements such as DO, pH and water clarity.

Chlorophyll *a* is a specific form of chlorophyll used in photosynthesis and gives plants their green pigment. It absorbs sunlight and plants use the energy in the production of sugar during photosynthesis. Chlorophyll *a* concentrations are an indicator of phytoplankton abundance and biomass in water. To properly understand the trophic status, nutrient levels and Chlorophyll *a* should be considered together since these are linked by cycles operating on various time scales.

Nutrients are contained in the water column and sediments, both as dissolved compounds as well as living and dead organic material. Nutrient and Chlorophyll *a* concentrations follow linked biochemical cycles – e.g.

as nutrients are consumed by algae, nutrient concentrations reduce but Chlorophyll *a* levels increase and conversely, as algae dies and breaks down, nutrient levels increase again as Chlorophyll *a* drops.

Nutrients also move between the water column and the sediments at the bed of the lake. As decaying organic matter sinks to the bottom, nutrients can be lost from the system through burial. However, in locations with low sediment inputs such as Lake Ainsworth, the rate of burial is low and recycling of nutrients into the water column readily occurs. The release of nutrients at the sediment-water interface is discussed further below.

3.5.1 Total Phosphorus

Total Phosphorus (TP) represents the sum of dissolved inorganic, dissolved organic and particulate phosphorus. Phosphorus is commonly regarded as the limiting nutrient for primary production in freshwater ecosystems. Phosphorus can also control the occurrence of nitrogen-fixing organisms such as some species of cyanobacteria (blue green algae).

Lake Ainsworth showed a range of TP between 0.02 and 0.35mg/L, with a median value of 0.12mg/L across all sites which equates to 12 times the ANZECC water quality guideline for ecosystem health (Figure 29). Levels observed in the lake are also generally above the NHMRC upper guideline for the susceptibility of a water body to harbour cyanobacteria. Current TP levels are almost double the levels assessed from 1993-1995 and reported by AWACS (1996) and this is discussed further below (refer Figure 36). There were no statistically significant differences in TP between any sites over the sample period (Appendix 2).

Seasonal trends in TP were apparent, with spring and summer coinciding with higher TP levels and autumn and winter consistently producing lower TP levels in the lake. This seasonal trend is likely to be linked to increased productivity in warmer months with more solar radiation stimulating photosynthesis. The trend may also be related to relatively higher rainfall in spring and summer, generating runoff and groundwater flows contributing TP to the lake. This is supported by the analysis of rainfall data (Figure 29) where a trend of increasing TP concentrations was indicated with rainfall, with moderate rainfall conditions having higher concentrations than low flow conditions, which was a statistically significant result (Appendix 2). There was no statistically significant difference between TP at any sites during high flows and therefore no indication of any potentially problematic stormwater sources (Appendix 2). Aerator function during the spring and summer months also impacts on TP levels and this is investigated further in Section 0. Phosphorus cycling and key processes in the lake are discussed in Section 3.10, Nutrient Cycling.

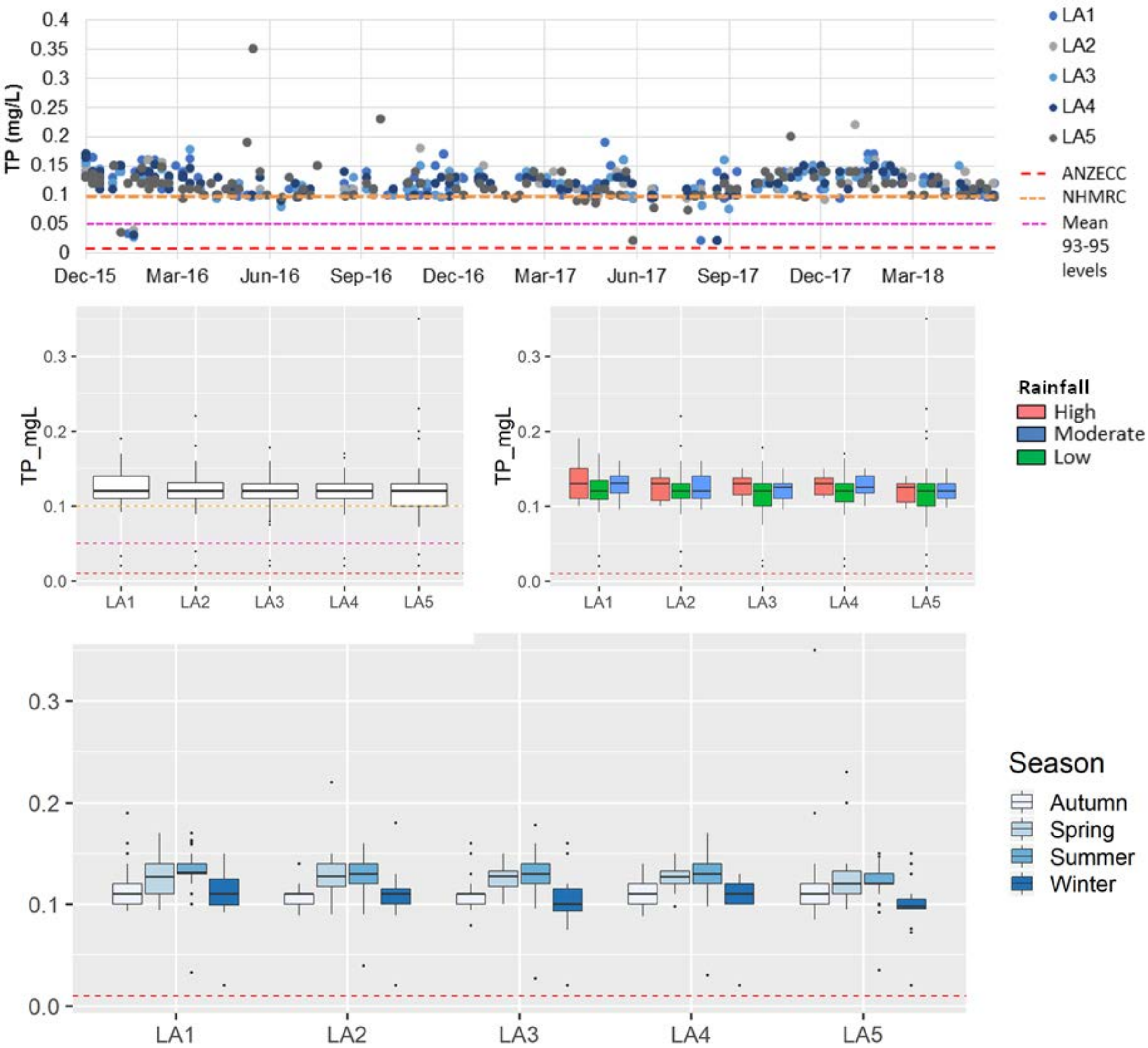


Figure 29: Lake Ainsworth Total Phosphorus (TP) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation. ANZECC upper guideline for protection of aquatic ecosystems; NHMRC upper guideline for the susceptibility of a water body to harbour cyanobacteria; Mean concentration of TP shown for 1995 reported by AWACS, 1996).

3.5.2 Dissolved Inorganic Phosphorus

Dissolved inorganic phosphorus (PO_4-P) is the form of phosphorus required by plants for growth and is the form readily available in aquatic environments for algal uptake. In freshwater, PO_4-P is often the limiting factor for algal growth, where light is not limiting.

Lake Ainsworth showed a range of PO_4-P between 0.02 and 0.34mg/L, with a median value of 0.118mg/L across all sites which is over 23 times the ANZECC water quality guideline for ecosystem health (Figure 30). PO_4-P makes up the majority of the total phosphorus contained in Lake Ainsworth, comprising 98% of TP. PO_4-P levels were also considerably elevated (increased by 4 times) compared to previously assessed levels in 1998-1999 reported by DPWS & MHL (2001) (refer Figure 36) and this is markedly more than the increase in TP suggesting that the dominant forms of phosphorus have shifted from organically-bound forms to biologically available forms. There were no statistically significant differences in PO_4-P between any sites over the sample period (Appendix 2).

Seasonal trends were similar to what was observed for TP, with spring and summer coinciding with higher PO_4-P levels and autumn and winter consistently producing lower PO_4-P levels. There was a trend of increasing PO_4-P concentrations with rainfall, with moderate rainfall conditions having higher concentrations than low rainfall conditions, which was a statistically significant result (Appendix 2). There was no statistically significant difference between PO_4-P at any sites during high flows and therefore no indication of any potentially problematic stormwater sources of PO_4-P (Appendix 2). Aerator function during the spring and summer months also impacts on PO_4-P levels and this is investigated further in Section 0. Phosphorus cycling and key processes in the lake are discussed further in Section 3.10.

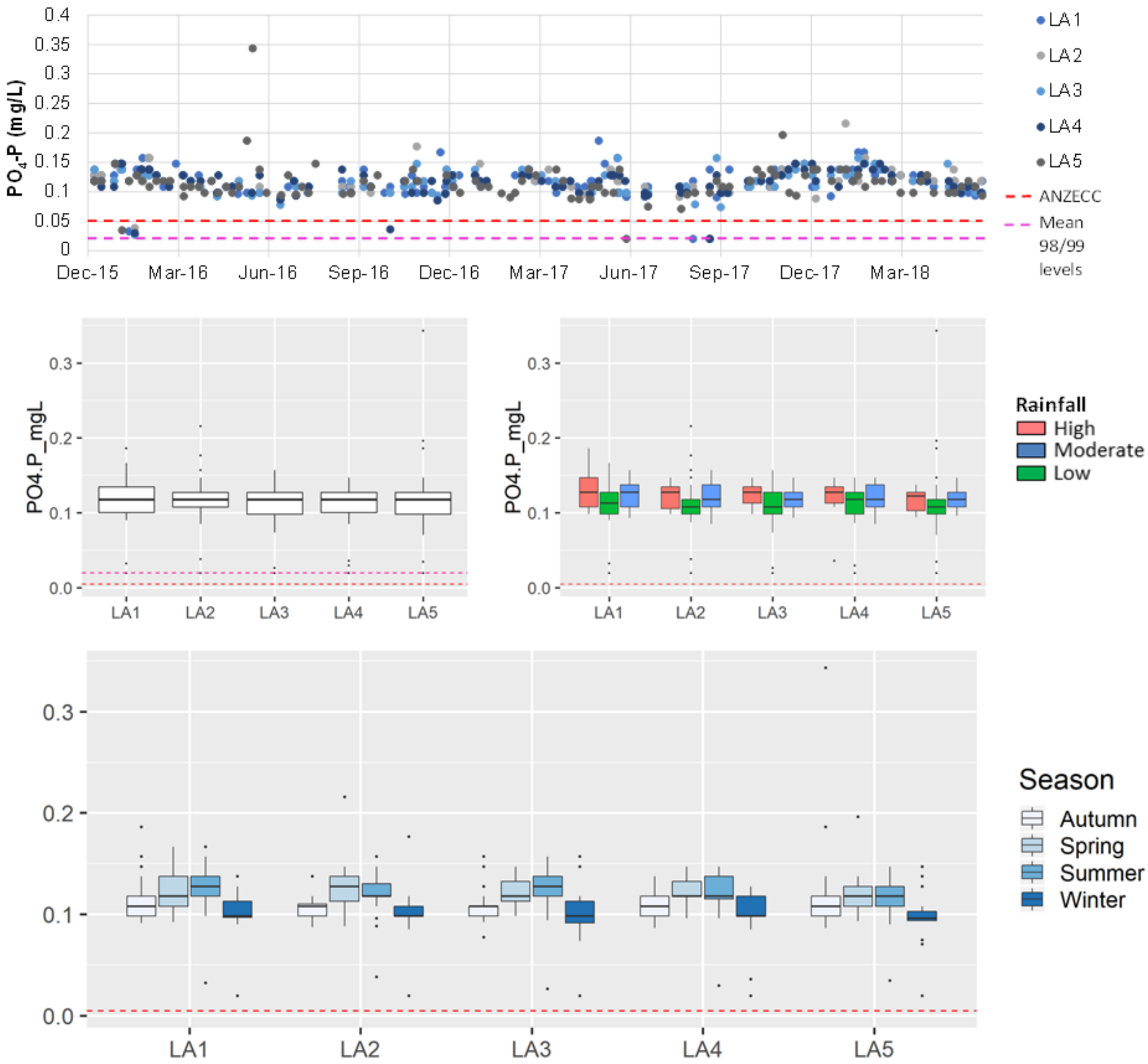


Figure 30: Lake Ainsworth dissolved inorganic phosphorus (PO_4-P) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation. Red line - ANZECC upper guideline for protection of aquatic ecosystems; Pink line - Mean concentration of PO_4-P shown for 1998/99 reported by DPWS and MHL (2001).

3.5.3 Total Nitrogen

Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Inorganic nitrogen is found both as oxidised species (e.g. nitrate (NO_3-) and nitrite (NO_2-)) and reduced species (e.g. ammonia (NH_4^+ and NH_3) and dinitrogen gas (N_2)) Total nitrogen represents the sum of all forms of nitrogen present in water.

Lake Ainsworth showed a range of TN between 0.12 and 2.79mg/L, with a median value of 0.76mg/L across all sites which more than double the ANZECC water quality guideline for ecosystem health (Figure 31). There were no statistically significant differences in TN between any sites over the sample period (Appendix 2). Unlike TP, current TN levels are reduced (reduced by 38%) when compared to 1993-1995 levels reported by AWACS (1996). Seasonal trends in TN were observed, with summer coinciding with higher TN levels and winter consistently producing lower TN levels in the lake. Spring and Autumn were similar in terms of TN. This seasonal trend is likely to be linked to increased productivity in warmer months. TN concentrations appeared to increase with rainfall, with high rainfall conditions having slightly higher concentrations than both moderate and low flow conditions, however this was not a statistically significant results (Appendix 2). Nitrogen cycling and key processes in the lake are discussed in Section 3.10.

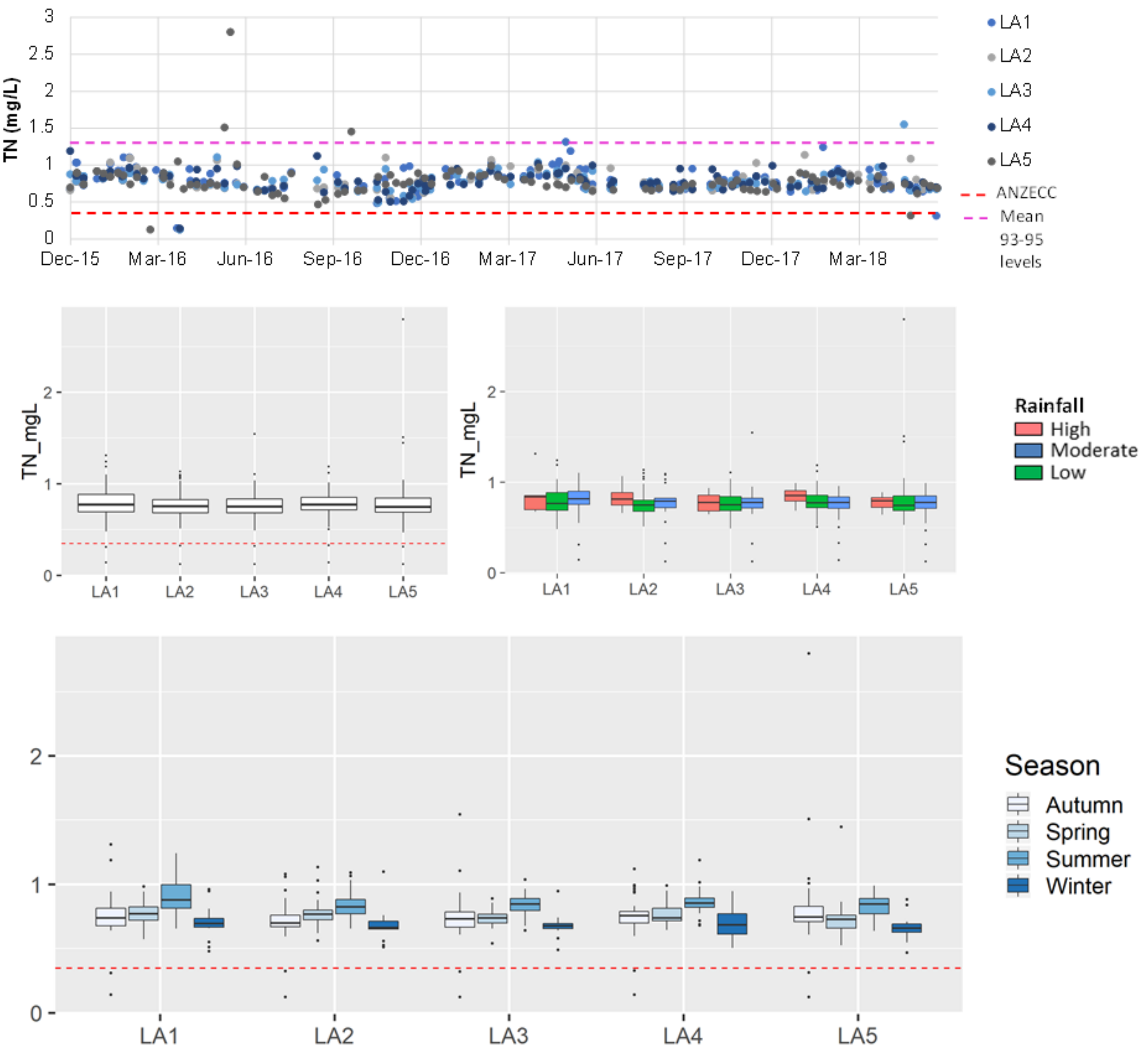


Figure 31: Lake Ainsworth total nitrogen (TN) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.

*Note: Red line - ANZECC upper guideline for protection of aquatic ecosystems; Pink line - Mean concentration of TN shown for 1993-1995 reported by AWACS (1996).

3.5.4 Ammonia

The most common sources of ammonia entering surface waters and groundwaters are domestic sewage, industrial effluents and fertiliser runoff (due to ammonia being a common constituent of fertilisers). Excess ammonia contributes to eutrophication of water bodies and at high concentrations is toxic to aquatic life. When sediments are anoxic, nitrification is inhibited and ammonia levels in the water column may be elevated.

Ammonia levels in Lake Ainsworth ranged between 0.01 and 0.25mg/L, with a median value of 0.067mg/L. From Figure 32 it is clear that ammonia has increased significantly from 1998/99 levels (Table 10). This result is likely to be linked to low dissolved oxygen levels at the sediment–water interface inhibiting nitrification and favouring ammonia release from sediments. Levels are highest in autumn and summer and lowest in winter, correlating to low and high DO conditions in these seasons respectively. There were no statistically significant differences in ammonia between any sites over the sample period (Appendix 2).

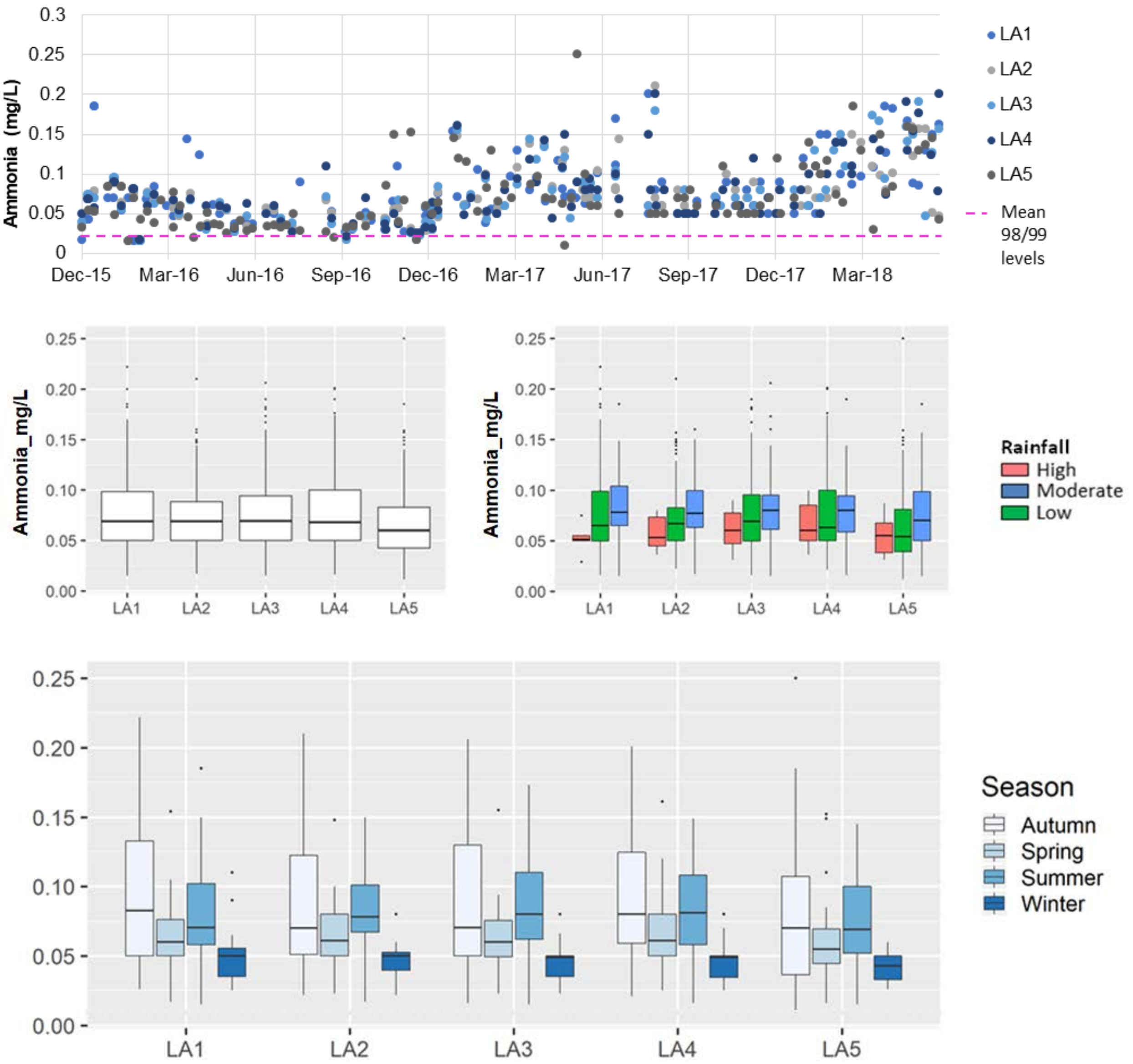


Figure 32: Lake Ainsworth ammonia Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation.
Pink line - Mean concentration of Ammonia shown for 1998/99 reported by DPWS and MHL (2001).

3.5.5 Oxidised Nitrogen

Oxidised nitrogen (NOx) is the sum of nitrite and nitrate. Oxidised nitrogen is immediately available to plants.

Lake Ainsworth showed a range of NOx between 0.01 and 0.34mg/L, with a median value of 0.05mg/L across all sites which is five times the ANZECC water quality guideline for ecosystem health (Figure 33). Levels of NOx were similar across sites except for LA1 (North), where levels were reduced, however this was not a statistically significant result (Appendix 2). Seasonal trends in NOx were observed, with summer coinciding with higher levels and winter consistently producing lower NOx levels in the lake, except at site LA1 where summer, spring and winter levels were similar and autumn showing lower levels. There was a trend of increasing NOx concentrations with rainfall, with high rainfall conditions having slightly higher concentrations than moderate rainfall conditions, which was a statistically significant result (Appendix 2). There was no statistically significant difference between NOx at any sites during high flows and therefore no indication of any potentially problematic stormwater sources of NOx (Appendix 2). Nitrogen cycling and key processes in the lake are discussed in Section 3.10.

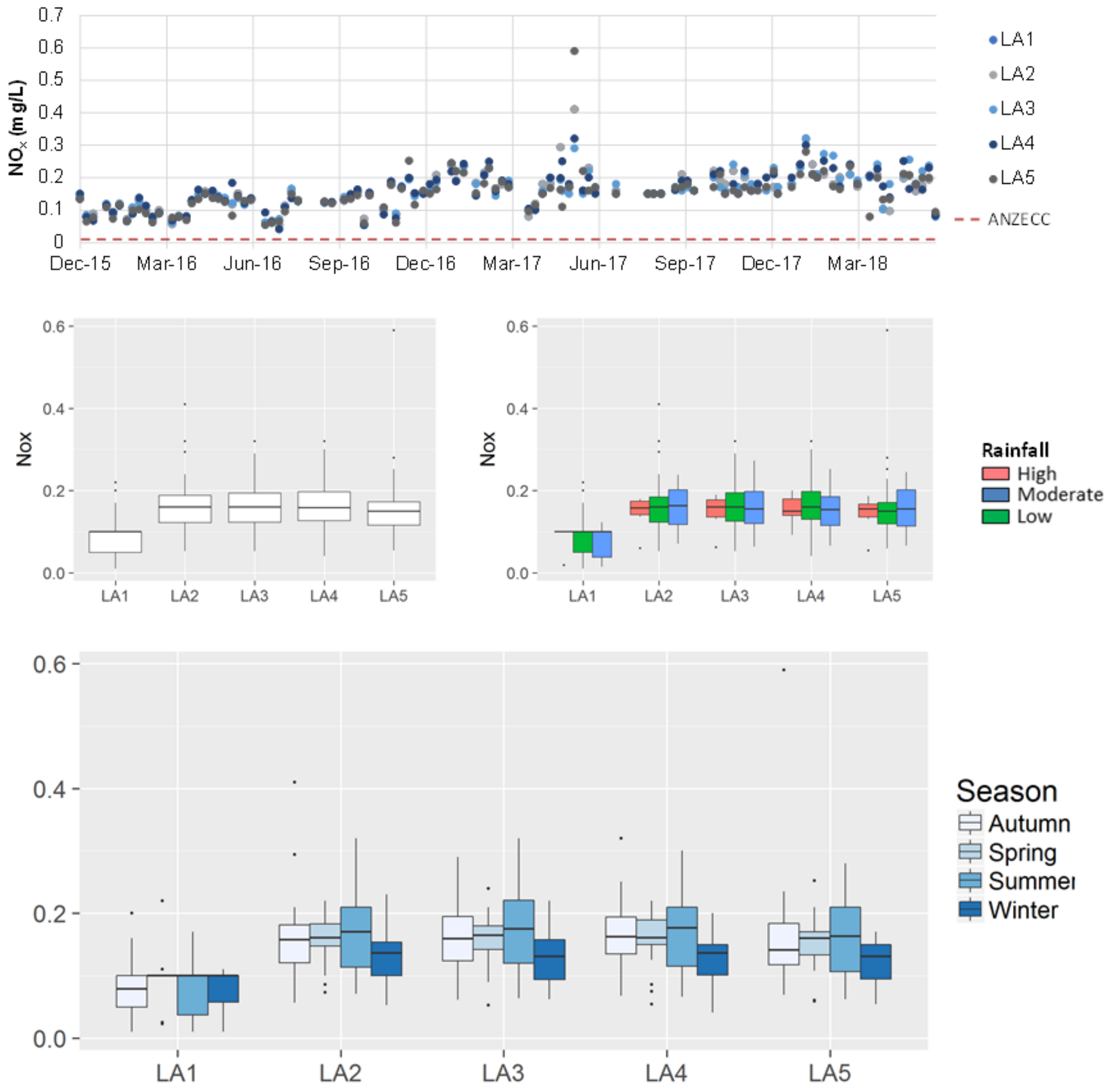


Figure 33: Lake Ainsworth oxidised nitrogen ($NO_x = NO_3 + NO_2$) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation. ANZECC upper guideline for protection of aquatic ecosystems.

3.5.6 Chlorophyll *a*

Persistently high Chlorophyll *a* levels can indicate eutrophication. It should be noted that natural peaks in Chlorophyll *a* concentrations do occur and include: higher levels after rainfall, particularly if the rain has flushed nutrients into the water; and higher levels are also common during the summer months when water temperatures and light levels are also higher. Chlorophyll *a* statistics therefore need to be evaluated with reference to nutrient trends, rainfall and other seasonal factors.

Chlorophyll *a* was added to the lake Ainsworth monitoring program in April 2017 and there is just over a year of data available for analysis at this time. Lake Ainsworth showed a range of Chlorophyll *a* between 0.02 and 0.12mg/L, with a median value of 0.11mg/L across all sites which more than double the ANZECC water quality guideline for ecosystem health (Figure 34). LA1, in the north displayed the highest levels of Chlorophyll *a* and this is an area frequently observed to have accumulations of algae thought to be due to predominant southeast winds pushing algae to the northern end of the lake. The higher levels at LA1 were not statistically significant based on the current dataset (Appendix 2). Chlorophyll *a* levels have remained relatively constant when compared to 1993-1995 levels reported by AWACS (1996). Seasonal trends were consistent with expectations: summer coincided with higher Chlorophyll *a* levels and winter consistently produced lower Chlorophyll *a* levels in the lake consistent with warmer temperatures and higher light levels stimulating increase in phytoplankton numbers. Chlorophyll *a* concentrations increased with rainfall, with high rainfall conditions having slightly higher concentrations than both moderate and low flow conditions, and this was a statistically significant result (Appendix 2).

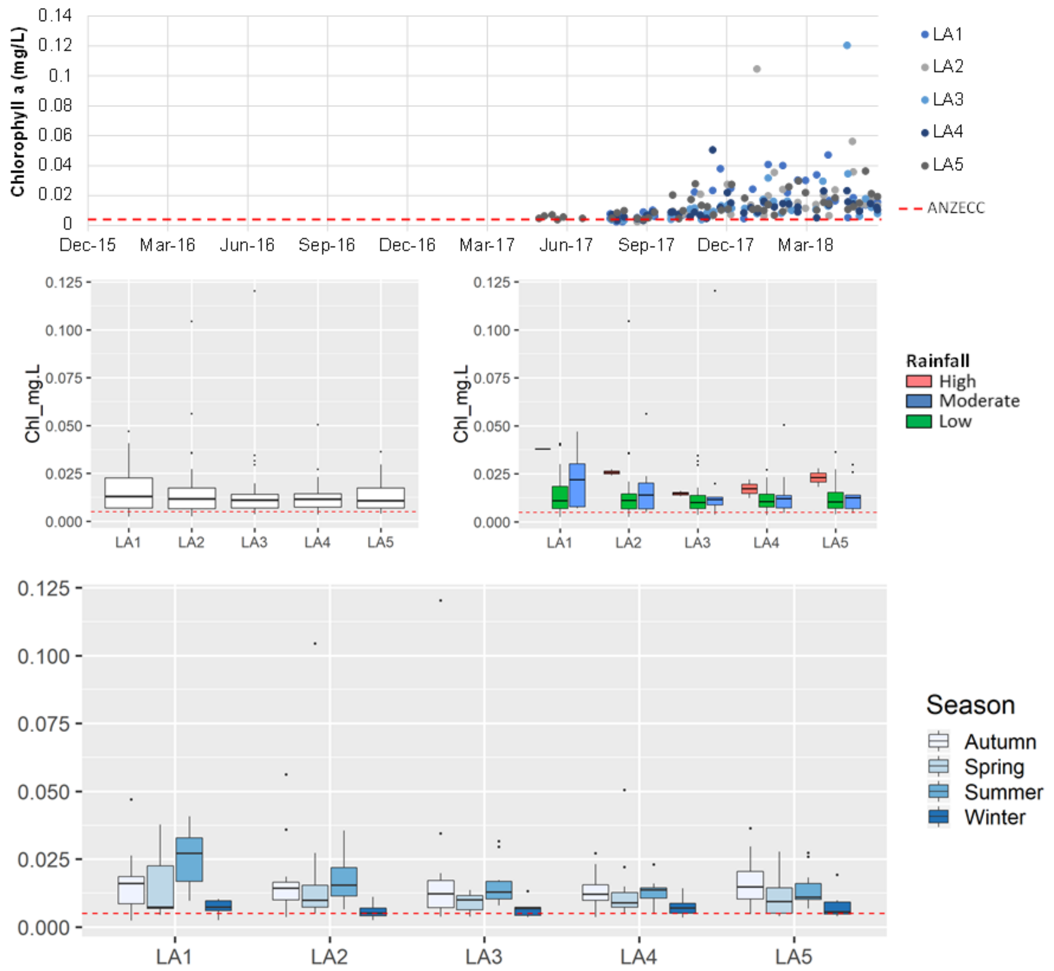


Figure 34: Lake Ainsworth Chlorophyll *a* (Chl-a) Dec 2015-June 2018. Top - temporal variation; Middle left - Box plot showing range of all data at each site; Middle right - Spatial variation during low, moderate and high rainfall conditions; Bottom - Seasonal variation. ANZECC upper guideline for protection of aquatic ecosystems.

3.5.7 TN:TP ratios

The ratio between TN and TP is commonly used to infer which nutrient is potentially limiting production within the system. The uptake ratio of TN to TP during growth is typically around 16:1 for most microalgae (e.g. phytoplankton) (Redfield, 1934). Where TN:TP falls below 16 it is generally held that the system is nitrogen limited. Under these conditions, addition of nitrogen to the system would stimulate algal growth, whereas extra phosphorus would not, as the system would remain nitrogen limited. However, when N and P concentrations are consistently high, as is the case with Lake Ainsworth, then neither nutrient may ever limit algal growth, irrespective of whether the ratio is high or low. In addition to this some cyanobacteria species are able to fix nitrogen from the atmosphere, and therefore nitrogen will never be limiting for these species.

The TN:TP ratio was predominantly well below 16 at all sites in Lake Ainsworth between Dec 2015 and June 2018 suggesting that the system tends toward N limitation. However, considering the points made above, it will be important that management effort in Lake Ainsworth focuses on reducing both bioavailable nitrogen and phosphorus in the water column.

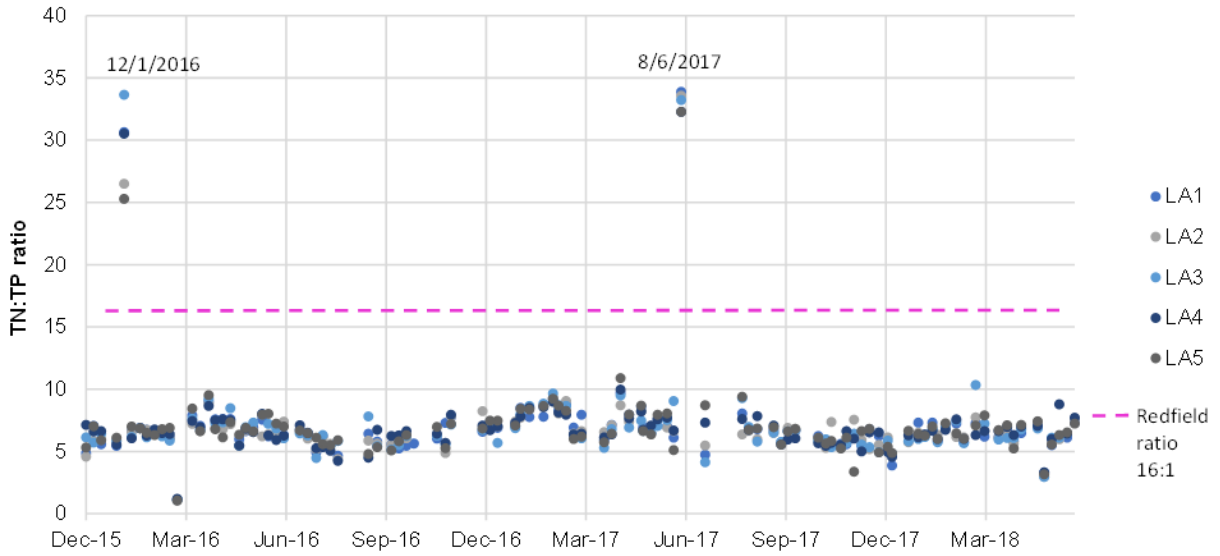


Figure 35: TN:TP ratio

3.5.8 Change in average nutrient concentrations over time

Historic water quality information is available for two time periods: 1993-1996 (reported by AWACS,1996); and 1998-1999 (reported by DPWS & MHL, 2001). While there are low sample counts from historical data compared to present (e.g. n=20 for TP 1993-1996 compared to n=600 in 2015-2018), it is considered sufficient to establish a baseline for comparison to present day water quality (i.e. approximately monthly sampling over at least 2 years recommended by ANZECC, 2000). Not all parameters were captured in both datasets and therefore current trends are compared to the applicable historic sets only (e.g. PO_4 not assessed in 1993-1996; and TP not assessed in 1998/99).

Table 11 presents the historical nutrient water quality information for Lake Ainsworth. Key outcomes of this comparison are summarised as follows:

- Ammonia concentrations increased by 59% from 1996 and 290% from 1999 to present.
- Nitrate concentrations were variable with a decrease of 92% observed since 1996, and an increase of 300% from 1999 to current.
- Total nitrogen has decreased 38% since 1996.

- Total phosphorus has increased 89% since 1996 and dissolved inorganic phosphorus has increased 441% since 1999.
- Chlorophyll *a* has remained constant since 1996, indicating that although there has been a significant increase in available phosphorus, this has not translated into a similar increase in algae and therefore something else must be limiting algal growth (e.g. natural ecosystem components such as light availability, temperature and turbulence). Note that even though Chlorophyll *a* has not increased through time, both the historical and present day levels are more than double the recommended levels for healthy aquatic ecosystems.

Table 11: Change in average nutrient, Chlorophyll *a*, and DO concentrations over time

Years	TN (mg/L)	NH_4 (mg/L)	NO_3 (mg/L)	TP (mg/L)	PO_4 (mg/L)	Chla (mg/L)	DO (mg/L)	Data Source
1993-1996	1.265	0.050	0.504	0.063	-	0.014	-	AWACS (1996)
n	20	20	22	21	-	12	-	
1998-1999	-	0.021	0.010	-	0.020	-	7.21	DPWS&MHL(2001)
n	-	21	22	-	22	-	22	
2015-2018	0.780	0.080	0.040	0.120	0.110	0.014	7.470	BSC (2018)
n	559	559	559	600	530	219	455	
change from 1993-1996 to current (mg/L)	-0.49	0.03	-0.46	0.06	-	0.000	-	
% change	-38%	59%	-92%	89%	-	0%	-	
change from 1998-1999 to current (mg/L)	-	0.06	0.03	-	0.09	-	0.26	
% change	-	290%	300%	-	441%	-	4%	

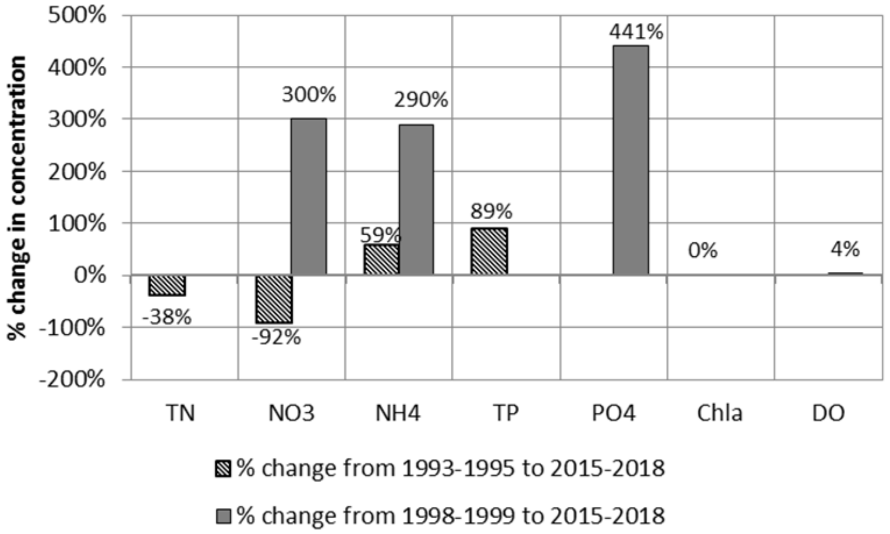


Figure 36: Percentage change in concentration of nutrients, Chlorophyll *a* and dissolved oxygen

3.6 Recreational Water Quality - Beachwatch

The water quality of beaches and other swimming locations is monitored under the NSW Government's Beachwatch programs to provide the community with accurate information on the cleanliness of the water and to enable individuals to make informed decisions about where and when to swim (OEH, 2018). Routine assessment also measures the impact of pollution sources, enables the effectiveness of stormwater and wastewater management practices to be assessed and highlights areas where further work is needed (OEH, 2018).

Contamination of recreational waters with faecal material from animal and human sources can pose significant health problems to beach users owing to the presence of pathogens (disease-causing micro-organisms) in the faecal material. Health risks include gastroenteritis, with symptoms including vomiting, diarrhoea, stomach-ache, nausea, headache and fever; and eye, ear, skin and upper respiratory tract infections if pathogens come into contact with broken skin or membranes in the ear and nose. Certain user groups may be more vulnerable than others including children, the elderly or immune-compromised people (OEH, 2018).

Four swimming sites are routinely monitored at Lake Ainsworth as part of the Beachwatch Program. The Beachwatch annual report documented the following results for 2017/2018 (OEH, 2018):

- Three of the four lake swimming sites were graded as poor: Lake Ainsworth North, Lake Ainsworth East and Lake Ainsworth West.
- Elevated enterococci levels were experienced at these sites during dry and wet conditions
- Swimming should be avoided during and for up to three days following rainfall or if there are signs of stormwater pollution such as turbid/murky water or floating debris.

Beach Suitability Grades for Ballina Shire Council lake/lagoon swimming sites

Results for individual sites are provided in Figure 37 to Figure 40. Lake Ainsworth North and West sites displayed the highest levels of enterococci. Previous analysis by BSC confirmed that Lake Ainsworth West harboured significantly more enterococci than Lake Ainsworth East and Lake Ainsworth South (BSC, 2017a). All sites showed a correlation between increased levels and increasing rainfall indicating faecal matter is washed into the lake from land surfaces during rainfall, rather than originating from leaking sewage pipes which would present a more constant source of contamination.

Plate 7: Recreational use of Lake Ainsworth

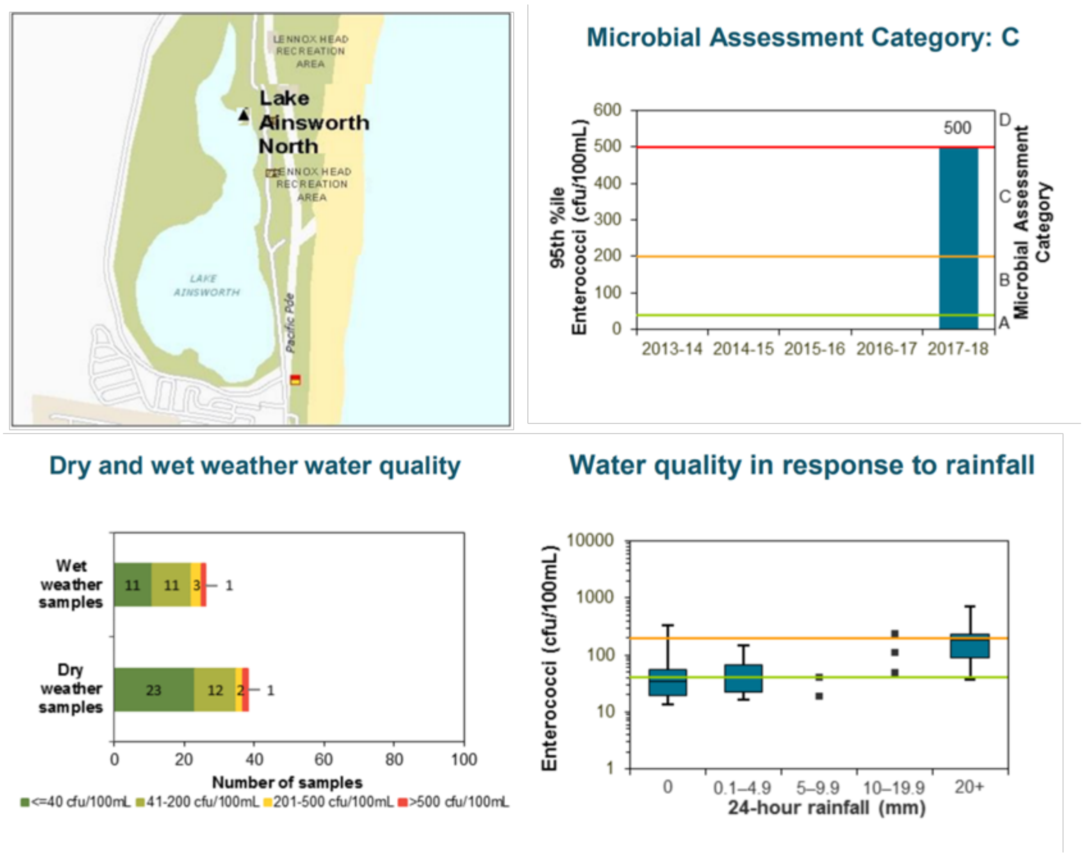


Figure 37: Beachwatch annual results Lake Ainsworth North site

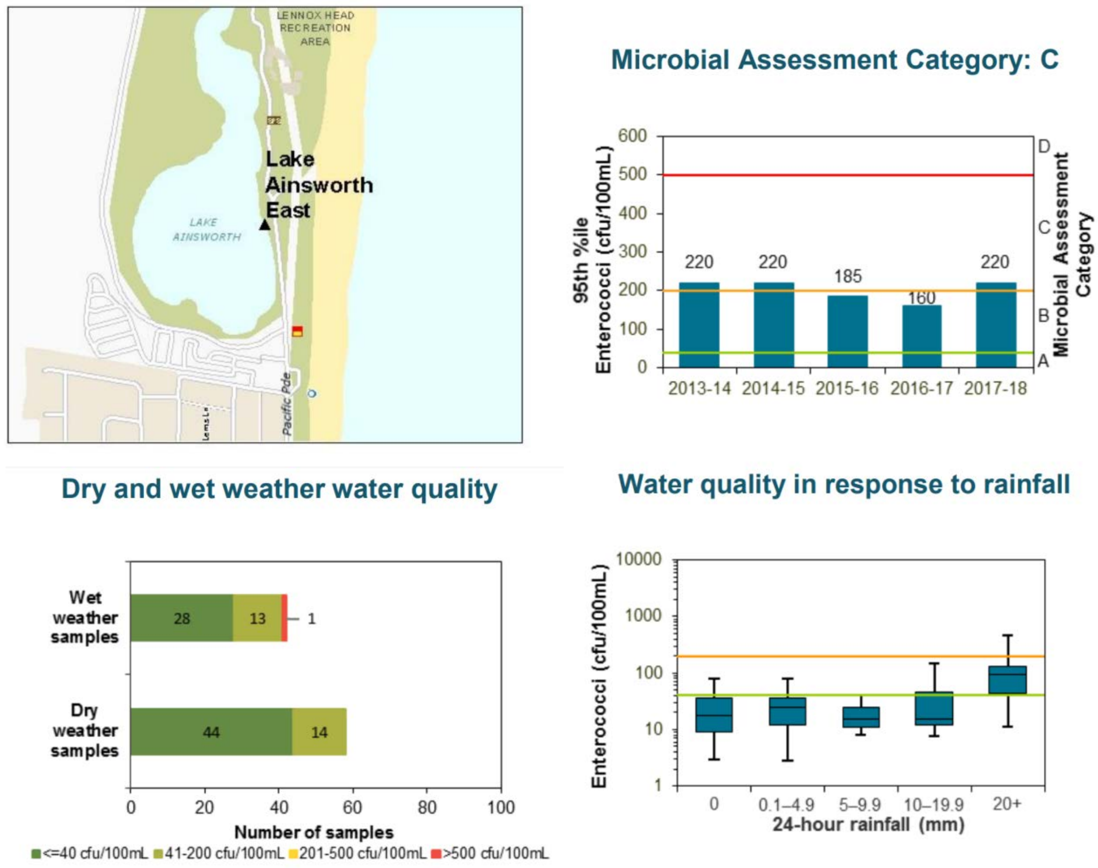


Figure 38: Beachwatch annual results Lake Ainsworth East site

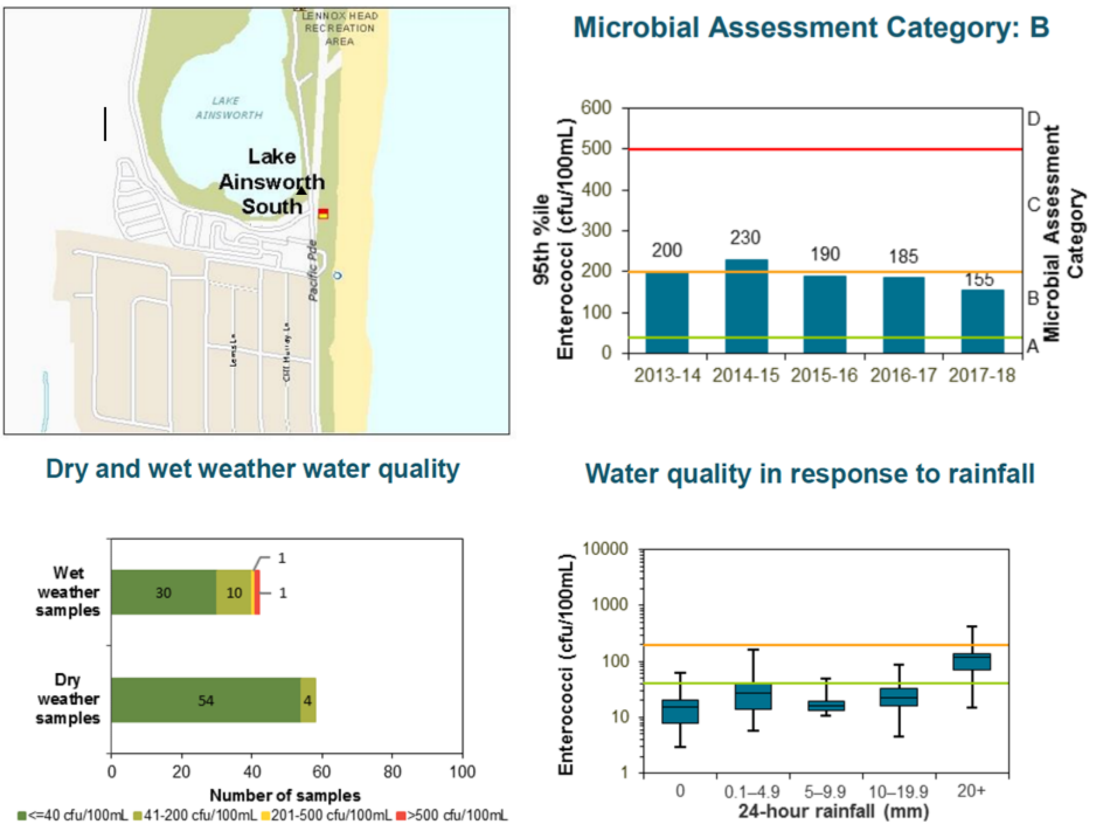


Figure 39: Beachwatch annual results Lake Ainsworth South site

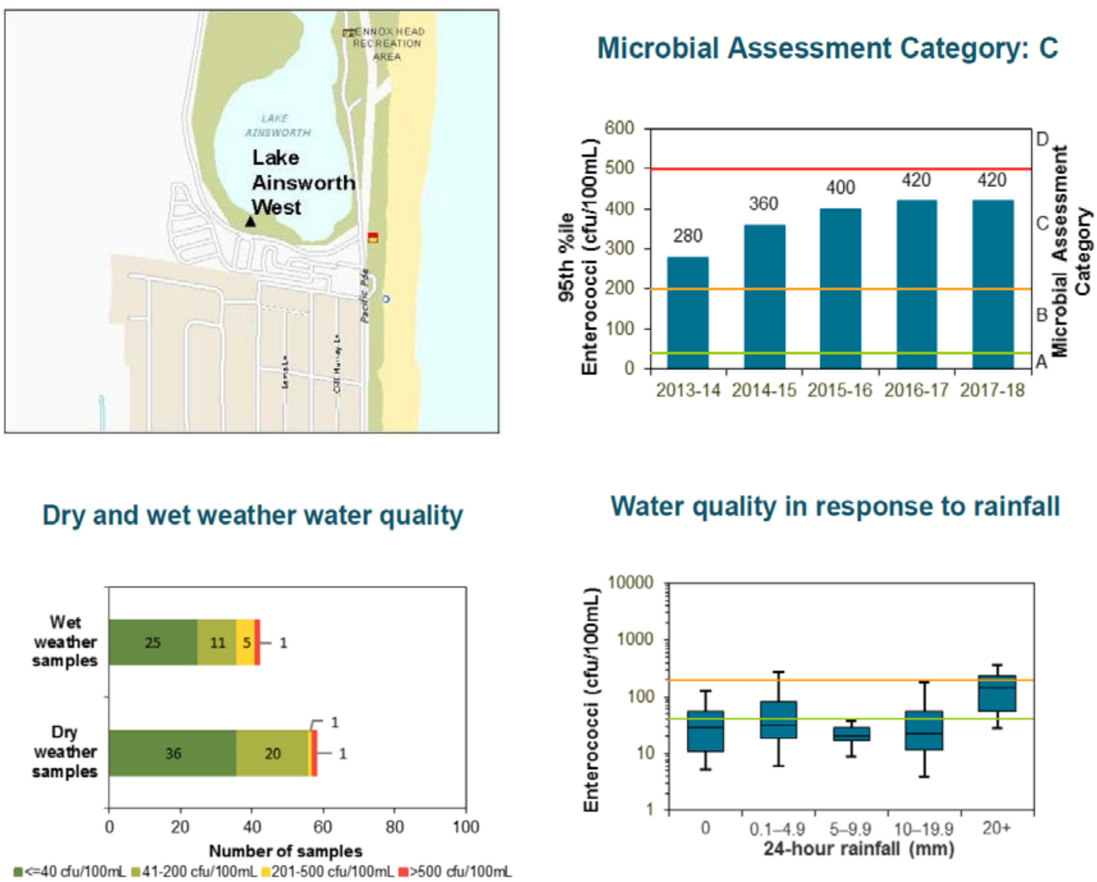


Figure 40: Beachwatch annual results Lake Ainsworth West site

3.7 Blue Green Algae (cyanobacteria)

3.7.1 What are they?

Blue green algae are actually not algae at all, but types of photosynthetic bacteria known as cyanobacteria. Cyanobacteria are a natural part of the freshwater environment and are one of the oldest forms of life on earth with fossil stromatolites in Western Australia containing remains of blue-green algae that are around 3.5 billion years old (Sainty and Jacobs, 2003). Low levels of cyanobacteria are present in freshwater all the time, but when conditions are favourable, a 'bloom' can develop to a point where there is discolouration, scum formation, unpleasant tastes and odours, effects on fish populations and a reduction in overall water quality. Some species can produce toxins, and when toxin concentrations are high enough they can be harmful to recreational users and animals that come into contact with the cyanobacteria (e.g. skin and eye irritations, nausea, vomiting, muscle weakness or cramps). In some species, the toxins are released to the water column after the cyanobacteria die and begin to decompose.

3.7.2 Toxicity

Species of potentially toxic cyanobacteria that have occurred in Lake Ainsworth include: *Dolichospermum* (formally *Anabaena*) *circinale, Lyngbya spp., Microcystis spp*., and *Oscillatoria spp* (BSC, 2017a). Results from genetic testing conducted by BSC in November 2014 indicated that there were no genes present that produce harmful toxins in blooms of *D. circinale*. More recent testing undertaken in January 2017 and March 2018 indicate that the MycE gene was present in recent blooms of *Microcystis aeruginosa*, indicating that it is likely that toxins are being produced by this species. The hepatotoxins produced by *Microcystis aeruginosa* are known to have acute effects on liver function at high doses which may lead to severe illness or even death (if ingested at high doses). Carcinogenic and/or tumour growth rate promotion effects have also been documented from sub-acute doses (Sainty and Jacobs, 2003). Recent research has also drawn links with environmental toxins such as those associated with in certain types of blue green algae to a range of neurological diseases (Murch *et al.*, 2004; Dunlop *et al.*, 2013; Price, 2013), however further study is required to better understand the risks associated with recreational exposure. Decomposing cyanobacteria can also cause depletion of oxygen and induce fish kills (CSIRO, 2018).

Cyanobacterial toxins have been shown to bioaccumulate in aquatic organisms such as shellfish, prawns and fish, and have previously resulted in restrictions on the collection of these organisms from other lakes in Australia (Mulvenna *et al.*, 2012; Meriluoto and Spoof, 2008; and Van Buynder *et al.,* 2001). The level of toxins present in fish and shellfish of Lake Ainsworth is currently unknown.

Plate 8: Cyanobacteria bloom, Lake Ainsworth 6/12/2008 (Source: BSC, 2008)

3.7.3 Causes of cyanobacteria blooms

Cyanobacteria may dominate and increase excessively in water when:

- There is adequate nutrient supply;
- There is adequate light;
- Water is still and turbulence is low;
- Weather is warm (although blooms can occur in cooler weather too); and
- Weather patterns are stable for an extended period.

A key characteristic of cyanobacteria is their buoyancy, which enables floatation during periods of low turbulence when other species tend to sink below the diurnal (day time) thermocline. The depth of the diurnal thermocline changes in response to wind mixing and air temperature and consequently on warm, calm nights a shallow thermocline persists. As the thermocline deepens, the phytoplankton are mixed deeper and spend more time out of the euphotic zone (zone at which photosynthesis occurs) and may become light limited. Under these conditions, floating cyanobacteria have a competitive advantage relative to other taxonomic groups, namely diatoms and green algae and can quickly become the dominant species. Species such as *Microcystis aeruginosa* and *D. circinale* have maximal growth rates when the diurnal thermocline is approximately the same depth as the euphotic depth (Brookes *et al.,* 2008).

Another important adaptation is the ability of many species to fix nitrogen from the atmosphere. It is believed that this ability, most notably present in *D. circinale and Nodularia* may be a key factor in sustaining growth in waters containing low available nitrogen concentrations. This is not the case for all species, including the common bloom-forming genus *Microcystis,* which is common in Lake Ainsworth but does not fix nitrogen (Sainty and Jacobs, 2003).

Although cyanobacteria are often perceived as a symptom of eutrophication, the paradox is that they do not require high concentrations of nutrients to reach relatively high biomass (Brookes, *et al.*, 2008; Sainty and Jacobs, 2003). Concentrations of phosphorus less than 0.01 mg/L dissolved inorganic phosphorus (PO_4-P) are considered to be growth limiting (Sas,1989) and 0.1 mg/L soluble inorganic nitrogen is considered the minimum concentration to maintain growth during the growing season (Reynolds, 1992). Higher concentrations however, support rapid growth. The dissolved PO_4-P concentrations current in Lake Ainsworth are well in excess of these minimum requirements with median levels at 0.118mg/L (over 10 times the minimum). Median values of soluble inorganic nitrogen (the sum of nitrate, nitrite and ammonia) are closer to the minimum requirement with a median value of 0.117mg/L. As cyanobacteria require both phosphorus and nitrogen to grow, this tends to suggest that management would be best directed at reducing soluble nitrogen to limit cyanobacterial growth. However, as discussed above it is known that Lake Ainsworth harbours species of cyanobacteria that are able to fix atmospheric nitrogen when needed, so it is unlikely that this strategy would be effective at reducing these species. Such a strategy may see a reduction in the species unable to fix nitrogen (e.g. *Microcystis*), but it is likely that the nitrogen fixers will dominate with no overall reduction in cyanobacteria numbers.

The high nutrient levels in the lake suggest that nutrients are not limiting algal growth, however the excess nutrients are likely to support rapid growth of algae once other requirements (i.e. light, low turbulence and stable, warm weather) are met and this has been seen repeatedly played out in the lake with blooms forming during extended periods of warm, calm weather.

Recent research has also found that overstocking of fish can trigger cyanobacteria blooms. The theory proposes that larger predatory fish eat smaller fish removing pressure on small crustaceans (micro-grazers). These micro-grazers increase in biomass and have greater grazing pressure on cyanobacteria, thus reducing algal biomass and water quality improves. However, an experiment conducted in Lake Maroon resulted in a complete reverse of this situation after a second year of Australian bass stocking (Meredith, 2005). The micro-grazer population crashed and a large cyanobacteria bloom occurred. Researchers concluded that moderate fish stocking can have a positive effect on the health of a lake, but there is a threshold beyond which excessive stocking will trigger a rapid decline in water quality. Meredith (2005) concluded that top-down biomanipulation by stocking of native piscivores has only a limited application in Australia.

3.7.4 Lake Ainsworth blue-green algae monitoring results

Blue-green algae has been monitored at Lake Ainsworth since the early 1990s, although much of the earlier data collection was inconsistent and *ad hoc* in nature. For the purposes of analysis for this study results were available from 2002 onwards. Current sampling of cyanobacteria involves routine weekly sampling during the swimming season from October to April, with more frequent sampling conducted in response to alert levels in accordance with the National Health and Medical Research Council (NHMRC) *Guidelines for Managing Risks to Recreational Water* (2008). In recent years additional sampling has been undertaken during winter months to better understand conditions year-round.

Figure 41 provides an overview of cyanobacteria results from 2002 to 2018, showing cell counts for total cyanobacteria and the potentially toxic species. The red, amber and green algal alert levels are shown on the chart and are defined in Table 12 below. Over the last 16 years, levels of cyanobacteria have fluctuated substantially in the lake with no overall trends observed through time. The alert levels have been frequently exceeded with impacts on recreational use and public health risks. An analysis of alert frequency and duration is provided in the following section.

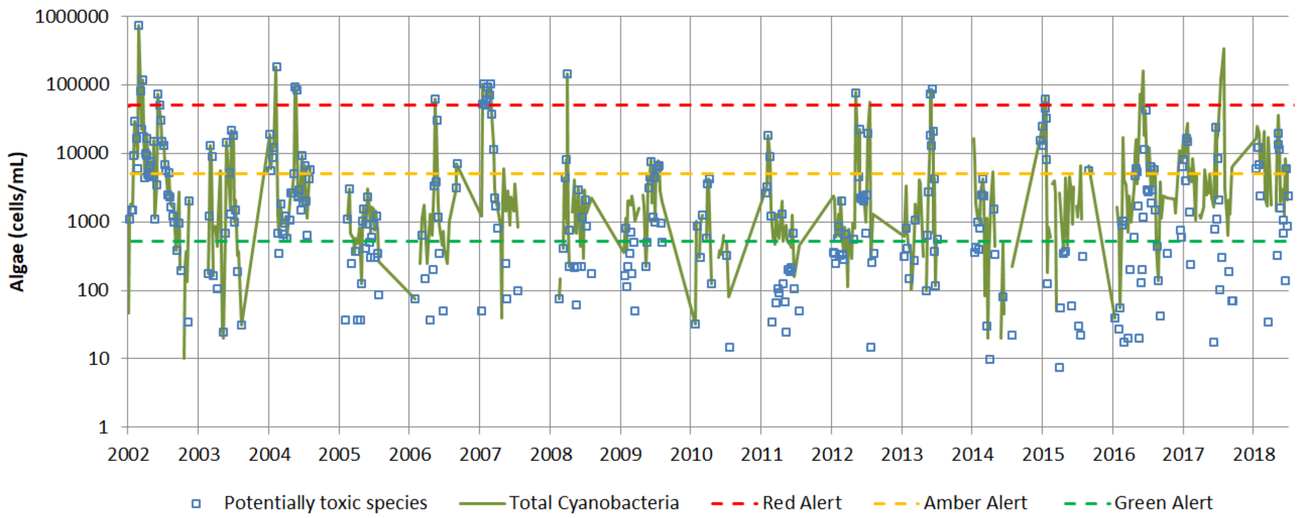


Figure 41: Cyanobacteria cell counts showing potentially toxic species and total of all cyanobacteria species.

*Note this chart uses a log scale

3.7.5 Lake Ainsworth Cyanobacteria Alert History

Table 12 presents the algae alert level definitions adopted by BSC for cyanobacteria monitoring and reporting.

Table 12: Algal Alert Definitions (Adapted from: NHMRC, 2008)

Alert Level	Triggers	Description
Red	>50,000 cells/mL of *Microcystis aeruginosa* are present or a biovolume of all toxin producing cyanobacteria exceeds 4 mm³/L. A red alert level is also triggered if the total of all blue-green algae (toxic and non-toxic) exceeds 10 mm³/L or scums are present for long periods.	Red alert levels represent 'bloom' conditions. The water may appear green and may have strong, musty or organically polluted odours. Blue-green algae may be visible as clumps or as scums. The 'blooms' should be considered to be toxic to humans and animals, and the water should not be used for drinking (without prior treatment), stock watering, or for recreation.
Amber	between 5000 and 50,000 cells/mL of *Microcystis aeruginosa* are present or the biovolume of all blue-green algae is between 0.4 and 4 mm³/L.	At amber alert levels blue-green algae may be multiplying in numbers. The water may have a green tinge and musty or organic odour. The water should be considered as unsuitable for potable use and stock watering. The water remains suitable for recreational use, however algal concentrations can change rapidly. Water users should use caution and avoid water where signs of blue-green algae present.
Green	>500 cells/mL of *Microcystis aeruginosa* are present or the biovolume of all blue-green algae is between 0.04 and 0.4 mm³/L.	At green alert levels blue-green algae are present in the water at low densities, possibly signalling the early stages of the development of a bloom, or a period where a bloom is declining. At these densities, the blue-green algae do not pose a threat to recreational, stock or domestic use.

Figure 42 shows the total duration of algal alerts issued by BSC each year since 2002, based on the algal monitoring program and the criteria given in Table 12 above. On average over the last 15 years (2002-2017), there are 86 days of the year when algal alerts were issued for the lake (24% of the time). Red alerts, signifying ‘bloom’ conditions and where swimming is not recommended were issued on average 7 days each year with many years have no red alerts and some years having as many as 47 days (2007) of lake closure. Alert duration has varied through time, but no obvious increasing or decreasing trends are apparent. Figure 43 shows that the majority of red and amber alerts occurred in spring, followed by summer. While the overall duration of alerts was greatest in summer, this was dominated by green alerts with no restrictions on recreational use of the lake.

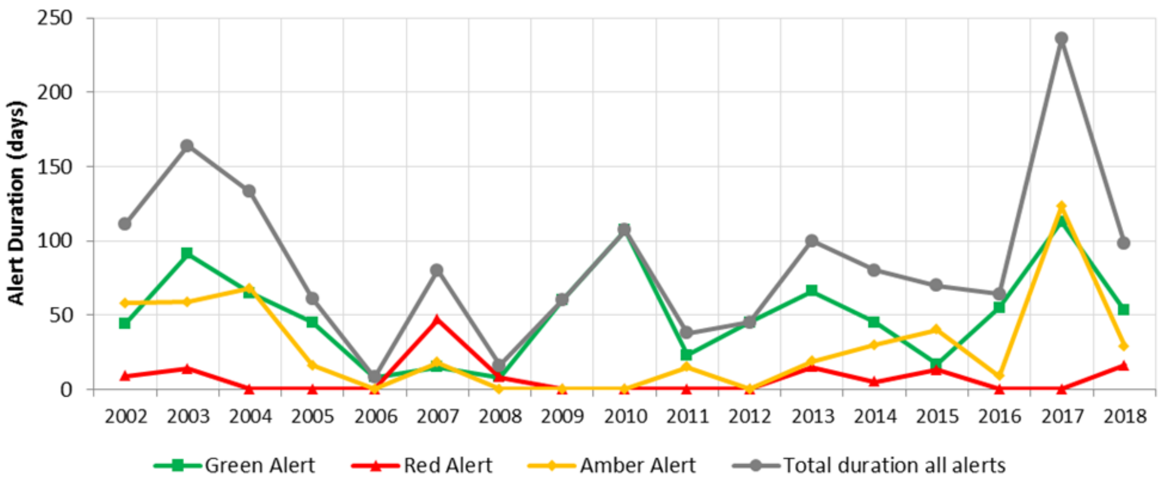


Figure 42: Total duration (days) of cyanobacteria alerts 2002- June 2018

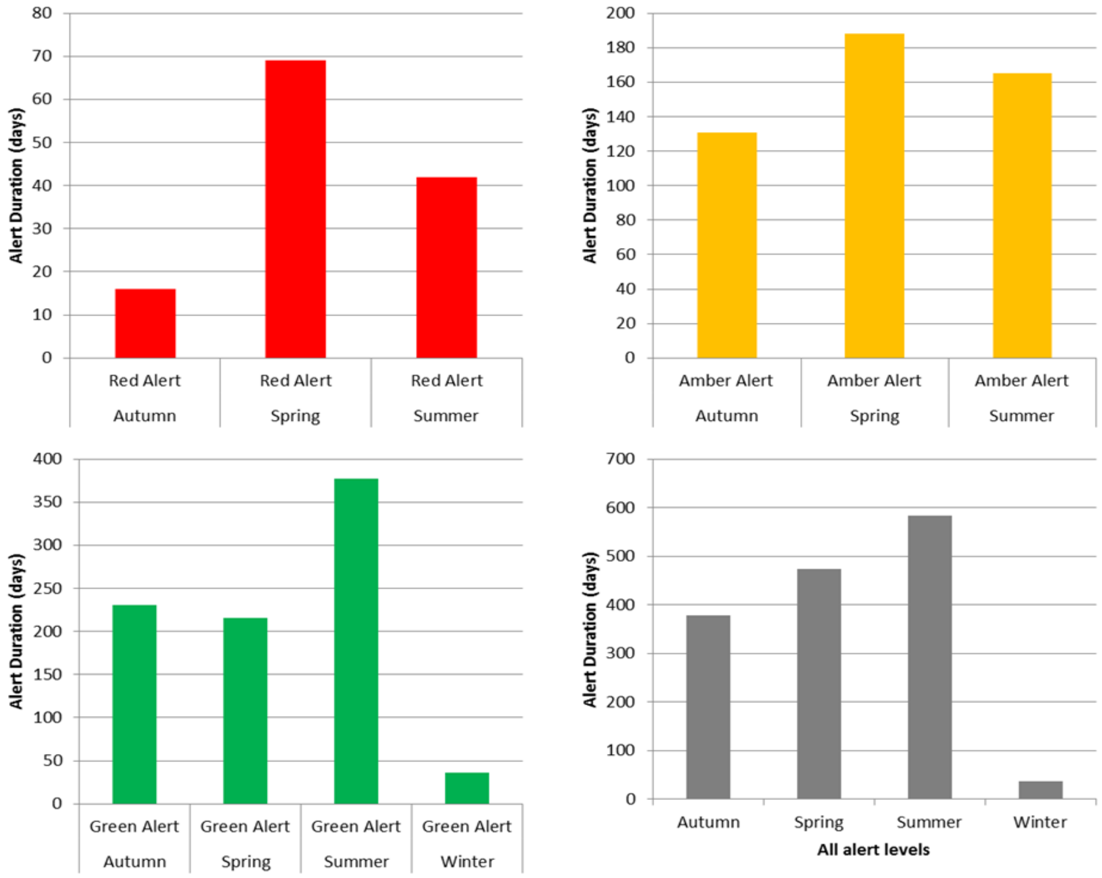


Figure 43: Seasonal variation in cyanobacteria alerts 2002- June 2018

3.7.6 Management options

Cyanobacteria are a natural part of the aquatic environment and it is likely that management will never be able to completely prevent algal blooms. Therefore the aim of management is to reduce the severity and duration of blooms at Lake Ainsworth to improve ecosystem health and reduce human health risks.

Although many methods for cyanobacterial blooms control are available, there is no ‘one-size fits all’ solution. The potential effectiveness of methods is influenced by a variety of circumstances such as the type and the size of the lake, retention time, the tropic degree and size of nutrient load, water chemistry, the quality and amount of sediments, a season etc. Generally the combination of several measures has a better chance to succeed than a single treatment.

A number of strategies are available to reduce the incidence or severity of blooms, including:

- Physical controls, such as artificially mixing the water column to create turbulence, break down thermal stratification or transport surface algae deeper in the water column where it cannot survive;
- Minimising nutrient levels in the water column available for biological uptake including both reduction of ongoing inputs of nutrients (e.g. catchment sources, human inputs) and methods to reduce internal nutrient release from sediments;
- Bio-manipulation techniques where the food web is altered to enhance predation of cyanobacteria;
- Restricting sunlight on the water surface (not usually feasible in natural systems); and
- Chemical controls, such as algicides (not usually feasible in natural systems).

In addition, it is common for members of the public to still swim in the lake when swimming closures are active. At these times, people will often comment on the lack of visual indicators of algal risk and assume that the water is safe. In addition to Council's current procedures, provision of additional information to the public regarding risk factors associated with cyanobacteria blooms should be undertaken to allow community members to make more informed decisions regarding swimming in the lake during closure periods. A review of the current signage used during alert periods is also recommended to ensure effective communication of risks and closure status.

Table 35 in Section 7 presents a preliminary assessment of the potential effectiveness of various management options at Lake Ainsworth. Options recommended for further consideration will be assessed in detail as part of Stage 3 of the CMP: Response Indication and Evaluation.

3.8 Review of Aerator Program

3.8.1 Background

Stratification is the physical layering of the water column resulting from density differences caused by temperature variation (OzCoasts, 2018). Usually, shallow (e.g. 2-3 m), wind-exposed lakes are non-stratified. Lakes of intermediate depth (e.g. 5-7 m) may develop transient thermal stratification for a few calm and sunny days, which is then disrupted by the next rain or wind event. In temperate climates deeper lakes can exhibit a stable stratification from spring to autumn. The formation of stratified conditions can influence light intensities experienced by cyanobacteria, bloom formation, dissolved oxygen and nutrient levels in the water (Newcombe *et al.*, 2010).

Before November 1997, Lake Ainsworth was experiencing intense stratification during the warmer months between October and March (Perkins *et al.*, 2015). AWACS (1996) reported that the stratified conditions were likely to be providing favourable conditions for cyanobacterial blooms due to a largely undisturbed water column and accelerated nutrient release from the sediments caused by low oxygen conditions on the lake floor.

In November 1997, an aerator was installed to destratify the lake and increase dissolved oxygen levels with the aim of reducing nutrient release from bottom sediments and therefore reducing the occurrence of cyanobacteria blooms. Figure 44 shows the typical water circulation patterns induced by a bubble plume aerator, mixing bottom waters upwards to the surface layers and also inducing some lateral movement of water. The Lake Ainsworth aerator is located in the deepest section of the lake at approximately 9m depth, is bar-shaped, 75m long and consists of 25 bubble fountains separated at 3m intervals through a cluster of five 1.5mm diameter holes (Perkins *et al.* 2015). The aerator operates for 12 hours each 24 hour period, generally during the night between September and April (BSC, 2017a). Plate 9 shows the bubbles reaching the surface due to aerator operation in October 2018. Plate 10 is a side-scan sonar image of aerators in operation, showing the bubble plume from the bottom of the lake at approx. 8.8m to the surface.

Previous study has reported that the aerator has achieved at least partial destratification and has been successful in maintaining elevated levels of dissolved oxygen (NSW Department of Public Works and MHL, 2001; Perkins *et al*. 2015). However, the effect of the aerator on nutrient levels and cyanobacterial blooms has not been conclusively assessed to date.

MHL (2001) conducted an assessment of aerator success, and concluded overall that there was insufficient data to assess links between algal blooms and aerator function. However, it was noted that maximum cyanobacterial numbers occurred when mixing was at its best, while numbers decreased when stratification was present in early January and early March. While this was a once-off measurement, it does suggest further investigation is required to determine the effect of the aerators on cyanobacterial numbers.

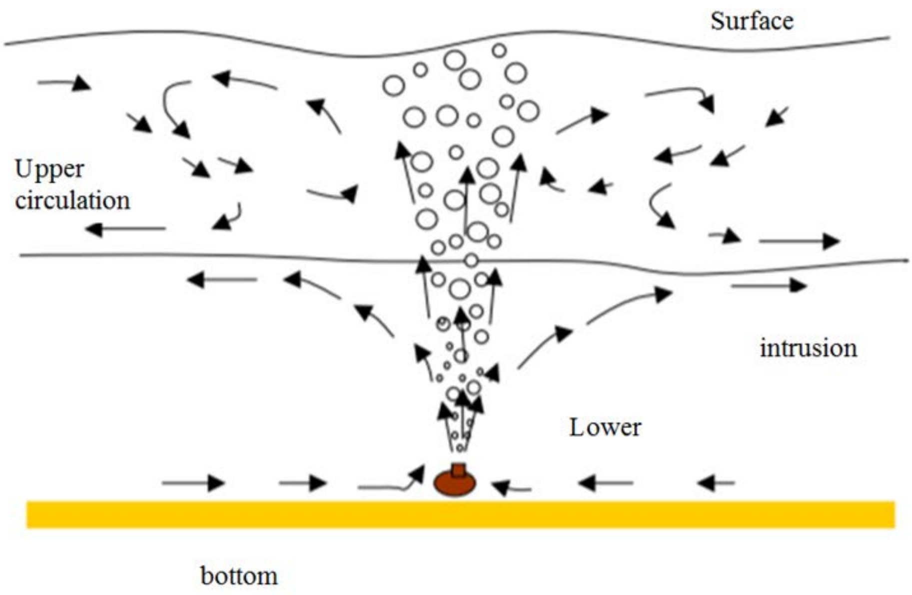


Figure 44: Typical water circulation around a bubble plume aerator (Source: Brookes *et al.*, 2008)

Plate 9: Aerators in operation 25th October 2018

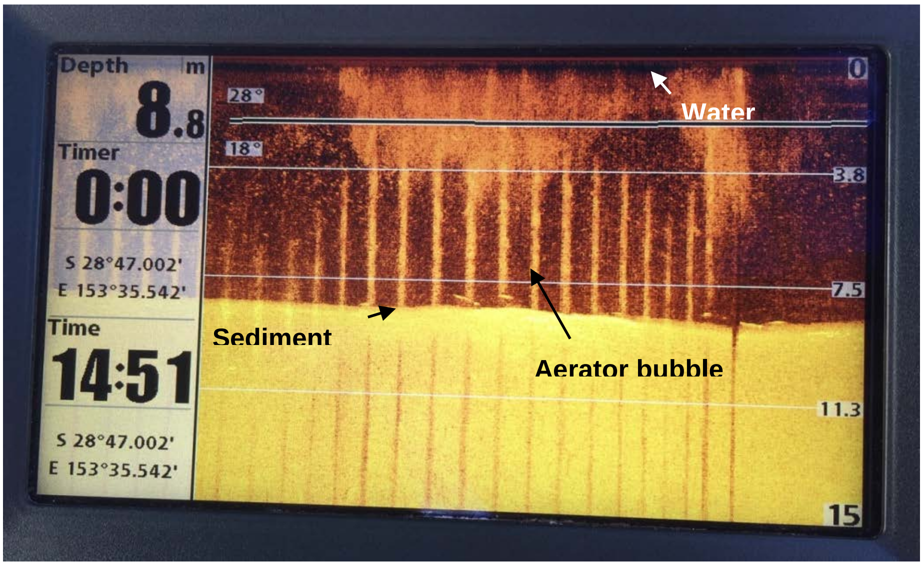


Plate 10: Side-scan sonar image of aerators in operation 25th October 2018

3.8.2 Review of existing water quality data

Despite the success of the aerators in breaking down stratification in the lake, elevated nutrient levels persist in the water column and appear to have increased over time since the aerators were installed, particularly with regard to bioavailable forms (refer Section 3.5). Current average total phosphorus concentrations (measured from 2015-2018) are almost double the levels measured in 1995 and current dissolved inorganic phosphorus levels are up to four times the levels measured in 1998/99 (Figure 30). Current total nitrogen concentrations have reduced compared to 1993-1995 levels. The bioavailable forms of nitrogen (NO_3 and NH_4-N) have varied over the sampling periods, increasing by 5 and 4 times respectively compared to 1993-1995 levels. These results indicate that either the aerator program is not effective at controlling the release of nutrients from sediment, despite apparent improvement in dissolved oxygen conditions throughout the water column, or nutrient sources/inputs other than sediments have more influence than previously estimated. As discussed in Section 3.5, the current water quality monitoring program has not identified any significant nutrient sources from the catchment and therefore it is most likely that sediment remain as the primary source of nutrients to the lake.

The *Lake Ainsworth Management Study* (DPWS and MHL, 2001) discussed the possibly that while the aerators are successful at reducing stratification while functioning, when switched off and particularly during hot summer days, stratification may form again. During the temporary stratified state, nutrients may be released into the benthic waters. When the aerators are turned on again at night, nutrients may be recirculated to upper layers. The sediment-liberated nutrients would then be available in surface waters for uptake by phytoplankton and cyanobacteria in the presence of sunlight.

From recent water quality monitoring data sampled from 2015-2018, surface total phosphorus and dissolved inorganic phosphorous concentrations were substantially higher in spring and summer compared to winter and autumn (Figure 29 and Figure 30). There are seasonal factors that could partly explain higher phosphorus levels in spring and summer. These include higher water temperatures stimulating release of inorganic phosphate via microbial degradation of organic matter; and higher rainfall and therefore nutrient inputs from stormwater and catchment runoff. The effect of aerator operation during spring and summer on nutrient levels is not currently known and requires further investigation.

Surface dissolved oxygen levels were also substantially higher during winter months compared to the rest of the year (Figure 27). This can at least be partly attributed to lower water temperatures, as colder water can hold more oxygen than warmer water. However, the effect of non-operation of aerators during winter and hence the absence of mixing of low DO bottom waters to the surface cannot be ruled out as a cause for elevated DO in surface waters. It is important to note that surface DO levels (monitored as part of the routine water quality sampling program) are rarely representative of the entire water column in systems where stratification is likely. It is the DO at the sediment/water interface which is critical in determining the release of phosphorus from sediment.

In 2018, cyanobacterial blooms continue to persist at the lake, and while the duration of algal alerts over the last 15 years have fluctuated from year to year, there does not appear to be any clear trend over time (Figure 42). It is not possible to make a statistically accurate assessment of aerator effectiveness through a direct comparison of cyanobacteria concentrations measured in the lake during aerated and non-aerated conditions due to a number of confounding factors including:

- The operation of aerators (during spring and summer) coincides with the high risk conditions for cyanobacteria growth (higher temperatures, increased daylight hours, typically lower water level). Conversely, the aerators are non-operational during most of autumn and winter which coincides with lower risk conditions for algal growth;
- Cyanobacteria sampling is conducted more frequently in spring and summer according to the NHMRC sampling protocols (NHMRC, 2008), and only in response to observed conditions in autumn and winter (infrequently or not at all in some years).

However, examining measured cyanobacteria levels over all months of the year provides a qualitative overview of cyanobacteria during aerated and non-aerated conditions, providing the above confounding factors are considered (Figure 45). During aeration, total cyanobacteria concentrations were generally elevated compared to non-aerated conditions. September displayed the highest levels of total cyanobacteria and this coincides with the start-up of the aerators after non-operation through autumn and winter.

While there are many complex factors controlling algal blooms, the persistence of elevated water column nutrients and cyanobacterial blooms indicates that the current aerator program it is not sufficiently effective to reduce blooms to acceptable levels.

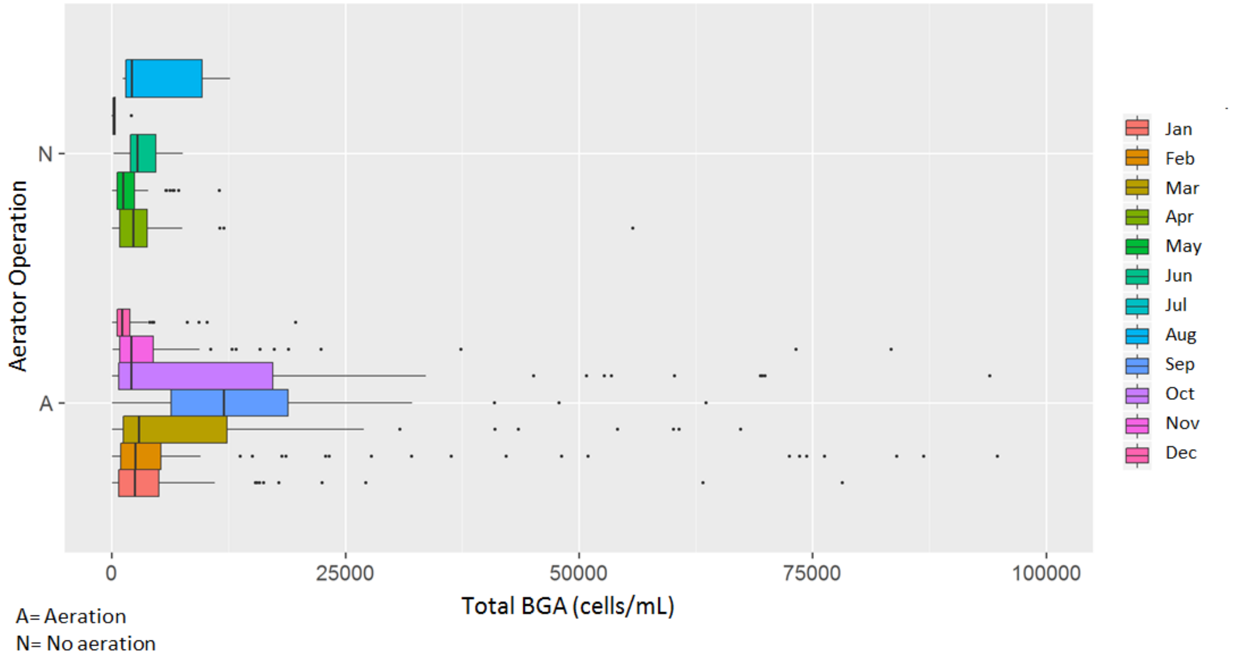


Figure 45:Total Cyanobacteria concentrations for aerated and non-aerated conditions, categorised by month from 2002-2018.

*Note maximum outliers in the data were omitted from the graph for clarity, they all occurred during aeration and were: Feb 180310; Apr 346560; Oct 185600; Nov 750922; and Dec 145600 cells/mL.

3.8.3 Case Studies

A review of the available literature was conducted to examine case studies evaluating artificial aeration as a tool to effectively manage eutrophication and improve water quality in lakes around the world. Overall there appears to be a wide range of results, with some systems being assessed as effective, others having no impact on nutrient and algae levels and some being shown to worsen conditions by redistributing nutrients from bottom waters to the surface thus stimulating algal growth in the photic zone (Table 13).

Ultimately it can be concluded from this that artificial aeration is not a 'one-size fits all' solution and systems must be tailored to individual waterbodies and monitored to ensure they are achieving intended results.

Table 13: Case studies of the effectiveness of artificial aeration in managing eutrophication in lakes

Water body name	Type/Uses	Location	Max Depth (m)	Aeration method	Reasons for aeration	Effectiveness	Source
Myponga Reservoir	Water supply reservoir	South Australia	35	Bubble plume aerator, raft-mounted surface mixers (directing warm surface layer including cyanobacteria to deeper depths) and $CuSo_4$ dosing.	Destratification, reduce Fe and Mn concs (taste and odour issues), reduce algae and cyanobacteria	The surface mixers and aerator were adequate to maintain DO at acceptable levels throughout water column and limit cyanobacteria growth to accepted levels for drinking water supply. $CuSO_4$ dosing was deemed not necessary. Surface mixers alone were capable of controlling cyanobacteria if flow rates were increased to $8m^3/s$.	Brookes, *et al*. (2008)
Various - 10 lakes	Man-made water supply lakes/dams	Auckland region, New Zealand	18-60	Bubble plume pipeline. Switched on in October run to March/April	Destratification, reduce Fe and Mn concs (taste and odour issues), reduce algae and cyanobacteria	Very effective at destratification and reducing taste and odour, algae and cyanobacteria with the exception of Lower Nihotupu which was susceptible to occasional cyanobacteria blooms.	Watson (2010)
Heinrich-Martin Dam Impoundment	Dam for recreational use	North Dakota, USA	10	Bubble plume pipeline. Switched on early summer to early winter (6 months a year)	Destratification, control nutrient release, reduce algae blooms	No significant differences in TP, Soluble Reactive Phosphorus (SRP) and TN between aerated and non-aerated conditions. Bottom NH_4 decreased under aeration while NO_3 and NO_2 increased. Aeration expanded aerobic habitats for fish and distributed bio-available nutrients through water column, stimulating algal growth.	Balangoda (2014)

Water body name	Type/Uses	Location	Max Depth (m)	Aeration method	Reasons for aeration	Effectiveness	Source
Lake Sempach and Lake Baldeaa	Natural lakes fishing, recreational use	Switzerland	87, 66	Bubble plume aerator in winter. Pure oxygen released to bottom waters as very small bubbles in summer to enhance benthic DO but avoid transport of nutrients to surface for algal growth.	Destratification, control nutrient release, improve fish habitat	P cycling not affected by increased DO in bottom waters due to aeration based on 10 year study. Study called for re-evaluation of the well accepted theoretical management strategy of limiting lake internal P cycling by maintaining an aerobic hypolimnion and sediment surface.	Gachter and Wehrli, (1998)
Lake Nieuwe Meer	Recreational boating/fishing/ swimming	Amsterdam, Netherlands	30	Bubble plume aeration	Destratification, control cyanobacteria	Shift from cyanobacterial dominance to flagellates, green-algae and diatoms. Mass of *Microcystis* 20 times lower than prior to aeration. No changes in TP and TN concentrations due to artificial mixing over 7 year study.	Jungo *et al.*, (2001)
Crystal Lake	Recreational boating/fishing/ swimming	Minnesota, USA	11m	Bubble plume aeration (16 diffusers). Aerated for 12 years before being shut off for two years.	Destratification, control nutrient release	Aeration period resulted in a two-to-three fold increase in TP, TKN, Chlorophyll *a* and decrease in secchi disk transparency over 4 year study. Summertime fish kill attributed to aeration and recirculation of BOD.	Osgood and Stiegler (1990)
Lake Tegel	Water supply, fishing, shipping and recreation	Berlin, Germany	16m	Bubble plume aeration	Destratification, control cyanobacteria	During year without aeration surface TP was 40-100ug/L, year with aeration bottom temperatures 2-3.5oC higher, P release began a month earlier and surface TP was 100-140ug/L, and increased turbulence favoured growth of some cyanobacterial species - *Aphanizomenon* and *Microcystis* over dinoflagellates.	Lindenschmidt (1997)

3.8.4 Lake Ainsworth Depth Profiles Monitoring

To assess the current effectiveness of the aerator program in Lake Ainsworth and its role in lake stratification and nutrient cycling, a water quality investigation was carried out in October 2018 (spring) and February-March 2019 (summer). Sampling methods for the two seasons are described below.

Spring sampling protocol

Water quality conditions were assessed prior to the aerators being switched on for the Spring/Summer season and at intervals after the aerators commenced operation. At the time of the initial sample, approximately 5 months (May-September) had elapsed since the aerators were last operational in the lake. Water quality was sampled at various depths across the lake to provide a comprehensive assessment of the system. The aim was to assess stratification and the effect of the aerators on disrupting stratification and overall water quality conditions.

Sampling was undertaken on 3 separate days:

1. The day prior to aerators being turned on after 5 months of inactivity over the autumn and winter months (18th October 2018);
2. Three days following aerator switch on (22nd October 2018); and
3. Six days after aerator switch on (25th October 2018).

Physico-chemical parameters were measured at fourteen sites across the lake at 0.5m increments down to 3m and then typically every 1m increment until the bottom. Figure 46 shows the location of sample sites across the lake. The deepest section of the lake was selected for nutrient and Chlorophyll *a* analysis at 0.5m, 2m, 4m and 7.5m depths. The location of sites was approximately equal to the location of sites selected for depth profiles during the *Lake Ainsworth Processes Study* (AWACS, 1996) to allow comparison.

Summer sampling protocol

Water quality conditions were assessed during typical mid-summer aerated conditions, after approximately 4 months of artificial aeration. Aerators were then switched off and conditions were monitored until stratification developed in the lake. The aerators were then switched back on and conditions were monitored to repeat the sampling conducted in spring and assess the effect of the aerators on disrupting stratification and overall water quality conditions during the ‘high-risk’ summer period. As spring sampling showed that water quality was comparable across the lake, summer sampling focussed on the deepest section of the lake as representative of conditions.

Sampling was undertaken as follows:

1. Typical summer aerated conditions (status quo), the day prior to aerators being turned off (11th February 2019);
2. Beginning the day after aerators were switched off, daily profiles of physico-chemical parameters were assessed until stratification developed (12th February – 12th March 2019);
3. Summer stratified conditions, the day prior to aerators being turned back on (13th March 2019);
4. Beginning the day after aerators were switched on, daily profiles of physico-chemical parameters were assessed;
5. Three days following aerator switch on (18th March 2019); and
6. Six days after aerator switch on (21st March 2019).

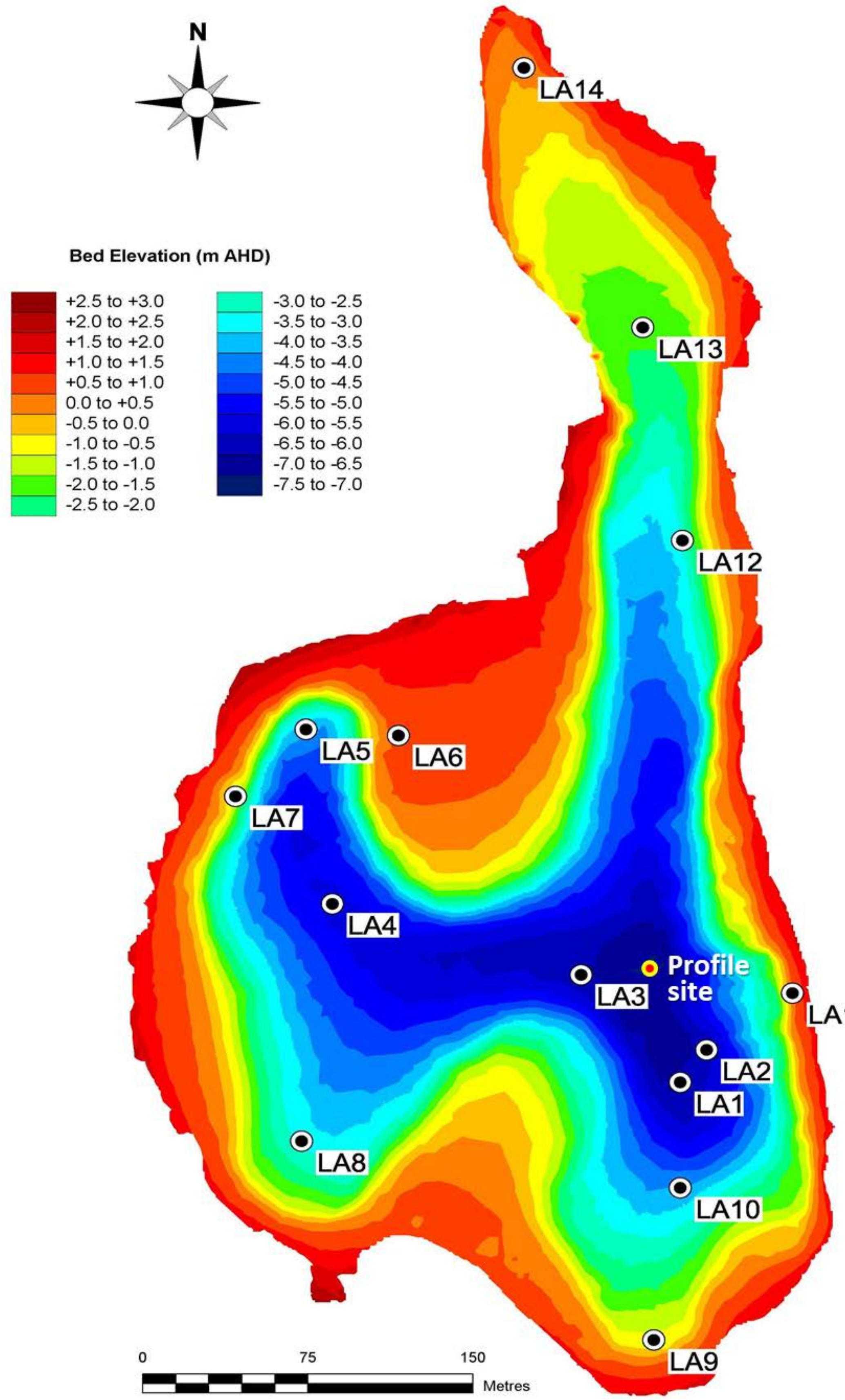


Figure 46: Depth profile sites showing bed elevation of the lake assessed July 2018

Table 14: Depth Profile site information

Site	Easting	Northing	Total water depth at time of spring sampling (m)	Description
LA1	557823	6815800	8.3	Deep basin, south east, organic rich sediments
LA2	557835	6815816	8.8	Deepest point, south east, organic rich sediments
LA3	557778	6815853	8.7	Deep basin, close to centre of lake, organic rich sediments
LA4	557665	6815888	7.6	Deep basin, west side, organic rich sediments
LA5	557653	6815974	6.2	Medium depth, north west, organic rich sediments
LA6	557695	6815971	1.3	Shallow, sandy sediments
LA7	557621	6815941	2.5	Shallow, sandy sediments
LA8	557651	6815771	5.0	Medium depth, organic rich sediments
LA9	557811	6815673	3.1	Shallow, sandy sediments
LA10	557823	6815748	6.2	Medium depth, organic rich sediments
LA11	557874	6815844	4.0	Medium depth, sandy sediments
LA12	557824	6816067	5.5	Medium depth, organic rich sediments
LA13	557806	6816172	4.1	Medium depth, organic rich sediments
LA14	557752	6816300	2.0	Shallow, sandy sediments

3.8.5 Weather and Rainfall conditions

Spring sample

An unseasonably wet spring preceded the depth profile sampling. The rainfall total for the week leading up to sampling was 185mm, with 7.8mm falling the day before the first sample (Figure 47). Winds were also quite strong with speeds up to 60km/hr predominantly from the east and south-east.

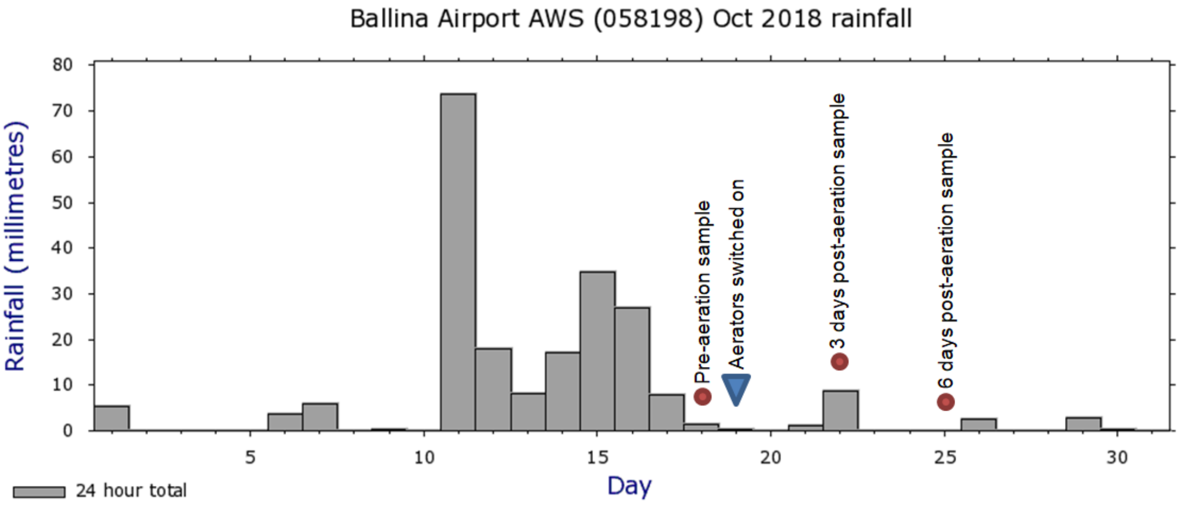


Figure 47: Ballina Airport AWS rainfall for October 2018 (Source: BOM, 2018)

Summer sample

An unseasonal dry summer preceded the depth profile sampling, with lake levels lower than in previous years. The rainfall total for January and February leading up to sampling was just 6.6mm, with 3.8mm falling in the week before the initial sample (Figure 48). In late February, Cyclone Oma dominated weather patterns causing high winds and moderate rainfall from 22nd – 25th February. Another period of moderate to high rainfall occurred after the aerators were switched back on from 16th – 19th March 2019 (Figure 49).

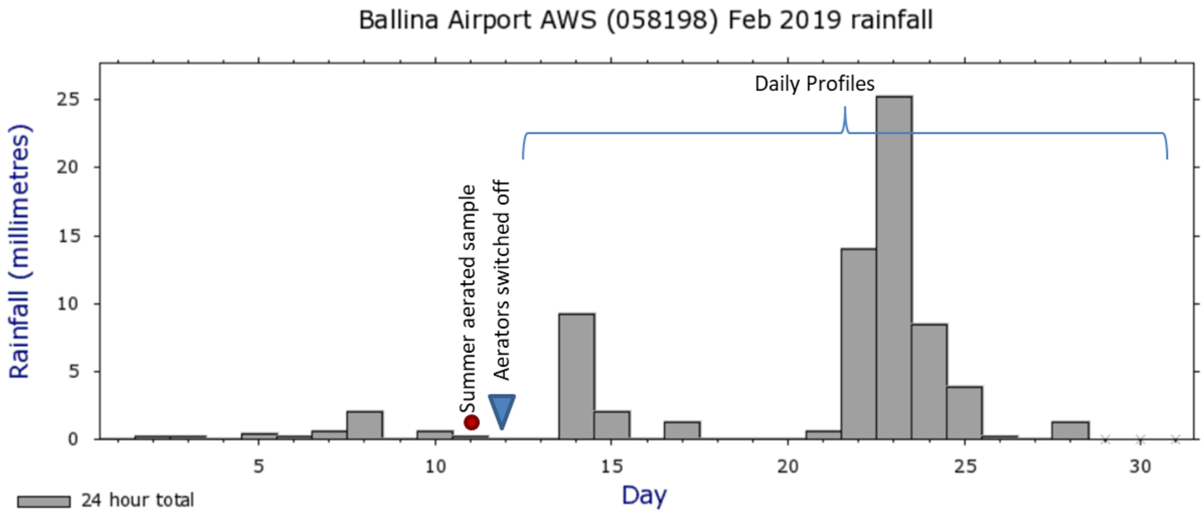


Figure 48: Ballina Airport AWS rainfall for February 2019 (Source: BOM, 2019)

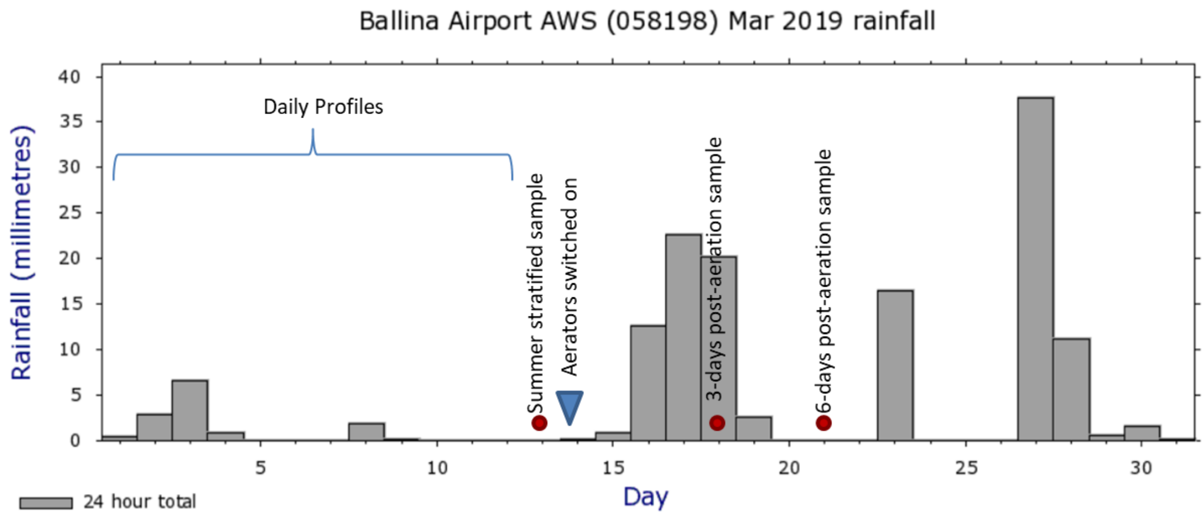


Figure 49: Ballina Airport AWS rainfall for March 2019 (Source: BOM, 2019)

3.8.6 Blue-Green Algae Status

Spring sample

Prior to spring sampling, Lake Ainsworth was experiencing elevated levels of blue-green algae. An “Amber Alert” was in place where “*between 5000 and 50,000 cells/mL of Microcystis aeruginosa are present or the biovolume of all blue-green algae is between 0.4 and 4 mm³/L*”.

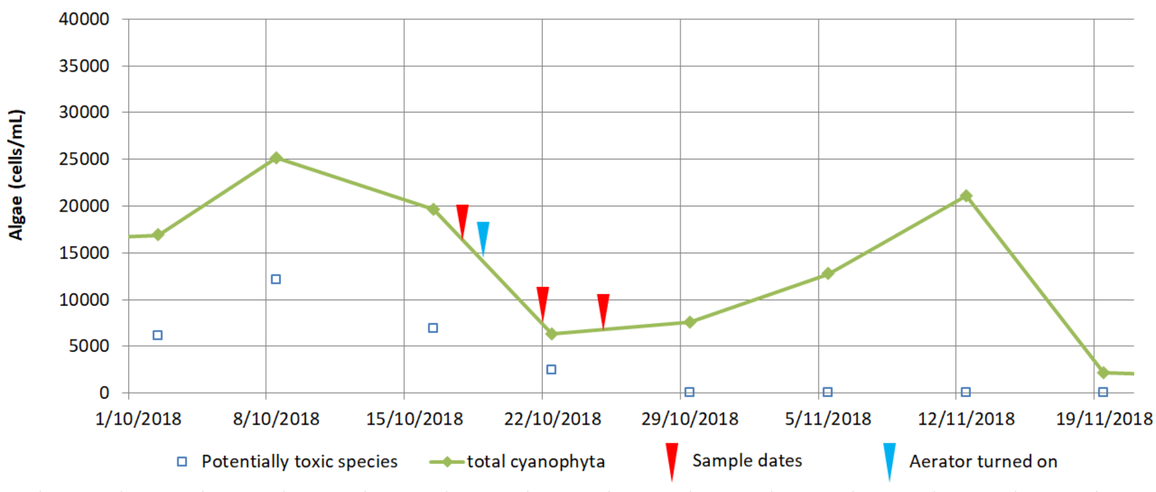


Figure 50: Cyanobacteria status spring 2018

Summer sample

Prior to the summer sample Lake Ainsworth was also experiencing elevated levels of blue-green algae. A "Red Alert" had been in place since 16th January 2019 with thick scums and slicks of cyanobacteria observed at the lake. The overall numbers of cyanobacteria had decreased prior to the start of summer sampling, and generally remained at low levels throughout sampling. However, some cyanobacteria scums were observed at some locations along the shore during sampling.

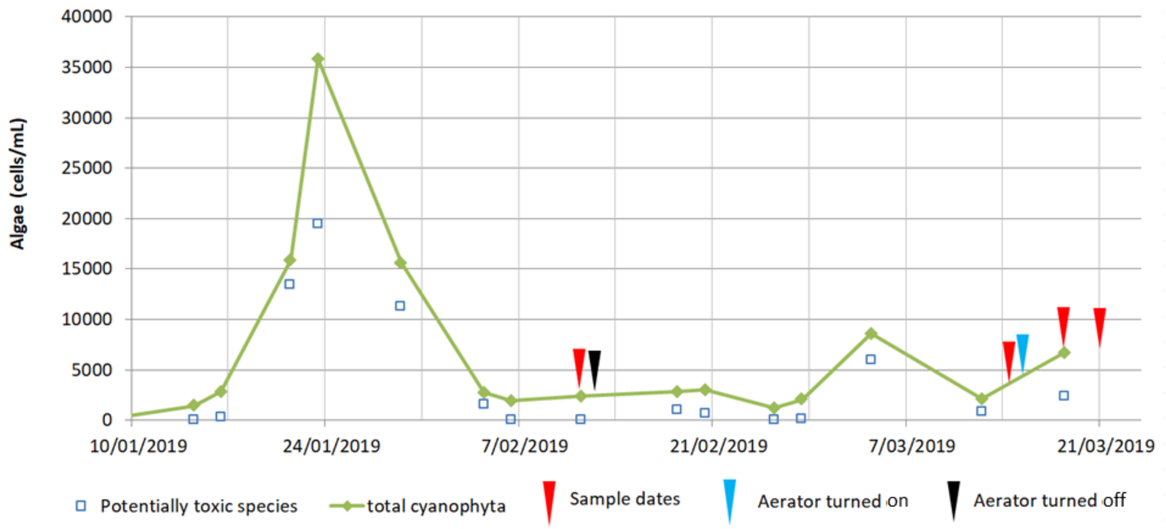


Figure 51: Cyanobacteria status summer 2019

3.8.7 Results

Spring sample

Figure 52 shows depth profile data at the deepest part of the lake during the spring sample. Despite the high rainfall and windy conditions leading up to sampling the lake was moderately stratified prior to aeration with a distinct thermocline at 3m depth across the entire lake (pre-aeration water quality is shown as red profiles in Figure 52). Post-aeration the water column was quite well mixed with generally consistent physico-chemical measurements and nutrient and algae concentrations throughout the water column. Comparison of the pre-aeration water quality with 3 and 6 days post-aeration highlights a number of changes summarised in Table 15.

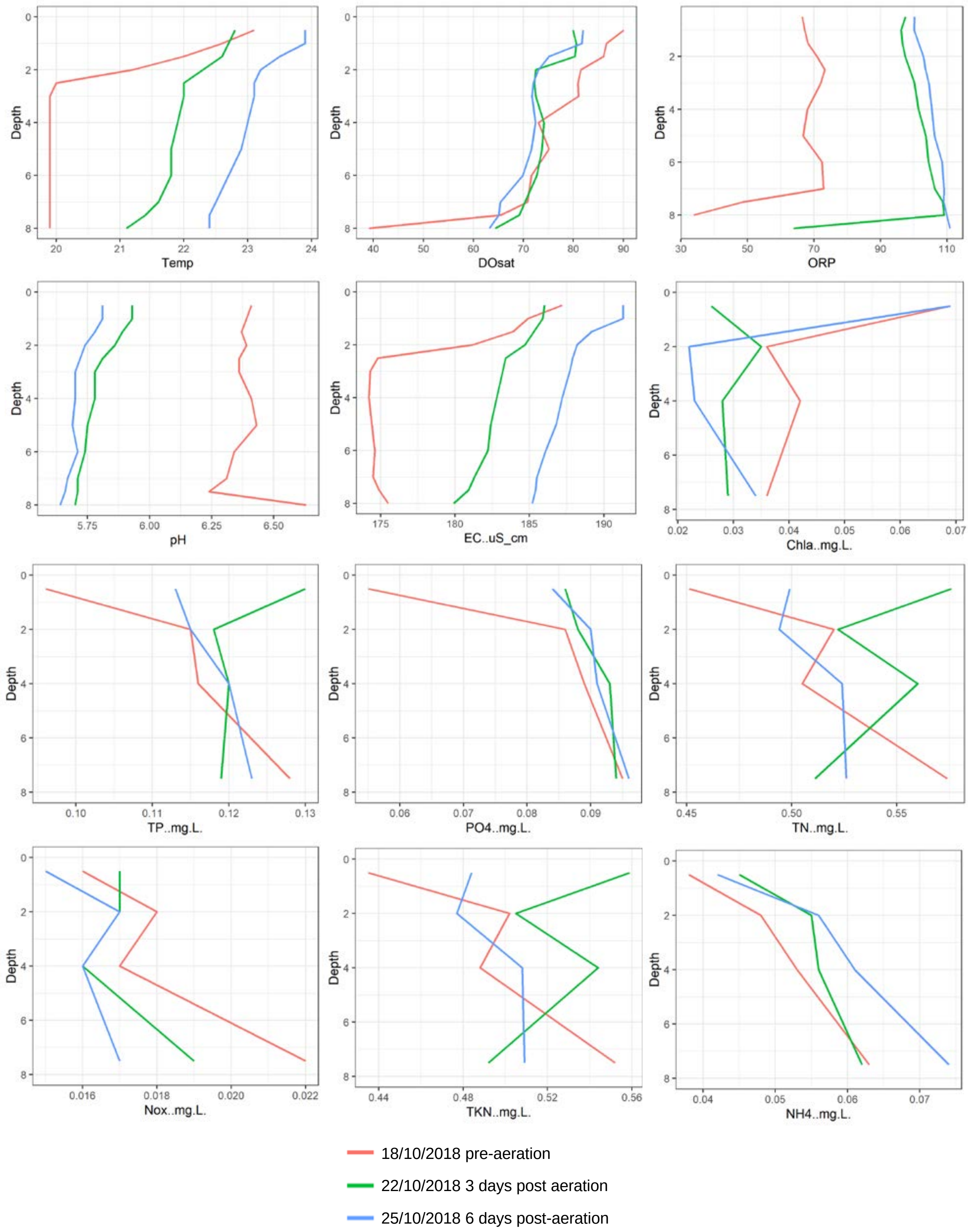


Figure 52: Depth profiles for water quality parameters in spring 2018.

Table 15: Comparison of water quality data pre- and post-aeration in spring 2018

Parameter	Pre-aeration	Post-aeration
Temperature	Water column characterised by a distinct thermocline at approximately 3m depth. Temperature decreased from surface temperatures (0.5m depth) average of 24ºC to 19.9ºC at 3m depth across all sites. Below 3m the temperature remained constant at 19.9ºC all the way to the bottom layers and this was consistent across all 14 sites.	Temperature generally increased throughout the water column and the 3m thermocline was only very weakly present, indicating mixed conditions across the lake. The exception was the top 1m, 3 days post aeration where temperature decreased slightly.
Dissolved Oxygen (DO)	DO measured in surface waters were good with levels ranging from 88-96% saturation across all sites. There was a generally decreasing trend with depth, with oxygen depleted bottom waters with DO 35-55% saturation across all sites.	DO generally decreased overall, with the greatest reduction seen in the surface layers with DO at 0.5m depth dropping from an average of 92% saturation pre-aeration to approx. 83% saturation across all sites. This could be partly due to a reduction in photosynthesis within the photic zone, corresponding to a decrease in Chlorophyll *a* and algal biomass levels at day 3. However, by day 6 Chlorophyll *a* and algal biomass had recovered to pre-aeration levels and DO remained reduced. At some of the deeper sites (e.g. LA1, LA2) DO increased slightly in bottom layers post-aeration, and this is likely due to mixing of oxygen rich surface waters. The increased DO was not significant with levels remaining below 50% saturation. It is possible that DO levels could improve with continued time under aeration, as further gas exchange with the surface occurs. Repeat sampling a few months into the aerator operation (i.e. summer sample) would be helpful to assess this.
pH	Approx. pH 6.4 and generally consistent throughout the water column, except for a slight increase near the bottom.	pH decreased at all depths to approx. pH 5.7 and was fairly consistent through the water column.
Conductivity	Stratification pattern similar to temperature with higher conductivity (187µS/cm) in surface layers, decreasing to the thermocline at 3m depth and then remaining constant at approx. 174µS/cm all the way to the bottom.	Conductivity generally increased throughout the water column and the 3m thermocline was only very weakly present, indicating mixed conditions across the lake.
ORP	Generally ORP values indicated mildly oxidising conditions (approx. 65mV), ORP was lower in bottom layers (approx.. 30mV) but still indicating oxidising conditions within the water column.	ORP increased to approx. 100mV, although at day 3 bottom ORP remained at approx. 65mV. ORP was consistent throughout the water column at day 6.
Nutrients	Stratification evident with a general increasing trend with depth.	Concentration of nutrients generally increased, particularly in surface layers and nutrients were mixed through water column. PO_4 concentrations increased by 40% in surface layers.
Chlorophyll *a* and Algal biomass	Stratification evident with higher concentration in surface water and lower concentrations fairly consistent from approx. 2m to bottom.	Concentrations in surface waters decreased initially (at 3 days post-aeration), before returning to pre-aeration levels at 6-days post-aeration.

Summer sample

Figure 53 and Figure 54 show contour charts of depth profile temperature and DO data respectively at the profile site. The large number of daily depth profiles (19) enabled plotting of a timeline of profile data over the sampling period, allowing better examination of changes in temperature and DO through time. Summer aerated conditions showed the lake was well mixed with warm (~28-29°C) oxygenated water consistent through the water column, and slight surface heating to 0.5m depth. After aerators were switched off, stratification took longer to develop than anticipated, with natural mixing events caused by wind and/or rain proving very effective at breaking down stratification. Stratification developed approximately one month after aerator switch off, with anoxia beginning to form at depth. The aerators were switched on immediately following the sampling of stratified conditions and again demonstrated the effectiveness of this setup in mixing the water column. Post-aeration the water column was quite well mixed with generally consistent physico-chemical measurements and nutrient and algae concentrations throughout the water column. Comparison of the various lake conditions sampled are summarised in Table 16.

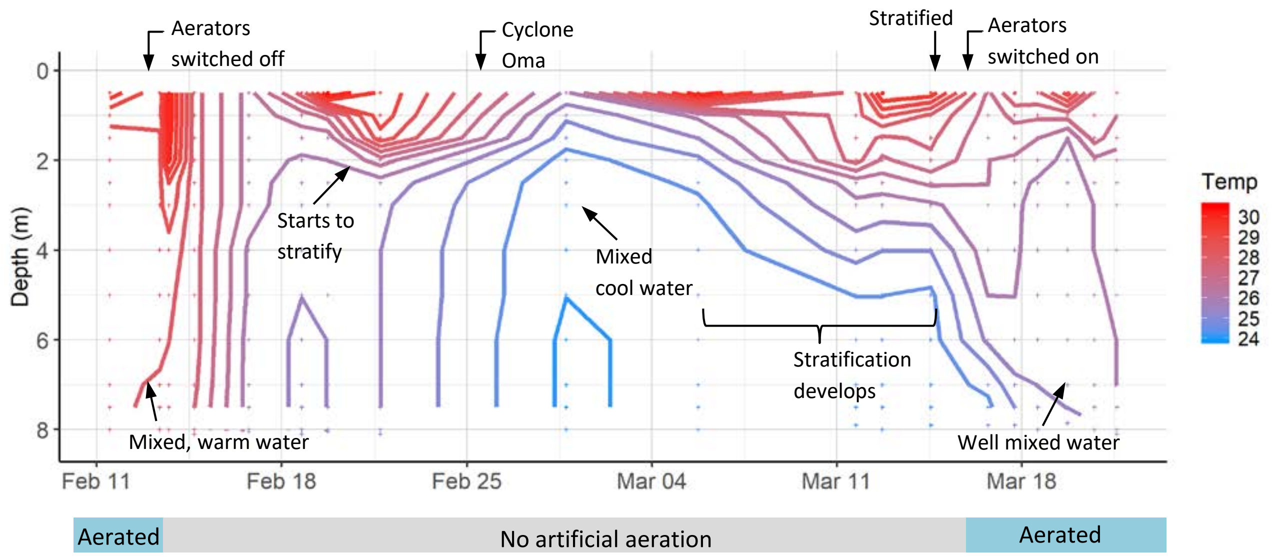


Figure 53: Contour chart of depth profile temperature measurements showing all samples

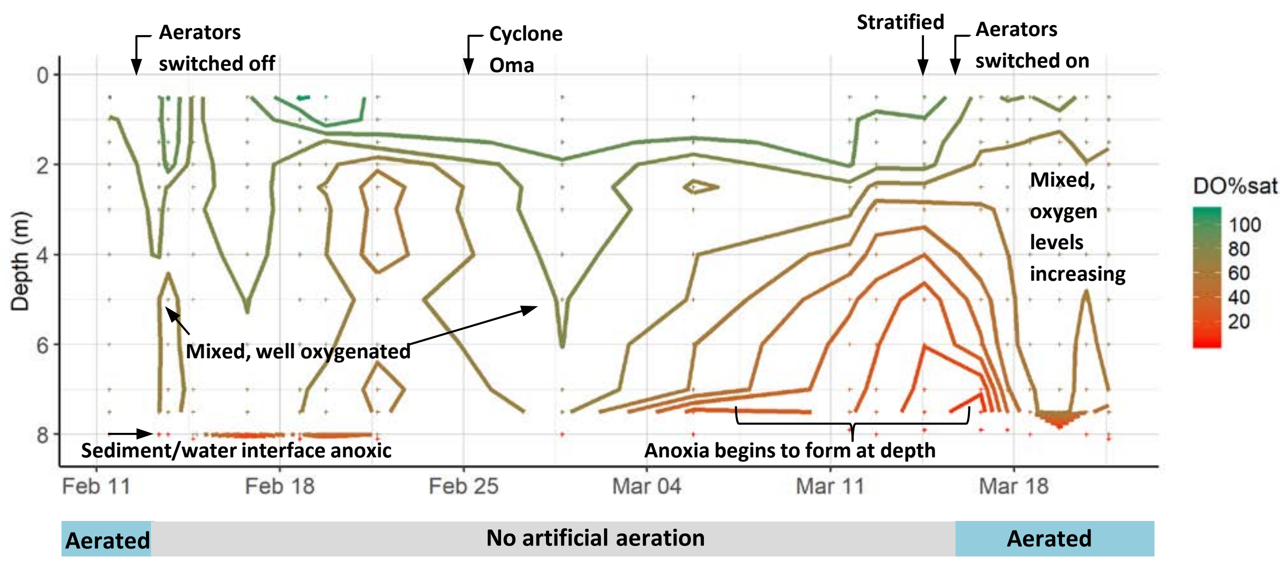


Figure 54: Contour chart of depth profile DO measurements showing all samples

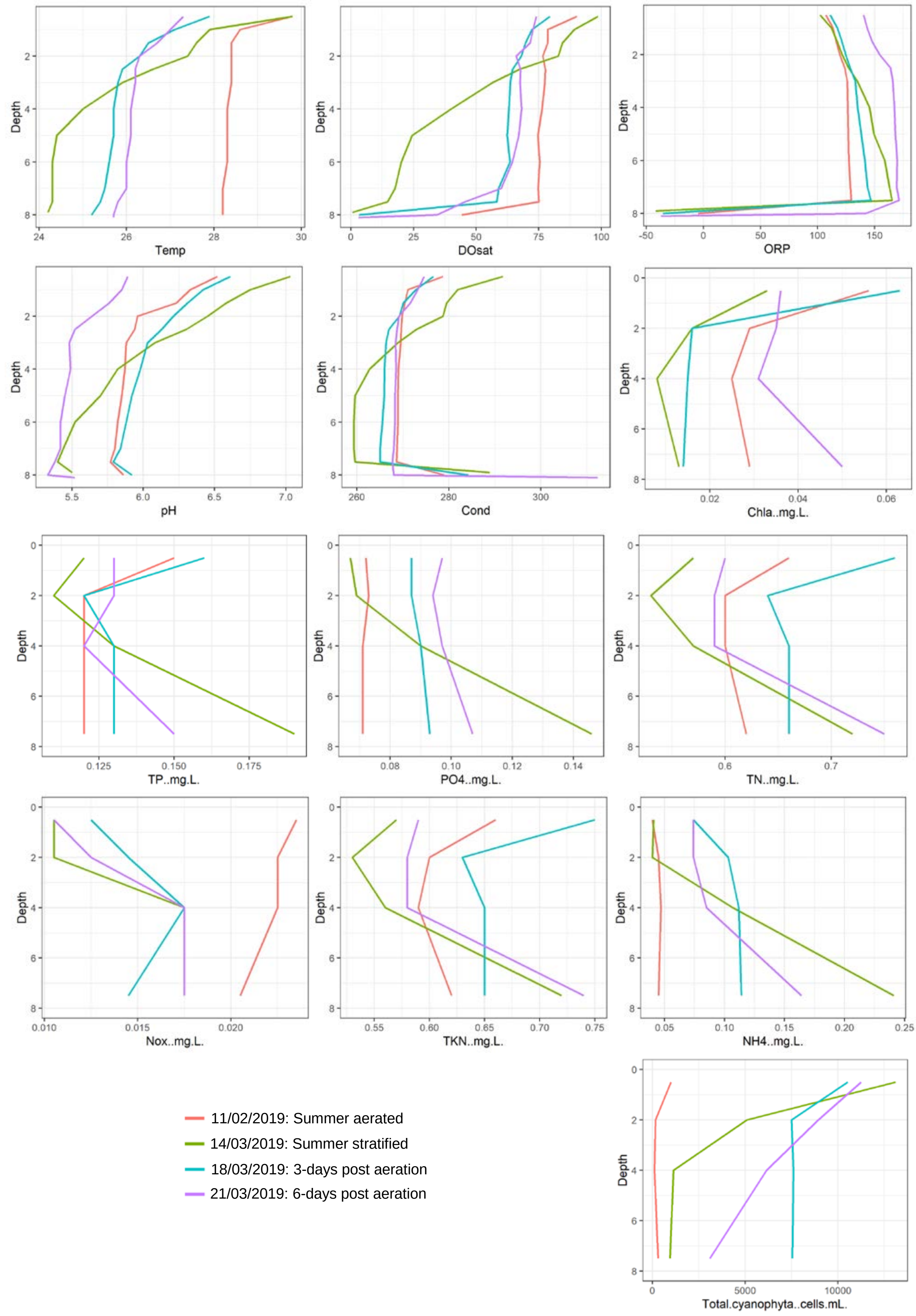


Figure 55: Depth profiles for water quality parameters in summer 2019

Table 16: Comparison of water quality data in summer 2019

Parameter	Summer Aerated (11/2/2019)	Stratification Developing (13/2/2019 – 12/3/2019)	Summer stratified (14/3/2019)	Post-aeration (16/3/2019-21/3/2019)
Temperature	Water column is well mixed with warm (~28-29°C) water consistent through the water column, and slight surface heating to 0.5m depth.	Weak surface stratification (~1m) observed on warm sunny days which is quickly broken down by windy/rainy weather. Cyclone Oma in late February causes high winds and moderate rainfall which mixes the water column and cools entire water column (Figure 53). Stratification begins to form with an extended period of hot still weather in early March.	Stratification establishes approx. 1 month after aerators are switched off. Temperature decreases gradually from surface temperature of ~30°C to 24.4°C at 5m depth and remains constant from 5m-8m depth.	Stratification is quickly broken down indicating mixed conditions across the lake. Temperature generally decreased at the surface post-aeration and this is likely to be due to cooler cloudy days associated with rainfall occurring during this time (Figure 49).
Dissolved Oxygen (DO)	The water column was well-mixed and oxygenated with DO levels ranging from 90% saturation at the surface to 74% saturation at 7.5m depth. Despite healthy DO level in the water column, a low DO zone remained (44% saturation) at the water/sediment interface (~8m depth).	The water column remains well oxygenated with the low DO zone at the water/sediment interface remaining at ~8m depth. DO begins to stratify in surface layers, but is quickly broken down by natural mixing. Mixing associated with Cyclone Oma oxygenates the water at depth. Stratification begins to form with an extended period of hot still weather in early March. Anoxia begins to form at depth and progresses quite quickly.	Surface water remains well oxygenated (DO ~99% saturation). DO decreases with depth, with oxygen depleted bottom waters with DO ~15% saturation. The sediment water interface is anoxic (~0.6% saturation).	DO decreased in surface water to approx. 80% saturation at 3-days post-aeration and further to 74% saturation at 6-days post-aeration, likely due to the mixing with low DO bottom waters. The water column was well-mixed with DO levels ~60-70% saturation throughout. The low DO zone remained at the water/sediment interface (DO~3% saturation).
pH	Surface pH was ~6.5, decreasing to approx. pH 5.9 at 3m depth and remaining constant to 7.5m depth, with a slight increase near the bottom. Algal blooms at the time of sampling are likely to have increased pH levels in surface layers.	pH varies from day to day in response to algae and mixing events but as stratification develops, pH tends to increase at the surface and decrease at depth.	Surface pH was ~7.0, decreasing to approx. pH 5.4 at 7.5m depth.	pH decreased at the surface and increased at depth at 3 days post-aeration. pH decreased at all depths to between pH 4 and 5.8 at 6 days post-aeration.
Conductivity	Conductivity showed a slight increase at surface but generally consistent through the water column indicating mixed conditions. An increase was observed at the water/sediment interface.	Conductivity remained fairly consistent with aerated conditions	Stratification pattern similar to temperature with higher conductivity (291µS/cm) in surface layers, decreasing slightly with depth (260µS/cm).	Conductivity generally decreased in surface layers and increased at depth as the water column became mixed.
ORP	Generally ORP values indicated oxidising	Conductivity remained fairly consistent with aerated	ORP decreased slightly at the	ORP increased at 6-days post aeration to approx.

Parameter	Summer Aerated (11/2/2019)	Stratification Developing (13/2/2019 – 12/3/2019)	Summer stratified (14/3/2019)	Post-aeration (16/3/2019-21/3/2019)
	conditions through the water column (approx. 100-130mV), ORP was approx. -4.5mV at the sediment/water interface indicating reducing conditions.	conditions, maintaining negative redox values at the sediment/water interface indicating reducing conditions.	surface and increased at depth. The sediment/water interface ORP was -42mV indicating strongly reducing conditions.	140-170mV throughout the water column. The sediment/water interface remained in a strongly reducing state (ORP was -37mV).
Nutrients	Concentration of TN and TP was highest in surface layers and generally consistent below approx. 2m depth. This is likely to be associated with higher Chlorophyll *a* and Algal biomass in surface layers. Dissolved nutrients PO_4-P and NOx were well mixed throughout the water column.	No nutrient samples taken during this time.	Nutrient concentrations decreased in surface water and increased with depth. This could be associated with anoxia development and release of nutrients from sediments.	Concentration of nutrients generally increased, particularly in surface layers and nutrients were mixed through water column. PO_4 concentrations increased by 30% in surface layers at 3 days post-aeration and 33% by day 6 post-aeration. Levels were higher than the summer aerated sample.
Chlorophyll *a* and Algal biomass	Levels higher in surface layers down to about 2m indicating presence of algae	No samples taken during this time.	Stratification evident with generally reduced levels compared to aerated conditions.	Concentrations in surface waters increased initially (at 3 days post-aeration), before reducing and becoming more well-mixed through the water column at 6-days post-aeration.
Blue-green algae	Levels were consistent throughout the water column, apart from a slight increase in surface layers.	No samples taken during this time.	Stratification evident with generally increased levels at surface compared to aerated conditions and decreasing with depth. Levels are elevated compared to aerated conditions.	Higher levels in surface layers, but generally consistent from 2m depth at 3 days post-aeration. At 6 days post- aeration a gradual increase in concentrations with depth.

3.8.8 Conclusions and Recommendations

Spring sample

Water quality conditions assessed prior to commencement of the Spring/Summer aeration program showed a moderately stratified lake with a defined thermocline at 3m depth across the entire lake. After artificial aeration, water quality observations indicated the lake was well-mixed and water quality conditions generally deteriorated across the lake, and particularly in surface layers. This was due to decreased DO, and increased nutrient concentrations (40% increase in PO_4-P at the surface). Chlorophyll *a* and algal biomass concentrations in surface waters decreased initially (at 3 days post-aeration), and this could be due to physical mixing of algae-free benthic water to the surface diluting surface water temporarily, or possibly mixing of surface algae to below the photic zone where algae can't photosynthesise and dies off. Levels returned to pre-aeration levels at 6-days post-aeration, as algae re-established in surface layers.

The pre-aeration, stratified conditions appeared to allow for nutrients to concentrate in deeper water with much higher concentrations present below the thermocline and below the level at which light can penetrate and therefore stimulate algal growth. The aerators were very effective at mixing the entire lake, however in doing so, the nutrient rich and oxygen poor benthic waters were brought to the surface ready for uptake by algae and aquatic plants.

Based on the results of spring sampling, the aerator program appears to be having an overall adverse effect on water quality during the initial start-up. This also coincides with the highest frequency and duration of algal blooms in the lake, occurring in spring (refer Section 3.7).

Summer sample

Summer depth profile sampling allowed for further assessment of aerator function during summer extremes and indicative of conditions conducive to stratification and deoxygenation of bottom waters. Initial sampling during the typical 'summer aerated' condition, indicated that the water column was well mixed and oxygenated. DO levels were somewhat improved compared to the initial start-up of aerators in spring with a range of 90-74% saturation from surface layers to the bottom. However, low DO conditions were detected at the water/sediment interface and this was encountered during all mixing states, albeit at varying degrees of anoxia. This result is very important as it is the DO at the sediment/water interface which is critical in determining the release of phosphorus from sediment, regardless of DO concentrations in the overlying water.

The summer stratified conditions revealed a concentration of nutrients in the deep layers, while concentrations at the surface were reduced. This was consistent with findings in spring. This was accompanied by a reduction in Chlorophyll *a* and algal biomass in surface waters. Also consistent with trends observed in spring, the aerators were again very effective at mixing the water column, and this again resulted in nutrient rich and oxygen poor benthic waters being brought to the surface.

The results indicate that oxygen depletion at the water/sediment interface facilitates the release of phosphorus and particularly PO_4-P from sediment in the lake and this state remains relatively unchanged whether the aerators are functioning or not. From recent sediment sampling (refer Section 4.4.3) it is known that a significant store of nutrients remain within the organic-rich mud layer in the deeper sections of the lake, which could continue to fuel algal blooms in the lake indefinitely. The aerators are very effective at mixing the water column and do assist in oxygenating the water column, however the results of this study indicate that the aerators are also continually mixing nutrients released from sediment from bottom waters up into the photic zone stimulating algal growth.

Conclusion

Based on the results of this study, a longer-term trial evaluating the effect of extended non-operation of the aerators appears to be warranted. A one year trial period would allow for water quality and algal concentrations to be assessed across all seasons and a range of conditions. There are many inherent risks with this approach that should be carefully considered and these are outlined in Table 35, Section 7. If the trial is undertaken, it will be important to carefully monitor conditions in the lake, particularly with regard to the depletion of DO at depth and the impact of natural mixing events. It may be necessary to institute an adaptive management plan to mitigate any developing risks such as turning the aerators back on to re-oxygenate the water column and avoid a major deoxygenation and subsequent turnover event. There are two broad options:

1. Continue artificial aeration - actively mix the water column, maintaining DO at reasonable levels throughout the water column but also continually cycling nutrients from sediments to the lake surface and thus contributing to continued algal growth; or
2. Allow the lake to stratify and mix naturally according to weather conditions and accept that there is a risk of occasional natural mixing events (turnover) occurring when low DO and nutrient-rich waters will be brought to the surface resulting in algal blooms and potential low DO conditions.

Table 35 in Section 7 presents a preliminary assessment of the potential effectiveness of various management options at Lake Ainsworth including the options outlined above. Options recommended for further consideration will be assessed in detail as part of Stage 3 of the CMP: Response Indication and Evaluation.

3.9 Environmental impacts of sunscreen

The community has raised concerns about the impact of sunscreen pollution on Lake Ainsworth. Sunscreen-related ‘slicks’ have been reported on the surface of the lake during high use periods (GeoLink, 2002; Hydrosphere Consulting, 2018). There is an emerging body of evidence from around the World that many chemicals used widely in sunscreen and other personal care products are having detrimental effects on aquatic ecosystems. Links have been drawn between these chemicals and coral damage (bleaching, deformities in coral larvae etc.), endocrine disruption (e.g. feminisation of fish), nutrient enrichment, and toxic effects on algae, protozoa and crustaceans. Hawaii recently legislated a ban (to come into effect in 2021) on sunscreens containing oxybenzone and octinoxate, chemicals thought to be harmful to coral reefs.

While there has not been any assessment of sunscreen compounds in the water or sediment of Lake Ainsworth to date, the high visitation rates and closed nature of the system (low flushing) suggest there is potential for impacts on the aquatic ecosystem due to sunscreen pollution. Sunscreen as a potential source of nutrients (esp. Phosphorus) is also a key concern given the existing eutrophic conditions.

A summary of the current level of knowledge on this issue is provided below.

3.9.1 Chemical constituents of sunscreen

Active ingredients in sunscreens come in two forms: mineral; and chemical UV filters. The most common sunscreens on the market contain chemical filters. There are 30 active ingredients in chemical UV-filter sunscreens currently approved by the Therapeutic Goods Administration (TGA) in Australia (TGA, 2016), however products typically include a combination of two to six of the following active ingredients: oxybenzone, avobenzone, octisalate, octocrylene, homosalate and octinoxate. Mineral sunscreens are also referred to as ‘physical blockers’ which mainly work by sitting on top of the skin to deflect UVA rays. Active ingredients in mineral sunscreen are typically zinc oxide and/or titanium dioxide. These compounds can be found in mineral sunscreens in nanoparticle form or non-nanoparticle form. A handful of products combine zinc oxide with chemical filters.

3.9.2 Identified impacts from scientific study

Review of the available literature identifies the following impacts from studies in both marine and freshwater:

- Some chemical UV-filters can be toxic for phytoplankton species, microalgae, protozoa, and crustaceans (Juliano and Magrini, 2017; Downs *et al.*, 2016)
- Some chemical UV-filters have been linked to coral damage including bleaching and larval deformities in studies from Hawaii, USA, Italy, Spain, Israel, Iran, and the Caribbean (Downs *et al.*, 2016; Juliano and Magrini, 2017).
- Some chemical UV filters are able to bioaccumulate in the muscle and lipids of aquatic organisms (marine invertebrates, fish, marine mammals, aquatic birds) and are likely to enter marine food chains (Juliano and Magrini, 2017).
- Several common chemical UV filters have been reported as endocrine disruptors, affecting reproduction and development in animal studies (Krause, 2012; Juliano and Magrini, 2017; Tovar-Sanchez *et al.*, 2013)
- Nanoparticles of titanium dioxide (TiO_2) and zinc oxide in mineral sunscreen can react with sunlight to produce significant amounts of hydrogen peroxide, a major oxidising agent that generates high stress levels to aquatic organisms (Sanchez-Quiles and Tovar-Sanchez, 2014; Jeon *et al.*,2016).
- Sunscreens are a potential source of nutrients to water, particularly phosphates. Tovar-Sanchez *et al.* (2013) conducted laboratory trials and found the dissolution of sunscreens in seawater releases inorganic nutrients (N, P and Si forms). In particular, phosphate (PO_4) was released by these products in notable amounts. They estimated an increase of up to 100% background PO_4 concentrations in nearshore waters during low water renewal conditions in a populated beach in Majorca Island, Spain (Figure 56).

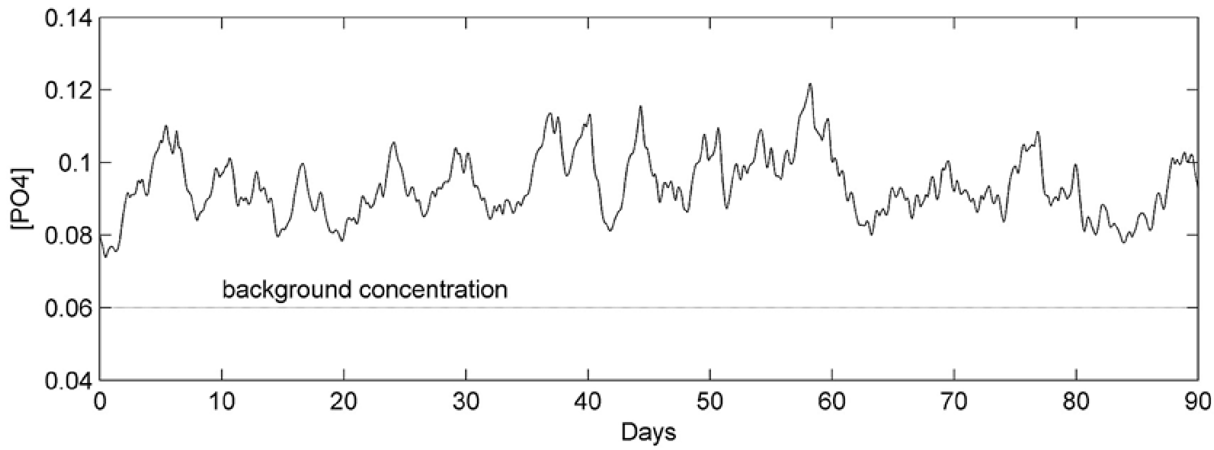


Figure 56: Modelled variations of PO_4 (μmol/L) at Palmira Beach (Majorca) estimated from sinusoidal variations of beachgoers and 6 hours averaged current velocities (Source: Tovar-Sanchez, 2013).

3.9.3 Prevalence in freshwater aquatic environments

The distribution and the fate of chemical UV filters entering the aquatic environment depend on their physico-chemical properties and their stability toward bio- and photo-degradation. The presence of UV filters in riverine and marine waters and sediment is widely documented in the literature. The filters most frequently identified in sediment are EHMC (ethylhexyl methoxycinnamate), OC (octocrylene), BMDM (butyl methoxydibenzoylmethane), OD-PABA (octyldimethyl-p-aminobenzoic acid), and benzophenone derivatives (Juliano and Magrini, 2017). Kaiser *et al.* (2011) found that lake sediments exhibited high UV-filter levels during summer and concentrations dropped in autumn, corresponding to recreational use patterns.

3.9.4 Assessment of potential contamination levels in Lake Ainsworth

An approximation of the potential load of sunscreen to Lake Ainsworth has been calculated based on available information and methods employed by researchers at other locations. Table 17 provides the estimates for total volume of sunscreen potentially entering the lake and Table 18 provides details of potential key chemical and nutrient input. Note that the calculations assume that every swimmer applies sunscreen at 50% the recommended rate by the Australian Cancer Council (assuming most people under-apply) and that the sunscreen contains the active ingredient oxybenzone (which has been a common ingredient in sunscreen over the last decade but is being phased out due to environmental risk).

Based on this assessment it is estimated that as much as 2.9L of sunscreen could wash into Lake Ainsworth during a peak visitation day, such as Australia Day when visitor numbers are expected to reach up to 2,184 people. At these levels, approximately 172mL of the chemical oxybenzone could be contributed to the lake per day. Put in perspective, studies have found that concentrations as low as 62 parts per trillion (equivalent to a single drop of oxybenzone in six and a half Olympic-sized swimming pools) has been shown to have aquatic ecosystem impacts such as coral larvae deformities (Downs *et al.*, 2016). At an annual scale, it has been estimated that approximately 192L of sunscreen (equating to 21 average sized buckets) and up to 12L of oxybenzone could enter the lake each year.

In terms of potential nutrient loads due to sunscreen, calculations have been based on figures derived from a laboratory-based nutrient release experiment conducted by Tovar-Sanchez *et al.* (2013). This experiment dissolved a range of sunscreens in an artificial seawater solution to determine nutrient release and figures for freshwater dissolution are not known. The results are therefore provided as indicative only to demonstrate the potential risk associated with sunscreens. Using the above assumptions, it is estimated that phosphate (PO_4-P) concentrations could increase by as much as 0.07mg/L due to sunscreen washed into the lake during a peak visitation day and 0.004mg/L on an average day. This equates to a potential average annual contribution of 10% of the current average PO_4-P levels measured in the lake. As noted, the science is currently limited on nutrient impacts from sunscreen in freshwater systems, however these preliminary estimations indicate that sunscreen could be a significant source of phosphate to the lake, particularly during peak visitation periods. This may also help to partly explain the marked increase in phosphate levels observed from 1998-1999 to the current levels 2015-2018 (441% increase, see Section 3.5: Change in average nutrient concentrations over time).

Table 17: Estimate of potential load of sunscreen to Lake Ainsworth

	Swimmers per day (approx.)[1]	Application rate (mL/person)[2]	% of sunscreen dissolved in water[3]	Sunscreen washed into lake (L/day)	Days/ year	Total sunscreen washed into lake (L/yr)	Notes/Assumptions
Peak day	2,184	13	10%	2.9	12	34	Public holidays and long-weekends
Average school holiday day	1,436	13	10%	1.9	58	109	Holidays excluding peak days above and winter holidays
Average day	124	13	10%	0.2	295	48	Remainder of the year
Potential annual total sunscreen washed into lake:						**192**	Equivalent to 21 average buckets (9L)

1. Calculated from BSC (2017b) local recreational user traffic counts assuming an average of 2 people per car and Lake Ainsworth Community Survey (Hydrosphere Consulting, 2019), 86% people said primary activity was swimming at lake
2. Australian Cancer Council (2018) recommended application rates assuming 50% under-application
3. Tovar-Sanchez *et al.* (2013)

Table 18: Estimate of potential load of oxybenzone and PO_4-P to Lake Ainsworth due to sunscreen

	Average oxybenzone concentration in many sunscreens[1]	Volume oxybenzone (mL/day)	Annual oxybenzone Volume (L/yr)	Potential phosphate contribution (mg/L)[2]	Potential % contribution to current average PO4-P levels[3]
Peak day	6%	172	2	0.073	56%
Average school holiday day	6%	113	7	0.048	37%
Average day	6%	10	3	0.004	3%
Potential average annual PO_4-P contribution due to sunscreen				**0.013**	**10%**

1. Maximum concentration permitted by TGA is 10%, but average is believed to be approx.. 6% (TGA, 2018)
2. Potential increase in phosphate concentrations is $2.5xe^{-5}$ per 1g sunscreen based on laboratory trials by Tovar-Sanchez *et al.* (2013)
3. Current average PO_4-P concentrations are 0.13mg/L (2015-2018)

3.10 Nutrient Balance

3.10.1 Nutrient Cycling

Nutrients are elements used by living organisms as nourishment. When a body of water becomes overly enriched with nutrients (primarily nitrogen and phosphorus) it may result in excessive growth of plants and algae, which can degrade natural ecosystem health, create health risks (e.g. toxic cyanobacteria), and decrease the aesthetic value of the system. Sources of nutrients to Lake Ainsworth include atmospheric sources, the catchment sources via surface runoff, eroded soils and groundwater, fauna and recreational users, as well as internal cycling of nutrients between sediments, biota and the water column. Catchment activities such as fertiliser use, stormwater and waste management may influence the nutrient loads entering the lake, although water quality monitoring did not indicate significant nutrient sources from catchment runoff.

Given the elevated levels of nutrients in lake sediments and the water column, it is likely that internal cycling of nutrients will act as a continuing source of nutrients to the system, even if all 'new' nutrient inputs were ceased. The drivers of these recycling processes can be due to physical, chemical, and biological factors such as water temperature, pH, dissolved oxygen concentration, sediment redox potential, chemical diffusion, bacterial activity and mineralisation processes, bioturbation, iron to phosphorous ratio and hydrological conditions (Bostrum *et al.*, 1982; Sondergaard *et al.*, 2003; Christophoridis and Fytianos, 2006). Physical hydrodynamic processes likely to occur at Lake Ainsworth include wind mixing and turbulence, bioturbation, and periods of high rainfall which can break down thermal stratification and induce mixing as well as artificial aeration which operates from September to April. Biochemical processes at the sediment-water interface are critical in determining the degree of nutrient re-animation in the aquatic ecosystem. Figure 57 presents a simplified diagram of nitrogen and phosphorus cycling in a wetland ecosystem, which is explained in further detail below.

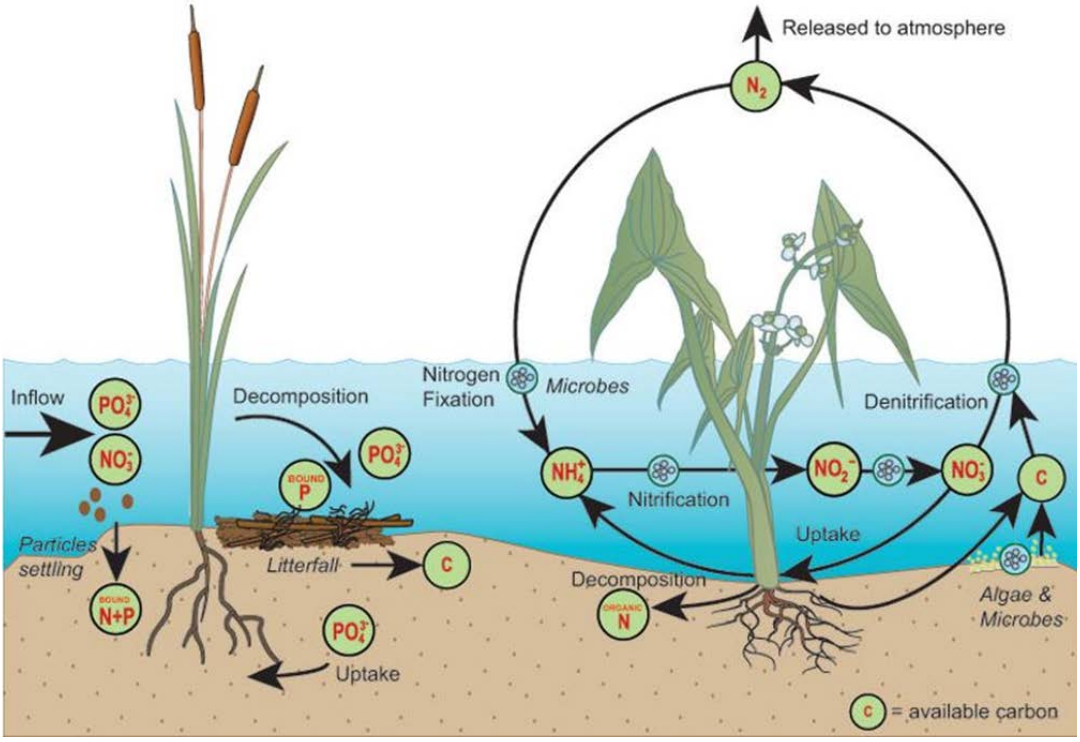


Figure 57: Simplified illustration of the nitrogen and phosphorus cycles in a wetland (The Wetlands Initiative, 2018)

3.10.2 Phosphorus Cycle

In an aquatic ecosystem, phosphorus can be found in the water column, within the bodies of aquatic organisms, or attached to particles (such as in sediment) in the water. Once at the bottom of the lake, phosphorus may become buried and unavailable to the system, or may be taken up by plants or released back into the water column through chemical reactions or physical disturbance (Figure 57).

Lake Ainsworth sediments are regarded as a major source for phosphorus. Annual estimates of P load due to sediment release in Lake Ainsworth was previously estimated to be 10 times that of runoff or groundwater (AWACS, 1996). AWACS (1996) determined that periods of stratification and the subsequent depletion of oxygen in bottom waters were likely to be producing conditions favourable for nutrient release from sediment. Mixing events, due to wind or heavy rainfall, then transported nutrients in deep water to near the surface where they become available to algae. More recently, a study of lake sediments under an induced stratification cycle found that anoxic conditions led to release of phosphorus and iron from sediments to the water column (Akhurst *et al.*, 2004). Results of the review of the aerator program completed as part of this study also indicate artificial aeration is a mechanism for transport of nutrients released from sediment to surface layers where algal growth occurs in the presence of sunlight.

pH is also believed to be an important regulating factor for phosphorus release from sediments, although this has not been tested to date at the lake. pH can affect sorption-adsorption, precipitation-solubilisation and oxidation-reduction reactions through its control over the concentrations of available iron, aluminium, and calcium (Golterman *et al.,* 1998). Many investigations from around the world have shown that phosphorus release rate from the sediments increases markedly in the summer, and one of the reasons was the increase in pH caused by intense algal photosynthesis (Xie *et al.* 2003; Eckert *et al.*, 1997). Qinghui *et al.* (2005) showed that percentages of iron-bound phosphorus released from sediment were well correlated to the pH values in solution and increased with increasing pH (Figure 58).

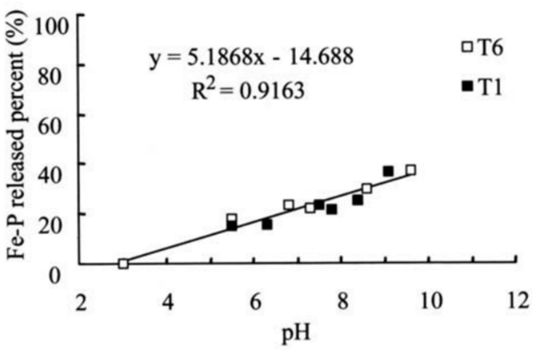


Figure 58: Percentages of iron-bound phosphorus released from sediments in Taihu Lake dependent on pH (Source: Gao, 2012)

Analysis of current water quality and sediment data and comparison with historical records has highlighted a number of trends through time:

- pH is increasing, meaning the lake is becoming less acidic (Section 3.4.3);
- Phosphorus concentrations are increasing (Section 3.5) ;
- Phosphorus concentrations in sediment have not changed markedly (Section 4.4.3);
- Algal blooms continue to occur in the lake and frequency and severity fluctuates from year to year with no long-term trends observed (Section 3.7.4).

Review of the scientific literature indicates the following:

- Photosynthetic consumption of carbon dioxide (especially in algal blooms) can drive pH to high levels (OZCoasts, 2019). It follows that continued algal blooms in Lake Ainsworth may be contributing to the increasing pH observed;
- Because many cyanobacteria and algae are intolerant to low pH (Burford *et al.*, 2018), the observed increase in pH may be making the lake more susceptible to algal blooms.
- Phosphorus release from sediments is known to increase as water becomes more alkaline, due to reduction in phosphorous binding capacity of Fe and Al compounds (Orihel *et al.*, 2017; Boers 1991; Christophoridis and Fytianos 2006) this in turn increases phosphorus water column concentrations which also favour increased algal blooms.

This becomes a self-perpetuating cycle of algal blooms, increased pH, greater release of phosphorus from sediments triggering increased algal blooms etc. (Figure 59). In order to address algal blooms, management action must seek to break this cycle.

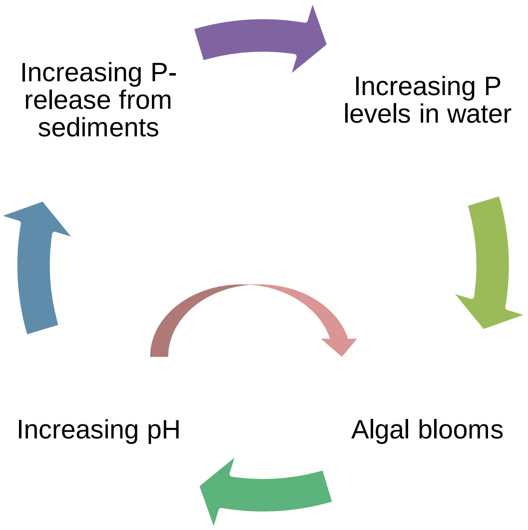


Figure 59: The proposed relationship between Phosphorus, algal blooms and pH at Lake Ainsworth

Nitrogen Cycle

Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Inorganic nitrogen is found both as oxidised species (e.g. nitrate (NO_3^-) and nitrite (NO_2^-)) and reduced species (e.g. ammonia (NH_4^+ + NH_3) and dinitrogen gas (N_2). Nitrogen removal involves a large suite of bacteria (or microbes) that mediate or conduct numerous chemical reactions. These microbes are found on solid surfaces within the wetland, such as soil, litter, and submerged plant stems and leaves.

Nitrification-denitrification is the process of conversion of soluble forms of nitrogen such as the plant nutrients ammonia and nitrate to nitrogen gas, which is then released to the atmosphere – thus exiting the aquatic ecosystem. This process relies on oxygenated conditions to allow the oxidation of ammonia, as well as anoxic conditions found within the sediment to allow denitrification. Hence this process occurs at the sediment-water interface or within the top fraction of the substrate. The process is influenced by a number of biotic and abiotic factors, principally driven by dissolved oxygen and carbon load. Environmental factors such as water depth, water colour, amount of benthic algae and possibly thermal and oxic/anoxic stratification will affect this process.

3.10.3 Nutrient Sources at Lake Ainsworth

Nutrient inputs to the lake can come from atmospheric sources, the catchment via surface runoff, eroded soils and groundwater, fauna and recreational users, as well as internal cycling of nutrients between sediments and biota. Table 19 describes identified nutrient sources to Lake Ainsworth and provides an update on current understanding of the issue.

Table 19: Nutrient sources

Source	Description	Current status
Benthic Sediments	The Processes Study identified sediments as a major source of phosphorus with annual estimates of P load due to sediment release was 10 times that of runoff or groundwater (AWACS, 1996). Historical nutrient load from past catchment sources such as past sewage/sullage contamination are believed to have contributed to the store of nutrient in sediment.	This study determined that the nutrient status of sediments is largely unchanged from what was measured in 1996 and remains as the primary ongoing source of nutrient to the lake.
Groundwater	The Processes Study identified groundwater from the town west of Gibbon Street and from the Sport and Recreation Centre as a nutrient source to the lake. Human activities such as over application of fertiliser and poor waste management considered to be key factors in nutrient contribution.	• Fertiliser is not applied in Council managed open space areas around the lake. • Fertiliser is not used within the Reflections Holiday Park. • Fertiliser use at the Sport and Recreation Centre is limited to one annual application on sporting oval north of the lake if required (not used every year). Application rates are calculated to minimise any excess and timing outside of rainfall events. Groundwater flow is generally to the east towards the ocean at this location (AWACs, 1996), with partial flow towards the lake possible dependent on hydrological conditions. • Fertiliser use within private property in Lennox Head is unknown and unregulated.
Sewage system overflows/ leakage	All development within the catchment is connected to the town sewer system with the exception of Camp Drewe which operates an onsite sewage management system (OSSMS). A sewerage pumping station is located south of the Sport and Recreation Centre and a sewerage main runs from the Sport and Recreation Centre along the eastern road adjacent to the lake. Should this system overflow or develop leaks, contamination could be carried by surface or groundwater flow to the lake.	Council water and wastewater team have confirmed there are no sewerage leaks within the catchment area (BSC, 2017a). Camp Drewe has a maximum capacity of 96 guests and usage is intermittent rather than constant. The majority of groundwater flows towards the coast rather than directly to Lake Ainsworth (AWACs, 1996).

Source	Description	Current status
Stormwater	Transport of nutrients via stormwater flow from catchment areas including the Sport and Recreation Centre, Caravan Park and adjacent roads/parklands identified as a potential source. Human activities in the stormwater catchments can greatly affect the impact of stormwater including: outdoor washing/cleaning; management of lawn clippings/garden waste; outdoor food preparation, use of soaps and detergents; waste management; litter etc.)	• The current water quality monitoring program has not identified any significant nutrient sources from stormwater (Section 4.2.3). • Beachwatch monitoring indicates faecal matter enters the lake from runoff of land surfaces (OEH, 2018) and likely due to animal sources (wildlife and domestic animals).
Recreational Use	Direct contamination from lake users is anticipated to be low due to the proximity of public amenities to the lake. However, it is a potential source and cannot be completely ruled out.	Input likely to be low compared to other sources.
Sunscreen	There is currently a lack of research in the area of nutrient enrichment due to recreational sunscreen use, with the majority of studies focused on the environmental impact of chemical constituents of sunscreens. From the limited studies available on nutrient impacts, there are indications that sunscreen can be a source of phosphate (PO_4-P) to aquatic ecosystems particularly where there is high recreational use and limited flushing (refer Section 3.9).	This study estimated that sunscreen washed into the lake from recreational users could account for up to 10% of phosphate (PO_4-P) concentrations as an annual average estimate and up to 56% on a peak visitation day.
Eroded banks	Nutrients can be transported to water via erosion of banks.	This study did not find any conclusive links between foreshore erosion and water quality and the risk is considered low due to the clean sands present in eroded foreshores.

3.11 Dominant Processes in Lake Ainsworth

Results of this study have identified the dominant water quality processes affecting lake health summarised as follows:

- The organic-rich muds located in the deeper sections of the lake are still considered to be the primary source of nutrients within the water column;
- Despite artificial aeration, a low dissolved oxygen zone was still detected at the sediment/water interface creating conditions suitable for P-release from sediments to the overlying water;
- Artificial aeration is very effective at mixing and oxygenating the entire water column, however this is also believed to be a mechanism for transport of nutrients released from sediment to surface layers where algal growth occurs in the presence of sunlight. This continued cycling of nutrients contributes to algal blooms;
- There is also some evidence to suggest that P-release from sediments increases as pH increases due to a reduction in the P-binding capacity of Fe and Al compounds in sediments as pH increases

(Boers 1991; Christophoridis and Fytianos 2006). From current water quality monitoring it is known that pH levels in the lake are slightly increased from levels monitored in 1996 and this may be facilitating increased P-release from sediments. Increased algal productivity may be the cause of increases in pH which in turn increases P-release, thus stimulating further algal growth.

3.11.1 Conceptual model

provides a conceptual model of the dominant processes affecting water quality in Lake Ainsworth.

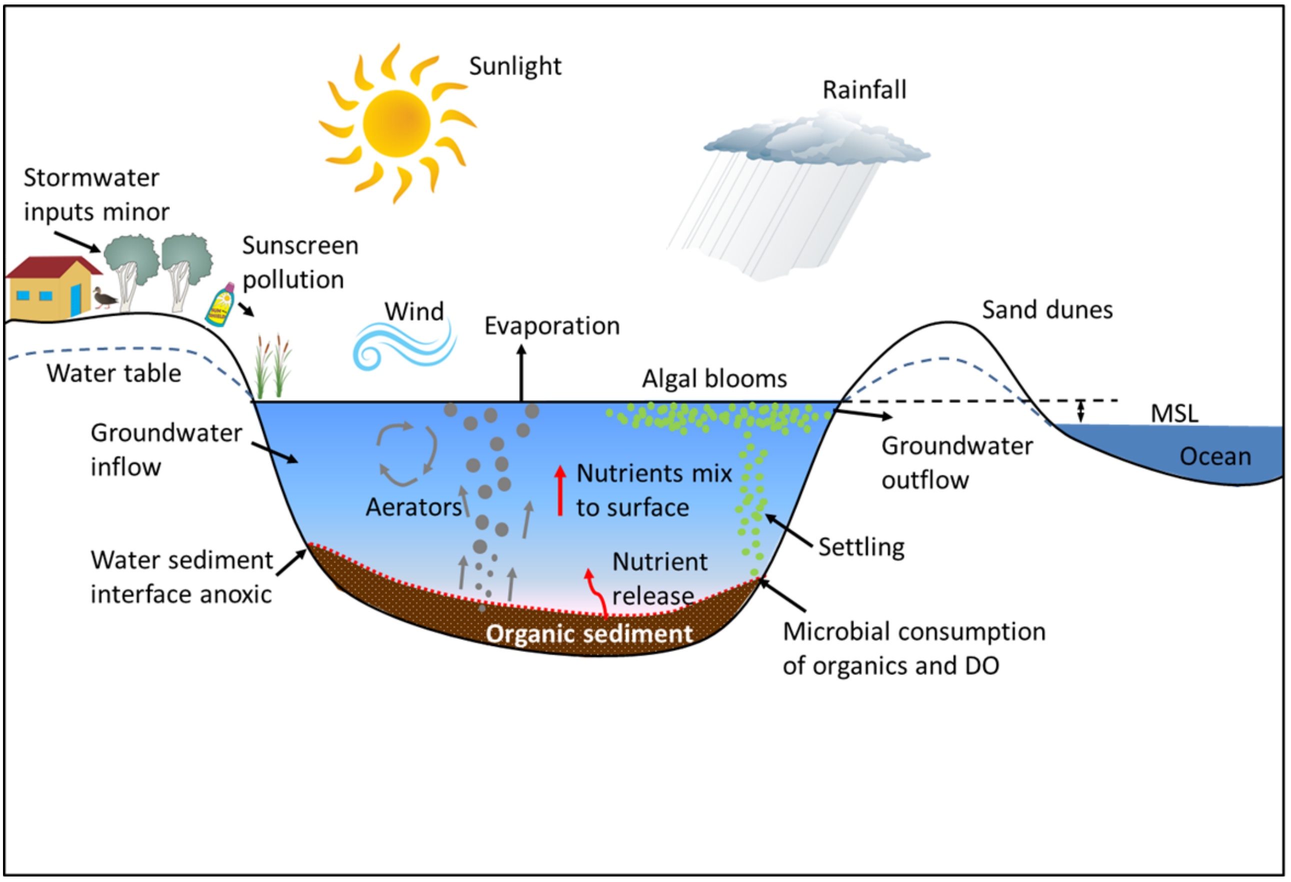


Figure 60: Conceptual model of key nutrient sources and dominant processes at Lake Ainsworth

4. SEDIMENT QUALITY

4.1 Previous Investigations

Previous benthic sediment investigations undertaken in the lake documented the presence of two main sediment types (AWACS *et al.*, 1996) (Figure 61 & Figure 19). These were reported as:

1. 'Gelatinous organic rich mud' ("gyttja") formed through the decay of plant material, located in the deepest sections of the central lake to about 4m below AHD. These sediments were about 4-6m deep; and
2. Medium grained sandy sediments occurring in the shallower depths from the lake edges to about 4m below AHD.

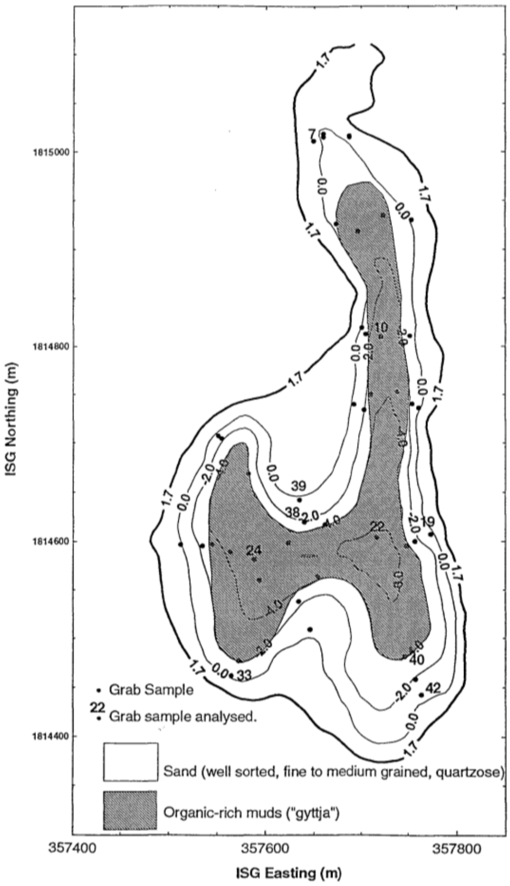


Figure 61: Classification of surface sediments in Lake Ainsworth (Source: AWACS, 1996)

AWACS (1996) conducted coring of lake sediments and found that lake morphology had not changed markedly in the 50 years preceding sampling in 1996. Carbon dating of the deeper organic sediments suggested an average sedimentation rate of 0.4 mm/year over the last 2,500 years (AWACS, 1996).

AWACS (1996) collected surface grab samples to determine sediment nutrient status and level of metal contamination. Nutrient levels in sediments were reported to be very high for the organic-rich muds and low for sandy sediments. It was estimated that the sediment source of phosphorus to the water column was 10x the level from other sources (catchment runoff and groundwater) (AWACS, 1996). Metal screening showed very low concentrations, generally within background levels for coastal and estuarine sediments. The only exception was for Zinc at site 40 towards the south east corner of the lake, where levels were 20x the background concentrations, however AWACS (1996) discussed this as mostly likely being an anomaly potentially due to metal fragments in sediment and not indicative of contamination.

4.2 Field Survey of Benthic Sediments

A field survey of benthic sediments was undertaken at Lake Ainsworth in November 2018 to confirm the current extent and composition of lake sediments in comparison to the previous AWACS (1996) mapping. Nutrient concentrations in the upper strata (i.e. at the sediment-water interface) were documented to assist in the development of the current nutrient balance and therefore inform contemporary management strategies for the lake.

Sampling sites were selected to be as close as possible to the sediment sampling locations undertaken by AWACS in 1996 to allow comparison of sediment quality over time. Sediment samples were collected at 54 sample points to a maximum depth of 500mm below the benthic surface. Nine (9) representative sites were selected for laboratory analysis of nutrients, metals and texture. Sediment samples were extracted using a Van Veen sediment sampler deployed by boat to enable sampling of sediments in deep water (>8m water depth). Samples were extracted and sealed in sample jars as quickly as possible to limit any exposed to oxygen. Samples were placed on ice until they were submitted to the laboratory for testing. Figure 62 shows the location of sites distributed across the lake.

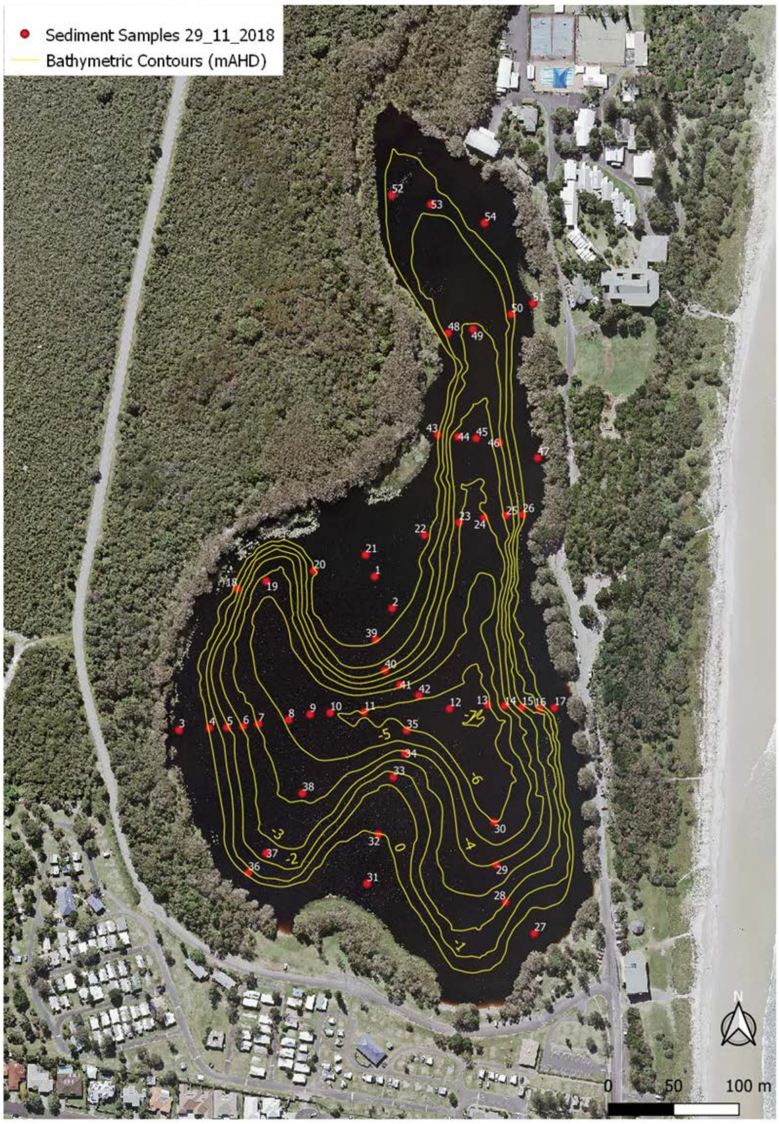


Figure 62: Location of sediment sample sites

4.3 Sediment Analyses

Sample analysis was undertaken by Environmental Analysis Laboratory (EAL) at Southern Cross University, Lismore. The EAL is NATA accredited for all the analyses undertaken. Samples were taken for analysis as follows:

- Redox;
- pH and EC;
- Basic Metals Scan – Total Acid Extractable (ICPMS) includes Aluminium, Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Selenium, Silver and Zinc;
- Particle Size Analysis – Hydrometer. Particle size of sediments and soils by hydrometer for fractions; >2 mm – gravel ,>50 µm – sand, 2-50 µm - silt, 2-20 µm, and <2 µm – clay;
- Moisture Content; and
- Nutrients – Acid extractable Nitrate, Phosphate, Total Phosphorus and Ammonium; and Total Nitrogen (%); Total Organic Carbon (%).

4.3.1 Sediment Quality and Contaminated Land Guidelines

The revised ANZECC/ARMCANZ Sediment Quality Guidelines (Simpson *et al.*, 2013) provide a recommended approach for the identification of sediments that are likely to result in adverse effects on ecosystem health. Figure 63 is taken from the guidelines and sets out the 'decision tree' recommended for the assessment of metals in sediments.

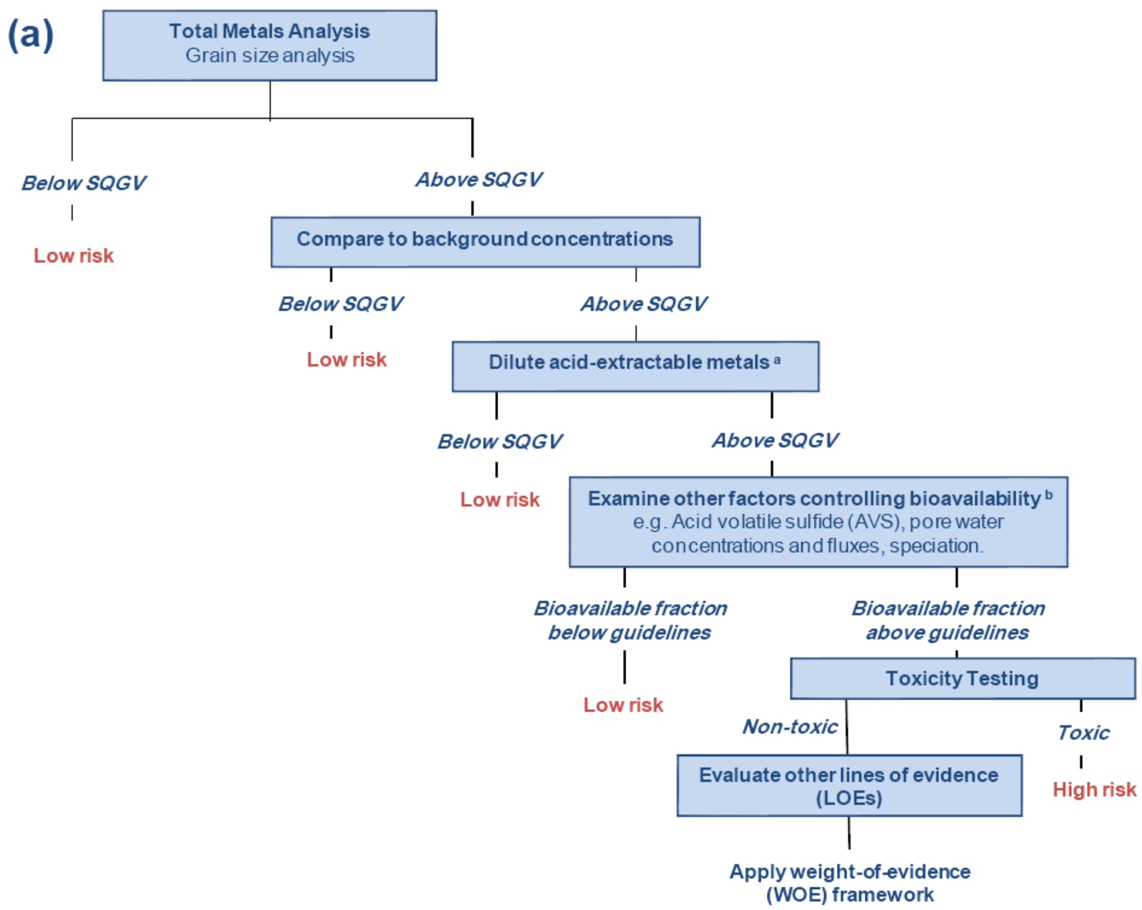


Figure 63: Decision tree for the assessment of contaminated sediments (ANZECC, 2000 p3.5-6)

The National Environment Protection (Assessment of Site Contamination) Measure (NEPM) 1999 are national guidelines for assessment of contaminated land. The guidelines provide 'investigation levels' and 'response levels' for a range of environmental settings and land-use scenarios based on the protection of health, ecology, groundwater, structures and aesthetics. An 'Investigation Level' is the concentration of contaminant above which further investigation and evaluation will be required. 'Response Level' is the concentration of a contaminant for which some form of response is required to provide adequate margin for safety. While these guidelines are designed for the assessment of soil, and are not directly applicable to sediments, they offer an established benchmark data for comparison with the interim ANZECC sediment quality guidelines.

There are no available sediment guidelines for Iron, Aluminium and Selenium. There are also no sediment nutrient guidelines available. The primary concern related to elevated nutrient concentration in sediments is that sediments act as a source of nutrient to the overlying water column and can result in algal or macrophyte blooms. The processes controlling nutrient exchange between sediment and water column are complex and subject to many factors unique to each site. Simpson *et al.* (2013) notes that the effects of nutrients will be highly dependent on the ecosystem being assessed. The present study assesses the distribution of sediment nutrient concentrations across the lake in relation to main sediment types and will compare levels to 1996 nutrient concentrations.

Table 20 collates guidelines from ANZECC/ARMCANZ and the NEPM 1999 assumed triggers NEPM 1999 provides the most stringent Health Investigation Level (HIL) (NEPM A) as well as the Ecological Investigation Level (EIL). The guidelines are used to assess whether further investigation or response is required to protect public health and/or the environment. The guidelines are used to assess whether further investigation or response is required to protect public health and/or the environment.

Table 20: Guideline values for comparison (Source: Simpson *et al.*, 2013; and NEPM, 1999)

	SQGV	SQG-High	NEPM HIL - A*	NEPM EIL **
Silver (mg/Kg)	1	4	na	na
Arsenic (mg/Kg)	20	70	100	20
Lead (mg/Kg)	50	220	300	600
Cadmium (mg/Kg)	1.5	10	20	3
Chromium (mg/Kg)	80	370	100	na
Copper (mg/Kg)	65	270	1000	100
Manganese(mg/Kg)	na	na	1500	500
Mercury (mg/kg)	0.15	1.0	15	1.0
Nickel (mg/Kg)	21	52	600	60
Selenium (mg/Kg)	na	na	na	na
Zinc (mg/Kg)	200	410	7000	200
Iron (%)	na	na	na	na
Aluminium (%)	na	na	na	na

SQGV – Sediment Quality Guideline Value (above this level there is potential for biological effects)

SQG-High – Sediment Quality Guideline High (above this level there is a high probability of biological effects)

NEPM HIL A* – NEPM Health Investigation Levels (standard residential with garden/accessible soil includes children's day care centres, kindergartens, pre-schools and primary schools).

NEPM EIL** – interim Ecological Investigation Levels for an urban setting

na-guidelines not available

4.4 Sediment Results

The current study documented the approximate location of two main sediment types previously reported in (AWACS *et al.*, 1996) as “Gelatinous organic rich mud’ (“gyttja”); located in the deepest sections of the central lake and medium grained sandy sediments occurring in the shallower depths from the lake edges. The current day sediment distribution reveals an expansion of the organic rich mud layer further northwards and towards the south-east in the lake compared to 1996 mapping (Figure 64).

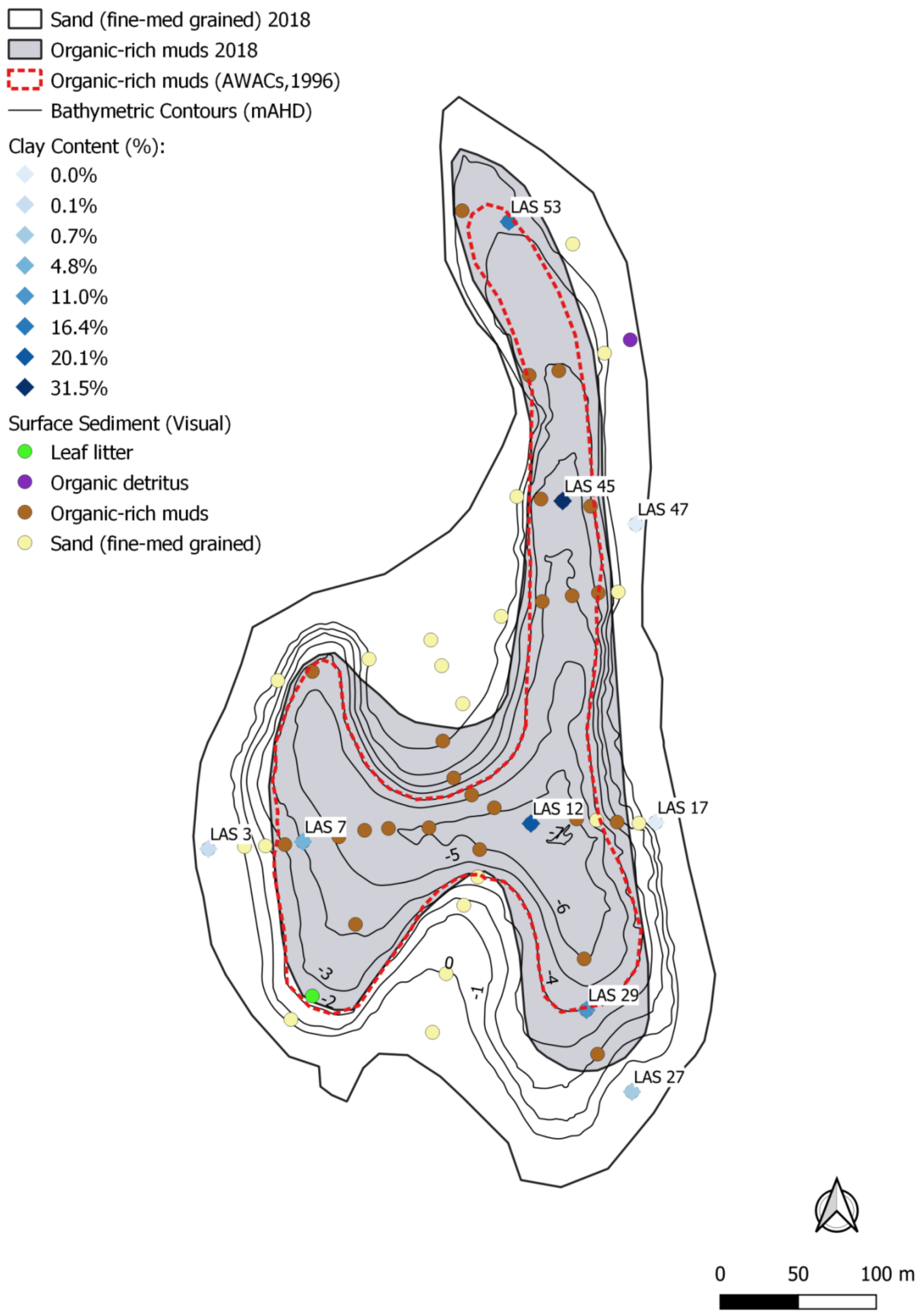


Figure 64: Approximate location of sediment types in Lake Ainsworth (Nov 2018 compared to 1996)

4.4.1 Physical properties

Sediment Texture

Particle size analysis results indicated that all sediments sampled within the organic rich muds were either 'Sandy Clay Loam' or 'Sandy Loam' texture with varying amounts of clay and silt present (Table 21 and Figure 65). All samples from the areas visually classified as medium grained sands were classified as 'Sand' with small amounts of silt and clay present. Gravels (>2mm) were only present in small amounts at sites LAS12, LAS27, and LAS47.

Table 21: Lake Ainsworth sediment particle size analysis results

SAMPLE ID	MOISTURE CONTENT (% Moisture)	GRAVEL > 2 mm (%)	SAND > 50 µm USDA (< 2 mm fraction)	SILT 2–50 µm USDA (< 2 mm fraction)	CLAY < 2 µm (< 2 mm fraction)	SOIL TEXTURE	SEDIMENT TYPE (VISUAL)
LAS3	23.0%	0.0%	99.0%	0.9%	0.1%	Sand	Sand
LAS7	88.9%	0.0%	73.8%	21.4%	4.8%	Sandy Loam	ORM
LAS12	91.5%	2.7%	63.4%	16.5%	20.1%	Sandy Clay Loam	ORM
LAS17	21.4%	0.0%	100.0%	0.0%	0.0%	Sand	Sand
LAS27	22.7%	0.8%	99.2%	0.1%	0.7%	Sand	Sand
LAS29	91.3%	0.0%	53.5%	35.4%	11.0%	Sandy Loam	ORM
LAS45	90.7%	0.0%	63.5%	5.0%	31.5%	Sandy Clay Loam	ORM
LAS47	45.6%	1.6%	99.8%	0.2%	0.0%	Sand	Sand
LAS53	92.3%	0.0%	61.9%	21.7%	16.4%	Sandy Loam	ORM

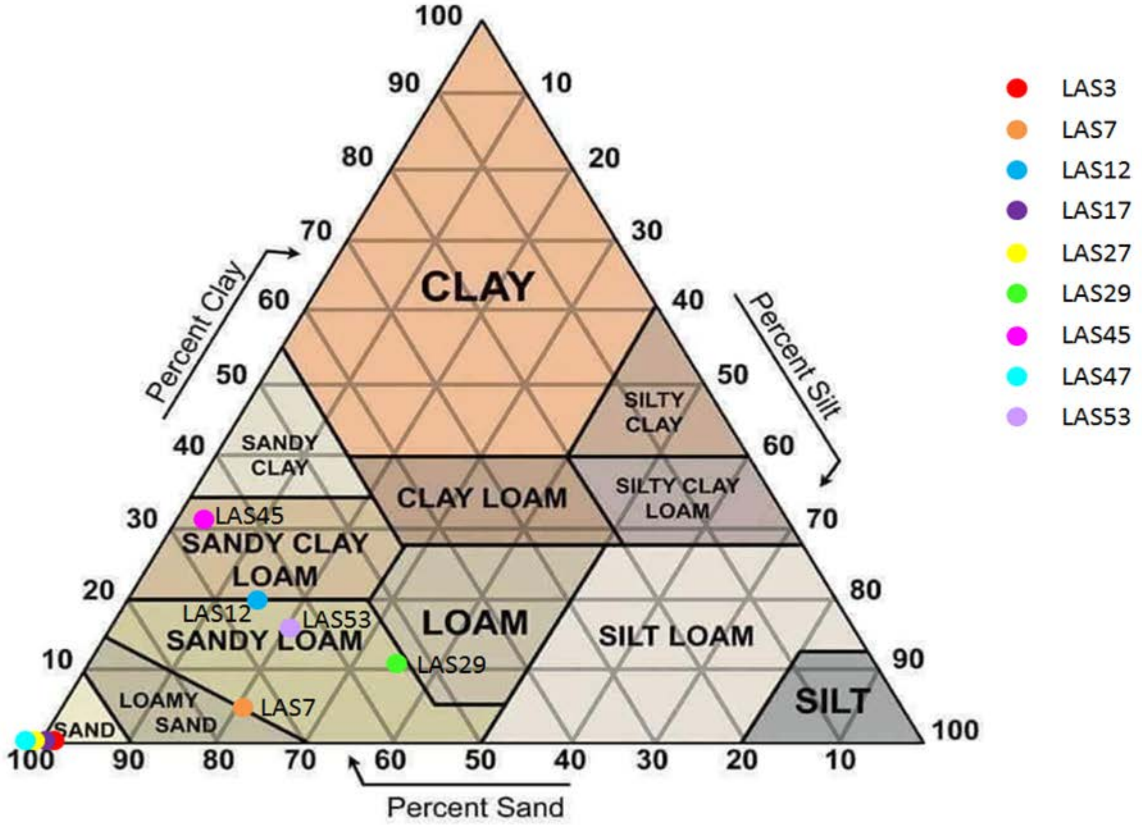


Figure 65: Ternary Plot of sediment texture (Generated using USDA Texture Calculator, USDA, 2019)

Total Organic Carbon

Total organic carbon measures the sum of particulate and dissolved organic carbon typically made up of material derived from decaying vegetation, bacterial growth, and metabolic activities of living organisms or chemicals. These organic coatings on inorganic particles provide binding sites for both metal and organic contaminants and can act to 'lock-up' these contaminants in the sediment, preventing them from being released to the overlying water and taken up by living organisms. Figure 66 compares TOC content of sediments across the lake, showing a high TOC content (23-35%) for the deeper organic rich muds, compared to low TOC for the fringing sandy sediment (0.1-1.8% TOC). This result is not surprising as it is expected that organic matter would collect in the deeper sections of the lake. Anaerobic microbiological processes are expected in high carbon environments such as the organic rich muds, creating anoxic, reducing conditions.

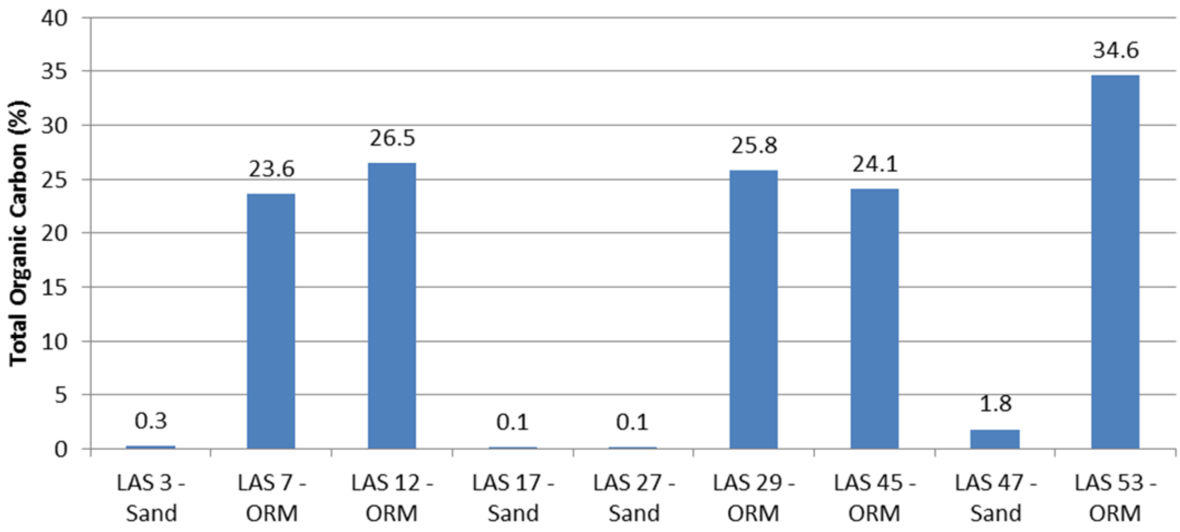


Figure 66: Sediment organic carbon results

Redox

The redox state of sediments (i.e. whether they in an oxidising or reducing environment) will be defined by the oxygen content of the pore waters. It is possible for sediments to be oxygen-deficient several millimetres below the surface. Oxygen deficiency will alter the chemistry of metals such as iron and manganese which in turn will affect the behaviour of other heavy metals and nutrients that were previously bound to oxides of iron and manganese (e.g. phosphorus bound to Fe). Figure 67 compares redox of sediments across the lake. Most sediments were in a reducing state (negative redox) except for sandy sediments as Site 3 and Site 17. Sandy sediments at site LAS27 and 47 were also recording reducing conditions and despite being made up of predominantly sand, both these sites had a surface layer of decaying leaf litter.

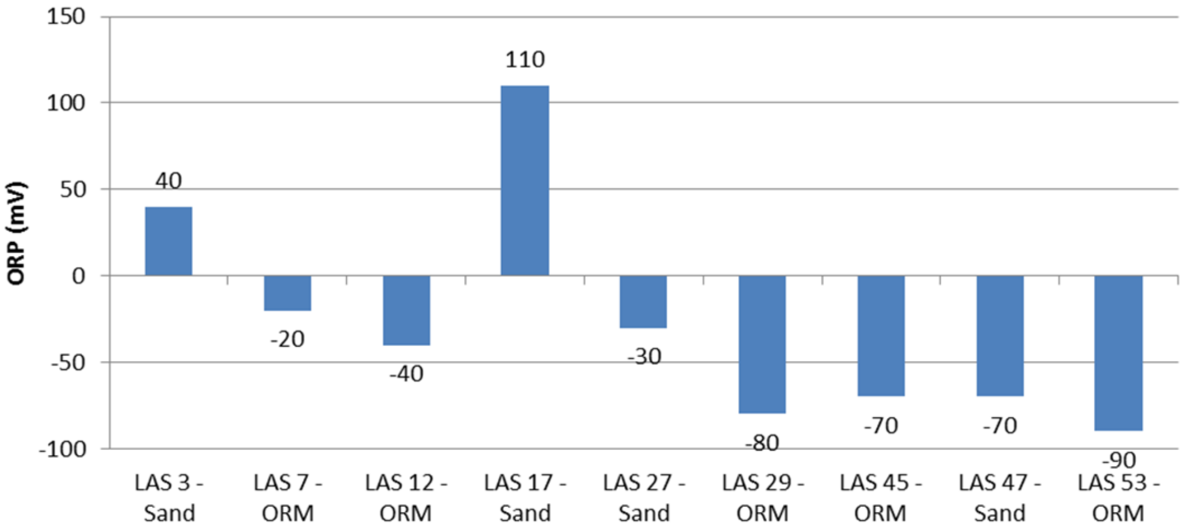


Figure 67: Sediment redox results

Sediment pH

Figure 67 compares the pH of sediments across the lake. All sediments were considered to be acidic with pH<7. The organic-rich muds with pH range 5.7 - 6.01 were more acidic than sandy sediments with pH range 6.19 - 6.69.

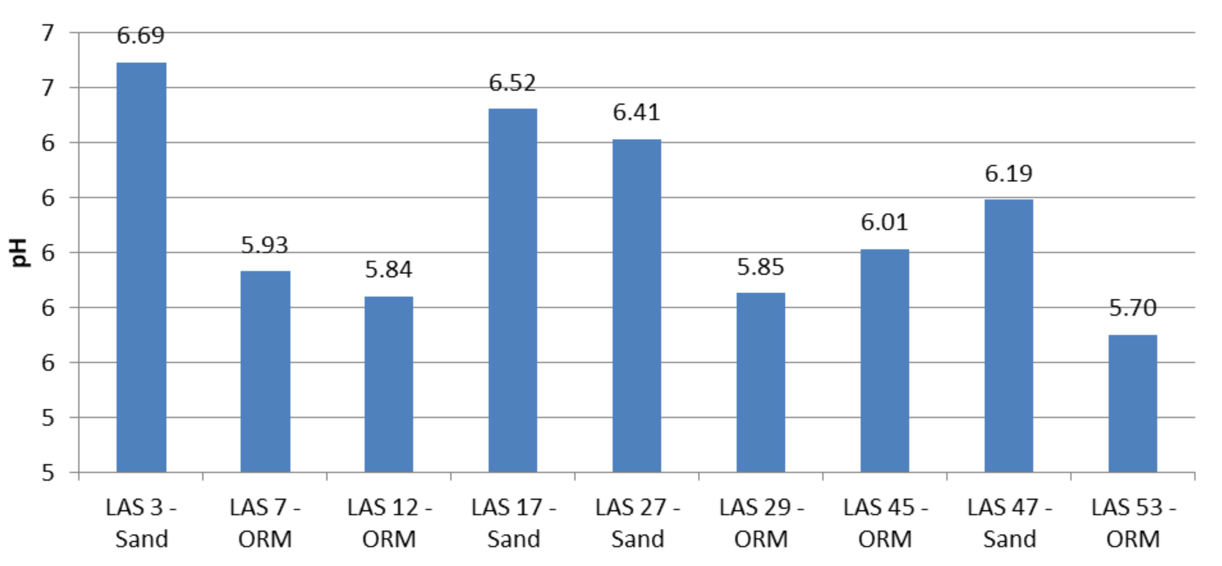


Figure 68: Sediment pH results

4.4.2 Sediment Metal Screening

Table 22 provides the results of sediment metal screening undertaken at selected sites in Lake Ainsworth and compares the results to ANZECC/ARMCANZ sediment quality guidelines (Simpson *et al*., 2013). The screening results identified exceedances of the guidelines for Lead (Pb) at five sites all within the organic-rich muds (LAS7, 12, 29, 45 and 53) (Figure 69). The highest levels were encountered at Sites LAS 53, 29 and 12. The lead concentrations were within the guideline 'transition' range between the SQGV (potential for biological effects) and SQGV-High (high probability of biological effects) indicating lead could be a potential contaminant of concern. Levels are well within the NEPM (1999) Health Investigation Levels and Ecological Investigation Levels. Additionally, the organic carbon at these sites is in the range of 23-35% and it is expected that lead present would be bound up and largely unavailable. This is supported by water quality sampling undertaken in 2015 and 2016 where lead concentrations dissolved in water were well below the ANZECC/ARMCANZ (2000) guidelines for recreational purposes (median value 20ug/L, guideline 50ug/L). The reasons for elevated sediment Lead concentrations is unknown but may be linked to proximity to roads and historical use of leaded petrol; historical wastewater discharge; or potentially lead sinkers used in fishing. Figure 71 shows that in general, lead sediment concentrations have remained the same or decreased slightly since 1996 and this may be associated with discontinued use of leaded petrol and other sources.

Mercury (Hg) levels at the same five sites also fell within the ‘transition’ range of the ANZECC/ARMCANZ sediment quality guidelines but below the NEPM investigation levels (Figure 70). As for lead, the high TOC content of sediments indicates that mercury present would likely be bound up and unavailable.

The ANZECC/ARMCANZ Sediment Quality Guidelines ‘decision tree’ approach indicates that exceedances of SQGVs require further investigation of the bioavailability of these metals to confirm no adverse effects on ecosystem health. Assessing background concentrations is the next step in the process which could involve further sampling of sediment at sites in the catchment (or similar local catchment) with little or no disturbance from natural state, thus providing natural baseline conditions for comparison.

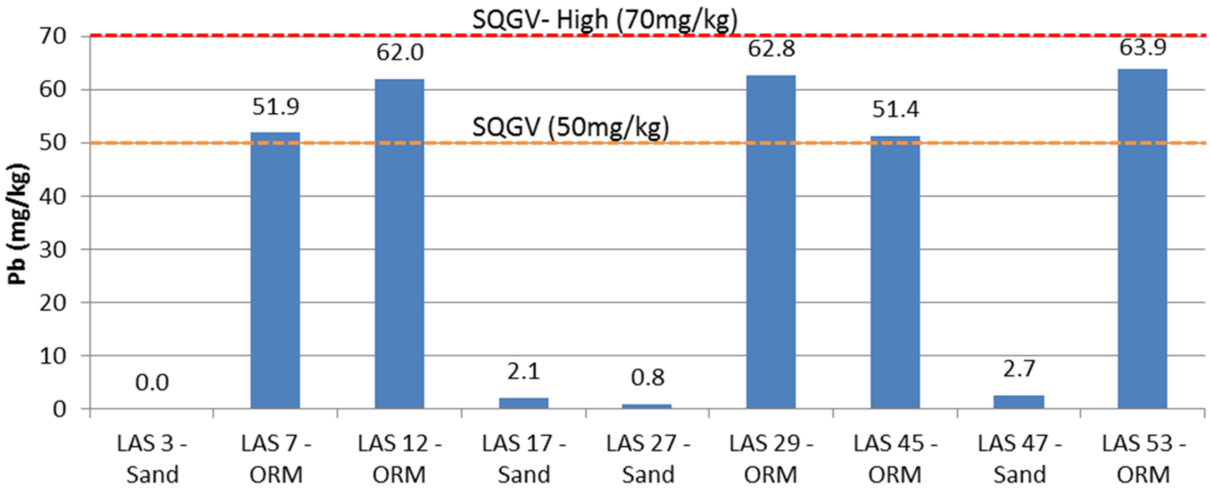


Figure 69: Lead (Pb) concentrations in sediment

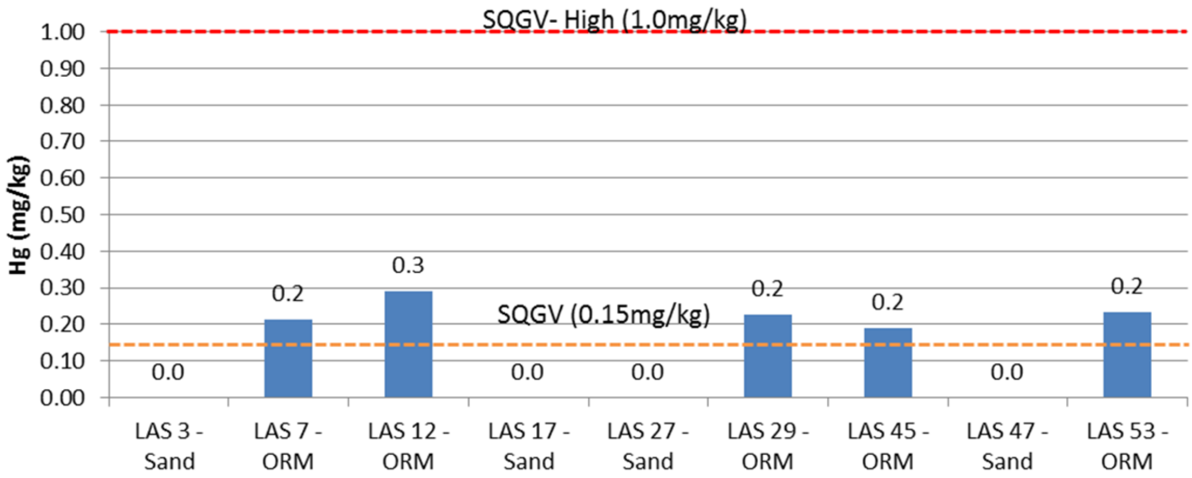


Figure 70: Mercury (Hg) concentrations in sediment

Plate 11: Main sediment types in Lake Ainsworth: Left to right: 'gelatinous' organic –rich muds; Medium sands

Table 22: Lake Ainsworth Sediment metals screening results

	Sample 1 LAS 3	Sample 2 LAS 7	Sample 3 LAS 12	Sample 4 LAS 17	Sample 5 LAS 27	Sample 6 LAS 29	Sample 7 LAS 45	Sample 8 LAS 47	Sample 9 LAS 53	ANZECC Guideline		NEPM Guideline	
	H6436/1 LAS 3	*H6436/2* LAS 7	*H6436/3* LAS 12	*H6436/4* LAS 17	*H6436/5* LAS 27	*H6436/6* LAS 29	*H6436/7* LAS 45	*H6436/8* LAS 47	*H6436/9* LAS 53	SQGV	SQG-High	NEPM HIL - A*	NEPM EIL **
Silver (mg/kg)	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	4	na	na
Arsenic (mg/kg)	<2	3.6	3.5	<2	<2	4.1	3.4	<2	5.1	20	70	100	20
Lead (mg/kg)	<1	51.9	62.0	2.1	0.8	62.8	51.4	2.7	63.9	50	220	300	600
Cadmium (mg/kg)	<0.5	0.4	0.5	<0.5	<0.5	0.5	0.4	<0.5	0.6	2	10	20	3
Chromium (mg/kg)	<2	12.5	13.6	1.4	<2	14.9	10.4	<2	11.2	80	370	100	Na
Copper (mg/kg)	<1	19	25	<1	<1	25	19	1	21	65	270	1000	100
Manganese (mg/kg)	2	83	92	17	8	94	63	5	75	na	na	1500	500
Nickel (mg/kg)	<1	10.1	10.9	<1	<1	11.2	8.6	<1	10.4	21	52	600	60
Selenium (mg/kg)	<0.5	2.8	2.2	<0.5	<0.5	2.5	2.6	<0.5	4.5	na	na	na	na
Zinc (mg/kg)	1	118	161	2	2	166	112	13	152	200	410	7000	200
Mercury (mg/kg)	<0.1	0.21	0.29	<0.1	<0.1	0.23	0.19	<0.1	0.23	0.15	1.0	15	1
Iron (%)	0.010	1.034	1.047	0.046	0.060	1.036	1.019	0.033	0.970	na	na	na	na
Aluminium (%)	<0.005	0.934	1.160	0.031	0.021	1.112	0.840	0.021	0.753	na	na	na	na
Sediment Type	**Sand**	**ORM**	**ORM**	**Sand**	**Sand**	**ORM**	**ORM**	**Sand**	**ORM**				

Note: Results in excess of ANZECC/ARMCANZ sediment quality guidelines highlighted in red

SQGV – Sediment Quality Guideline Value (above this level there is potential for biological effects)

SQG-High – Sediment Quality Guideline High (above this level there is a high probability of biological effects)

NEPM HIL A* – NEPM Health Investigation Levels (standard residential with garden/accessible soil includes children's day care centres, kindergartens, pre-schools and primary schools).

NEPM EIL** – interim Ecological Investigation Levels for an urban setting

na-guidelines not available

ORM – Organic Rich Muds

Comparison 1996 to 2018 sediment metal concentrations

AWACS (1996) analysed sediments for metals at three (3) sites and these were replicated in 2018 to allow for comparison of sediment metal concentrations over time. Figure 71 presents this comparison at sites LAS 12, 7 and 29. Metal results from 1996 and 2018 were similar with a slight increase in concentrations across most metals in 2018, except for lead (Pb), which showed a slight decrease in 2018 compared to 1996 levels at sites LAS 12 and 7. Marginal increases in metal concentrations over a 22 year period are not of concern particularly as none of the increased metal concentrations were at levels in excess of the ANZECC/ARMCANZ guidelines. Due to the nature of sampling, some error is expected which may also account for variation in results (e.g. exact location of sample sites, changes to laboratory methods/limits etc.).

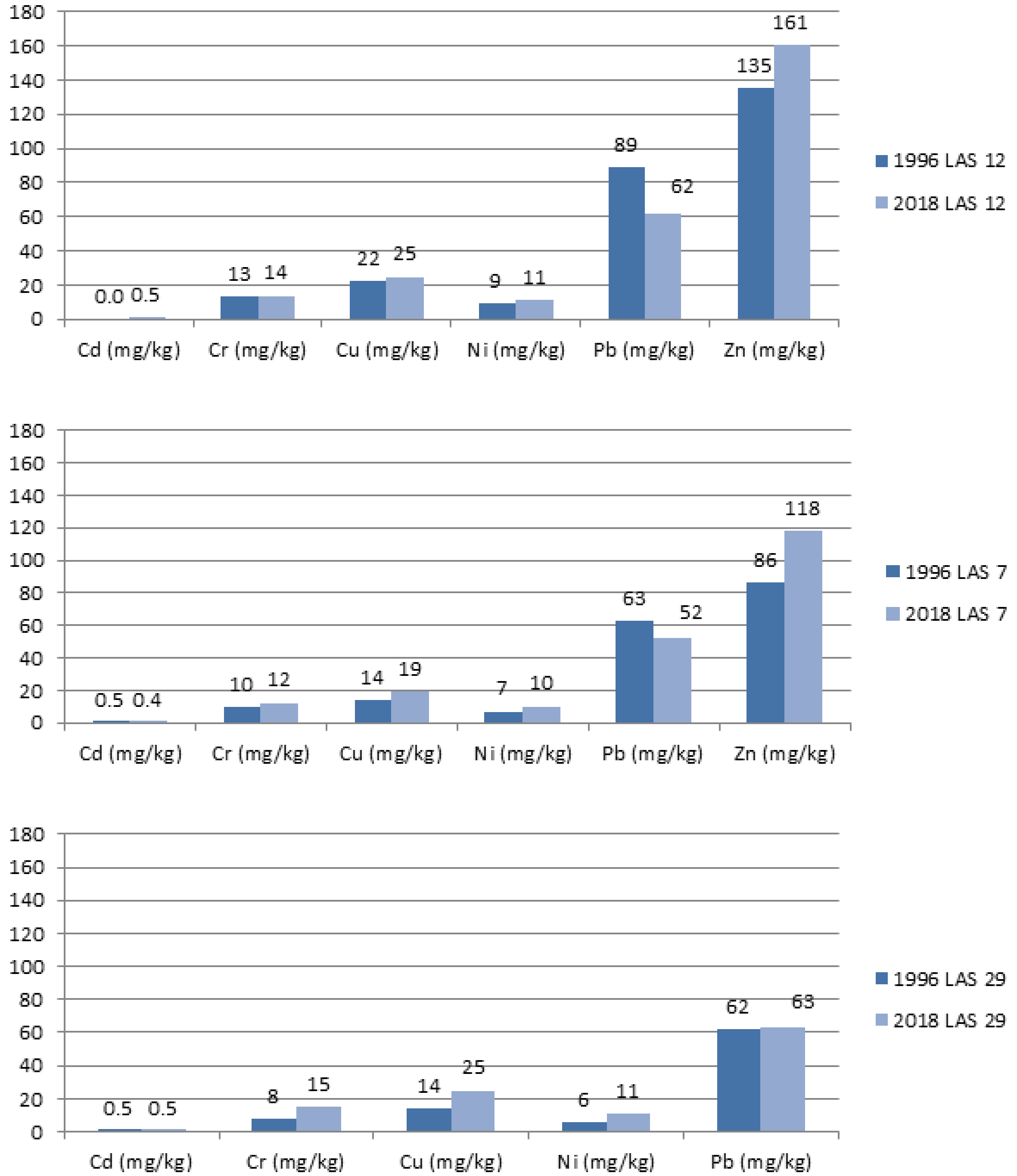


Figure 71: Comparison of sediment metal concentrations 1996 to 2018

4.4.3 Sediment Nutrient Screening

Table 23 provides the results of sediment nutrient screening undertaken at selected sites in Lake Ainsworth. Figure 72 to Figure 74 present results across the lake at sites with different sediment types. Nutrient concentrations are very high in the central organic-rich muds (TP 641 – 896 mg/kg; TN 1.4-1.9%; and NH_4-N 80-118 mg/kg), compared to fringing sandy sediments (TP <50 mg/kg; TN 1.4-1.9%; and NH_4-N 80-118 mg/kg). This result is consistent with previous sampling (AWACS, 1996).

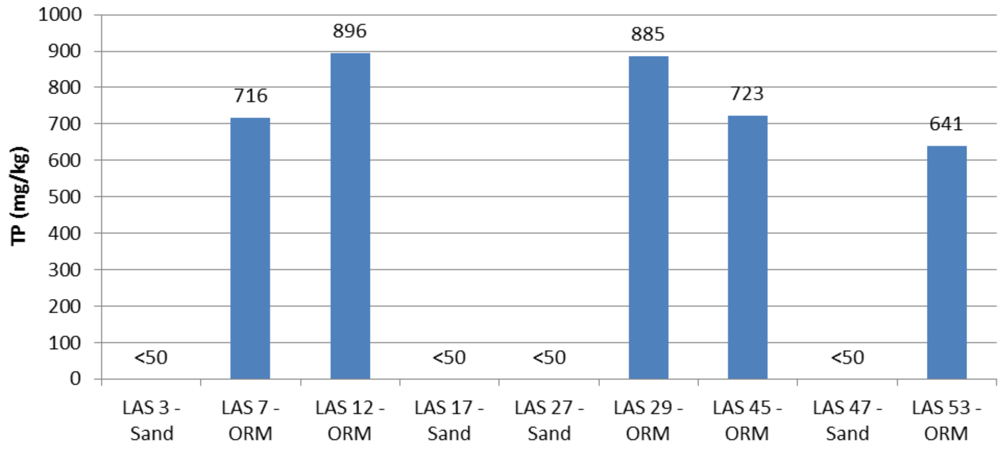


Figure 72: Sediment Total Phosphorus (TP) concentrations

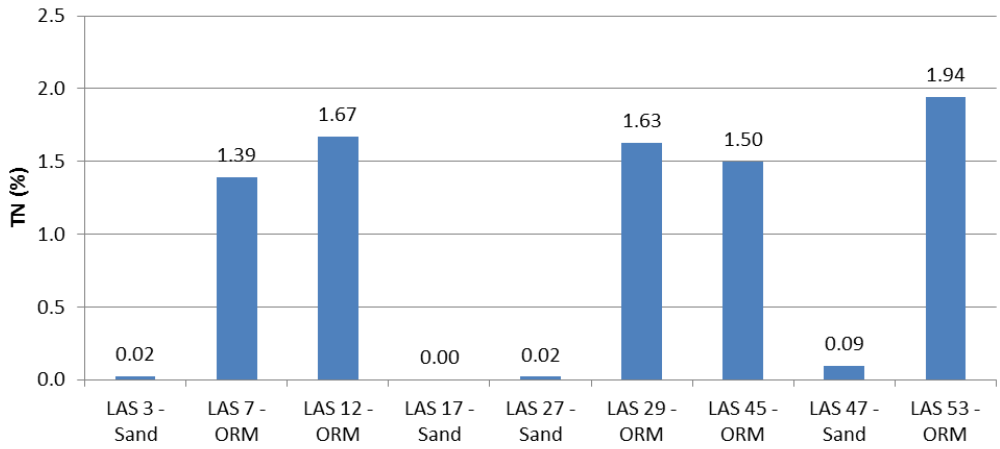


Figure 73: Sediment Total Nitrogen (%)

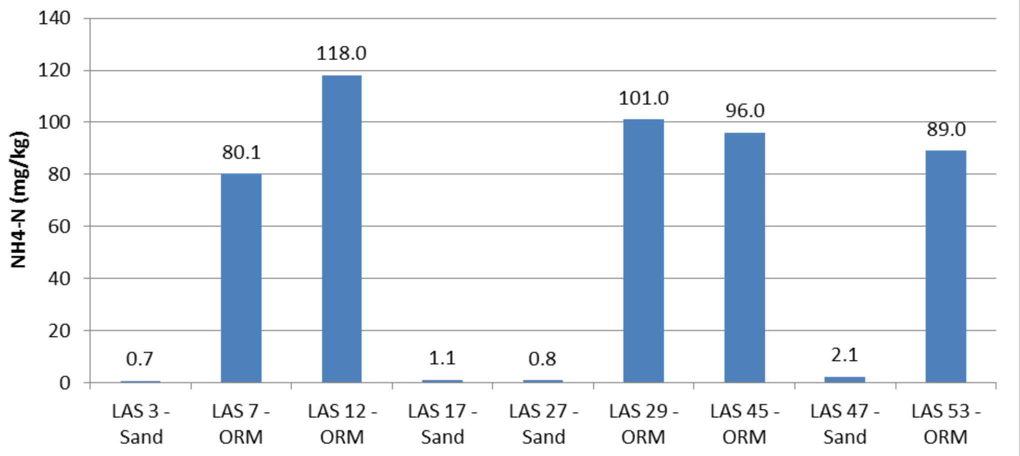
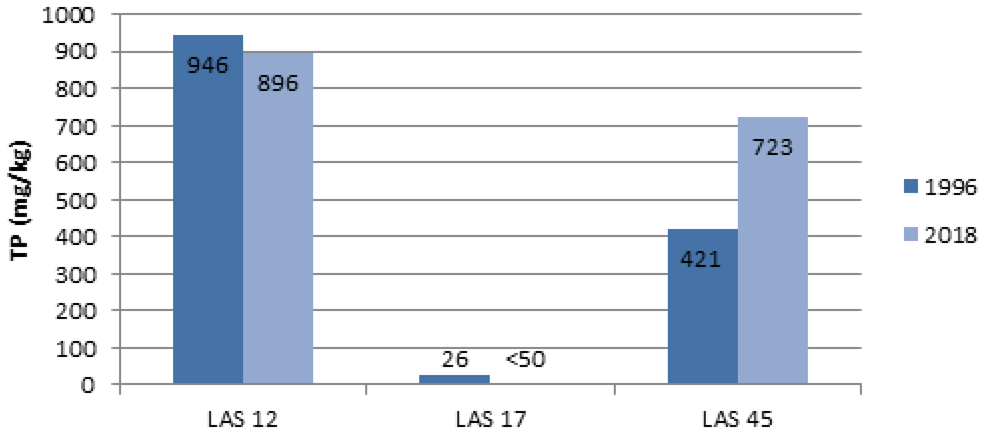


Figure 74: Sediment Ammonium (NH_4-N) concentrations

Comparison 1996 to 2018 sediment nutrient concentrations

AWACS (1996) analysed sediments for nutrients at three (3) sites and these were replicated in 2018 to allow for comparison of sediment nutrient concentrations over time. Figure 75 presents this comparison at sites LAS 12, 17 and 45. TP results from 1996 and 2018 were mixed with a slight decrease (-5%) in concentrations at site LAS12; a marked increase (+72%) at site LAS45; and no discernible change at Site LA17 due to 2018 value less than the limit of recording (< 50mg/kg). Total Organic Carbon (TOC) decreased slightly across the lake from 1996 to 2018. As for metals, due to the nature of sampling, some error is expected which may account for some variation in results (e.g. exact location of sample sites, changes to laboratory methods/limits etc.)



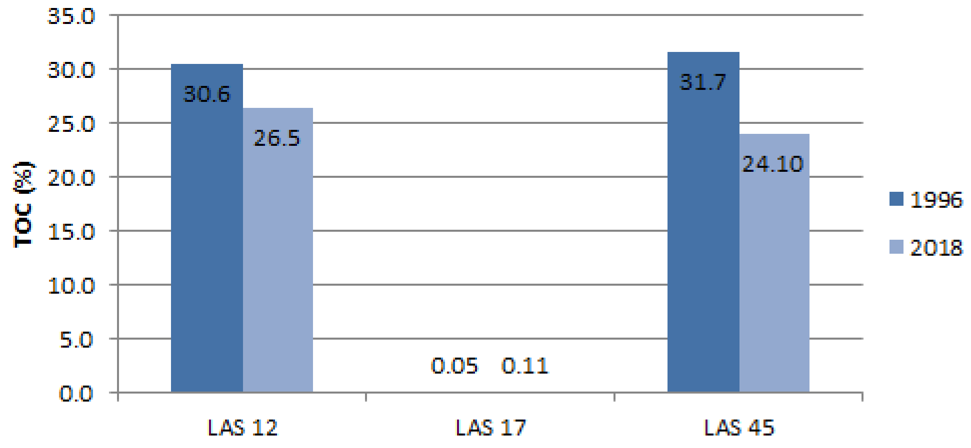


Figure 75: Comparison of TP and TOC from 1996 to 2018

Table 23: Lake Ainsworth Sediment nutrient and physical analysis results

Parameter	Sample 1 LAS 3 H6436/1	Sample 2 LAS 7 H6436/2	Sample 3 LAS 12 H6436/3	Sample 4 LAS 17 H6436/4	Sample 5 LAS 27 H6436/5	Sample 6 LAS 29 H6436/6	Sample 7 LAS 45 H6436/7	Sample 8 LAS 47 H6436/8	Sample 9 LAS 53 H6436/9
Nitrate Nitrogen (mg/kg N)	0.8	0.9	0.9	0.9	0.9	0.8	0.9	0.8	2.5
Ammonium Nitrogen (mg/kg N)	0.7	80	118	1.1	0.8	101	96	2.1	89
Extractable Phosphorus (mg/kg P)	0.4	0.3	0.3	0.2	0.4	0.3	0.5	0.6	0.3
pH	6.69	5.93	5.84	6.52	6.41	5.85	6.01	6.19	5.70
Electrical Conductivity (dS/m)	0.022	0.356	0.564	0.018	0.020	0.474	0.860	0.061	0.534
Total Nitrogen (%)	0.02	1.39	1.67	<0.02	0.02	1.63	1.50	0.09	1.94
Total Organic Carbon (%)	0.27	23.60	26.50	0.11	0.14	25.80	24.10	1.78	34.60
Redox Potential (mV)	40	-20	-40	110	-30	-80	-70	-70	-90
Phosphorus (mg/kg)	<50	716	896	<50	<50	885	723	<50	641
Sediment Type	Sand	ORM	ORM	Sand	Sand	ORM	ORM	Sand	ORM

ORM – Organic Rich Muds

5. FLORA AND FAUNA

5.1 Aquatic Fauna Assessment

A number of native and exotic/non-endemic fish species have previously been recorded in Lake Ainsworth as outlined below.

Native Endemic:

- Firetail gudgeons (*Hypseleotris galii*);
- Freshwater Eel-tailed catfish (*Tandanus tandanus*); and
- Leland *et al.* (2012) has also indicated the potential for native crayfish species*, Tenuibranchiurus sp*. and *Cherax cuspidatus*, to be present.

Exotics/non-endemic:

- Mosquito Fish (*Gambusia holbrooki*) (GeoLINK, 2002);
- Cane Toad (*Rhinella marina*) (MHL/ GeoLINK, 2002);
- Redclaw crayfish (*Cherax quadricarinatus*) (Leland *et al.*, 2012; Tierney (2019);
- Australian bass (*Macquaria novemaculeata*); and
- Silver Perch (*Bidyanus bidyanus*; Phil Buckland – records supplied by Lennox Wildlife Watchers).

The objectives of this fish survey were to document the fish species present with particular focus on detection of exotic fish species not previously recorded from the lake.

5.1.1 Methodology

Lake Ainsworth contains a range of aquatic habitat types that are likely to be utilised by a number of fish species. Fish habitat types within Lake Ainsworth include:

- Open water – shallow and deep, generally with sand substrate;
- Riparian vegetation and steep banks – overhanging or under-cut banks, vegetative shading, tree roots, etc.
- Emergent and floating aquatic vegetation – e.g. Typha, Lepironia,
- Woody debris – including sunken or partially submerged fallen trees

Backpack electrofishing in combination with dip-netting was utilised to target shallow water habitats around the margins of Lake Ainsworth. The main limitation with backpack electrofishing is limited depth range, which is limited to safely wadeable depths (approximately 1.2 m, depending on bed substrate). This method allowed every habitat in the lake except for deep open water to be targeted effectively.

Electrofishing was conducted in the lake by Hydrosphere Consulting personnel over 2 days in March 2019. Approximately 1,050 m of the margins of the lake were surveyed (Figure 76) with a total electrofishing effort of 4,899 seconds shock time. Margins of the lake surveyed included the eastern bank from the Sport Recreation Centre south 330 m and from the beach in the south-eastern corner north along the western bank approximately 720m (Figure 76). The north western margin could not be surveyed due to excessive depth and the far north and north east margins could not be surveyed safely due to high use of the area by the Sport and Recreation Centre during the time of the survey. Similarly, the south eastern margin could not be surveyed safely due to high recreational use by the public during the time of the survey.

All species captured were temporarily held in a covered plastic tub prior to sorting, identification and counting. Native species were immediately released back into the lake after identification and exotic species were humanely euthanased as per sampling permit conditions and ethics requirements.

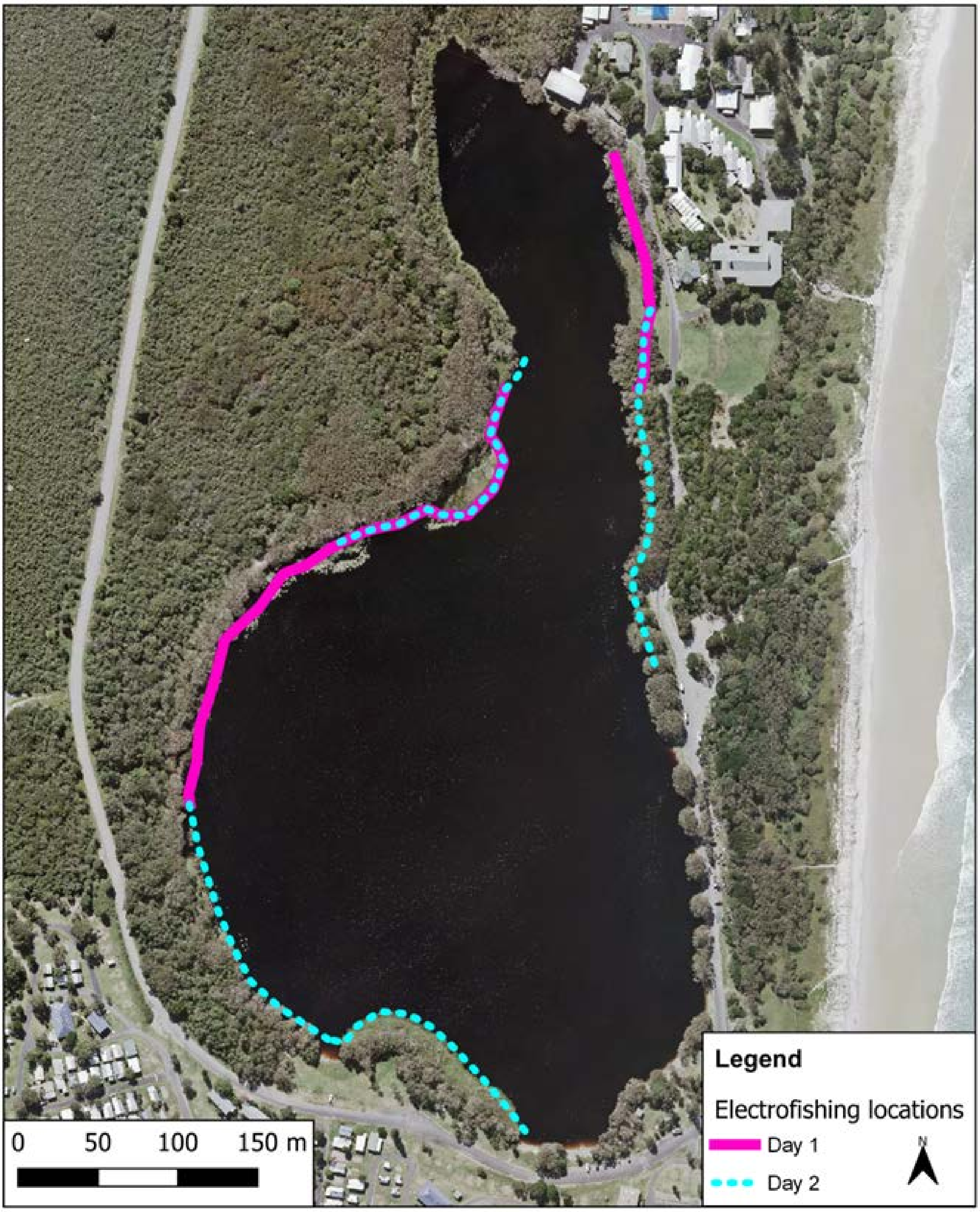


Figure 76: Backpack electrofishing locations

5.1.2 Results

A total of six fish species were captured in Lake Ainsworth during the fish survey (Table 24) including two exotic species and four native species. Incidental captures included Cane toad (*Rhinella marina*) tadpoles (exotic) and the non-endemic and invasive Redclaw Crayfish (*Cherax quadricarinatus*). Each of the species encountered are discussed below.

Table 24: Backpack electrofishing survey results

Species	Species Name	Type	Endemic/non-endemic	Count
Exotic				
Mosquitofish	*Gambusia holbrooki*	Fish	Non-endemic	727
Swordtail	*Xiphophorus helleri*	Fish	Non-endemic	7
Native				
Australian Bass	*Macquaria novemaculeata*	Fish	Non-endemic	4
Duboulays rainbowfish	*Melanotaenia duboulayi*	Fish	Unknown	11
Eel-tailed catfish	*Tandanus tandanus*	Fish	Endemic	2
Firetailed Gudgeon	*Hypseleotris galii*	Fish	Endemic	640
Total				**1,389**
Incidental captures				
Cane toad (tadpole)	*Rhinella marina*	Frog	Non-endemic, exotic	9
Redclaw crayfish	*Cherax quadricarinatus*	Crayfish	Non-endemic,exotic	15

Native Fish

Four native fish species were captured in the lake during the fish surveys including Eel-tailed catfish (*Tandanus tandanus*), Firetailed Gudgeon (*Hypseleotris galii*), Duboulays rainbowfish (*Melanotaenia duboulayi*) and Australian bass (*Macquaria novemaculeata*).

Eel-tailed catfish (*Tandanus tandanus*)

T. tandanus have been recorded previously in the lake and are expected to typically occur in waterways such as Lake Ainsworth. *T. tandanus* are generally considered to be a hardy species, tolerating a wide range of environmental conditions including low dissolved oxygen and high turbidity. This species completes its life cycle entirely within freshwater and it is known to breed well in dams and lakes, likely due to stable water levels and low flows which are conducive to their benthic nests. The breeding season extends from October to February, where the female deposits eggs in a nest that the male builds and defends vigorously. Introduced species, particularly redfin and carp (not recorded as present in Lake Ainsworth), are considered threats to *T. tandanus* however *T. tandanus* are also known to defend their nest from other fish species. The relatively small size of individuals recorded from the shallow water survey indicates that the species are likely to be successfully reproducing in the lake.

Plate 12: Eel-tailed catfish (*Tandanus tandanus*) captured during fish survey

Firetail gudgeon (*Hypseleotris galii*)

H. galii have been recorded previously in the lake and are expected to typically occur in waterways such as Lake Ainsworth. *H. galii* are also considered to be a very hardy species, tolerating a wide range of environmental conditions. *H. galii* have a wide distribution and are extremely common, occurring in most freshwater waterways in the region. A high number of individuals were captured during the survey with many more visually observed. The high abundance and broad size range of individuals captured suggests that the species is successfully breeding and flourishing in the lake.

Plate 13: Firetailed gudgeon (*Hypseleotris galii*) captured during fish survey

Duboulays Rainbowfish (*Melanotaenia duboulayi*)

Duboulays Rainbowfish (*M. duboulayi*) also known as Crimson-spotted rainbowfish (due to a bright red spot on the upper operculum) is a small native fish species (<80 mm) that has a narrow distribution restricted to coastal drainages from Baffle Creek (Queensland) in the north to Hastings River in the south. It is generally a widespread common species within its distribution being found in a range of lotic (flowing) and lentic (non-flowing) habitats including lowland rivers, upland rivers and streams, small coastal streams, dune lakes and stream systems on Fraser island, lakes, ponds and impoundments (Pusey *et al.*, 2004). The species is often found in large schools in the upper water column, however is often associated within structure including woody debris, aquatic macrophytes and root balls. The species spawns and completes its entire lifecycle in freshwater.

M. duboulayi have been recorded in coastal dune lakes similar to Lake Ainsworth on Fraser Island (Pusey *et al.*, 2004) and *M. fluviatilis* (considered synonymous with *M. duboulayi* pre-1986) have been recorded in several coastal dune lakes in northern NSW (Timms, 1982). Interestingly, *M. duboulayi* has not been recorded in Lake Ainsworth previously, however, the undectected presence of this species during previous surveys cannot be ruled out. *M. duboulayi* can be an elusive fish to capture and are a timid and agile species that easily evade common capture methods such as dip or seine netting.

M. duboulayi is a popular aquarium species that is easily bred in captivity. It is also possible that the species was illegally released into the lake as an unwanted aquarium species or as a way to establish a stock of the species for aquarium use, especially considering the presence of another aquarium species, Swordtail (*Xiphophorus helleri*).

It is currently unknown whether *M. duboulayi* naturally occur in Lake Ainsworth or have been introduced at some stage. The size range of *M. duboulayi* captured indicates that the fish are likely to be successful breeding in the lake.

Plate 14: Rainbowfish (*Melanotaenia duboulayi*) captured during fish survey

<u>Australian Bass (*Macquaria novemaculeata*)</u>

Four individuals of *M. novemaculeata* were captured during the fish survey. Two were captured around woody debris towards the northern end of the eastern bank and two were caught around aquatic macrophytes on the southern and western banks.

The species is native to the region however it is considered to be non-endemic (i.e. not naturally occurring) to the lake. *M. novemaculeata* is considered to be partly catadromous (born in brackish/estuarine water, migrate to freshwater then migrate back downstream to spawn), and as such is not likely to form a self-sustaining population within the land-locked Lake Ainsworth. While there is disagreement among authors about whether Lake Ainsworth was ever open to the ocean, Tibby *et al.* (2007) concluded that the most recent opening was in the 1930’s based on sediment cores, parish maps and aerial photos. Although not determined, published age/length relationships for the species indicated that the fish captured were unlikely to have been greater than 10 years in age, probably significantly less, and would not be relics from a time of historical opening to the sea. Considering this, the presence of *M. novemaculeata* is almost certainly due to deliberate introduction of the species to the lake.

There are no known records of official stocking of *M. novemaculeata* in the lake and therefore it is assumed they have been illegally released into the waterway by members of the public. The fish may have been released into the lake as fingerlings or recreationally caught at another location and released in to the lake, or a combination of both. The size of individuals caught in the survey ranged between approximately 20 and 30 cm however there are anecdotal reports of individuals >50cm being captured recreationally. Due to the small number of fish captured during the survey and variation in growth rates of individuals it is difficult to estimate an accurate age of fish captured and potential time(s) of release into the lake.

Plate 15: Australian Bass (*Macquaria novemaculeata*) captured during fish survey

<u>Silver Perch (*Bidyanus bidyanus*)</u>

No Silver Perch (*Bidyanus bidyanus*) were caught during the electrofishing survey however there are anecdotal reports of the fish in the lake (Lennox Wildlife Watchers, pers. comm.).

B. bidyanus is a native freshwater fish species which is not endemic to this area, with the natural distribution restricted to the Murray Darling basin. In their natural range, *B. bidyanus* are listed as Critically Endangered under commonwealth environmental legislation and are listed as Vulnerable under NSW legislation. Despite this, *B. bidyanus* are commonly bred in captivity, are a popular freshwater aquaculture species and are regularly stocked in farm dams. Hatchery fingerlings are easily obtainable commercially however if present in the lake, it is likely that the species was illegally introduced.

<u>Long-finned Eel (*Anguilla reinhardtii*)</u>

Long-finned eels (*Anguilla reinhardtii*) are usually expected to inhabit freshwater water bodies in this region however none were recorded in Lake Ainsworth during this survey. *A. reinnhardtii* are particularly susceptible to capture by electrofishing and therefore it is highly likely that the species would have been captured if present in the lake. There are no previous records of *A. reinnhardtii* from the lake.

A. reinnhardtii are catadromous and migrate to the sea to spawn, returning to freshwater habitats as juveniles. *A. reinhardtii* are adept at negotiating migration obstacles, and are also known to travel overland for short distances. Although located extremely close to the ocean the lake is not connected to the marine environment via surface water. As discussed previously, the lake may have historically been open to the ocean however this has not occurred since the 1930s. It is unlikely that adults of the species would have persisted in the lake for this long and it appears that the hydrologic isolation from the sea is preventing the recruitment of juveniles.

Exotic species

Two exotic fish species were recorded during the fish surveys: Mosquitofish (*Gambusia holbrooki*) and Swordtail (*Xiphophorus helleri*).

<u>Mosquitofish (*Gambusia holbrooki*)</u>

G. holbrooki is an introduced species endemic to eastern North America. Today, collectively with Gambusia affinis, Gambusia are the most widespread freshwater fish species in the world. They are present and widespread on every continent except Antarctica. *G. holbrooki* were originally introduced to Australia to control mosquitos based on some preliminary evidence of G. holbrooki successfully controlling mosquito populations (MacDonald & Tonkin, 2008). *G. holbrooki* were first introduced to Australia in 1925 (Rowe *et al.* 2008) and by the 1940's were established throughout most of NSW.

In North America, *G. holbrooki* is a prey species for piscivorous fish (feeds on other fish) such as catfish and bass, for birds including herons, egrets, bitterns, grebes, ducks, and kingfishers, for some snakes and for predatory invertebrates such as backswimmers, water boatmen, diving beetles and dragonfly larvae (Rowe *et al.* 2008). There appears to be little recent research into Australian predators of *G. holbrooki*. From a range of references, Rowe *et al.* (2008) provides a summary of G. holbrooki predators in Australia (both native and non-native). *G. holbrooki* make up a component of the diets of crayfish, marron, Redfin perch and Little black cormorants. They are also preyed upon by eels, gudgeons (*Mogurnda* and *Gobiomorphus sp*.), Spangled perch, Rainbow trout, Mouth almighty and Australian bass. Water rats and fishing bats are also said to eat *G. holbrooki*.

G. holbrooki 's aggressive nature, high reproductive potential, short life cycle, generalist and adaptive diet, dispersive nature and wide environmental tolerances all combine and contribute to their success as an invasive species and their ability to negatively impact native fish populations. These attributes also negatively impact on frogs, influence macroinvertebrate, zooplankton and phytoplankton communities and enhance primary productivity through increasing allocthonous (derived from terrestrial sources) nutrient loads (MacDonald & Tonkin, 2008).

G. holbrooki can negatively impact native fish communities by direct predation, competitive exclusion from food sources and habitat was well as aggressive interactions such as fin nipping (Tonkin *et al.* 2011). The implications of such interactions range from reduced condition of native fishes, such as stunted growth, reduced ovarian weight and low fecundity, and increased susceptibility of individuals to secondary infection due to damaged skin and fins, through to mortality or more or less competitive interference driven reductions in population size and distribution (Tonkin *et al.* 2011). In Australia, *G. holbrooki* have caused detrimental ecological impacts on many native small-bodied freshwater fishes. Rowe *et al.* (2008) compiled a summary revealing that at least 23 native freshwater fish species have been adversely negatively impacted by Gambusia.

Plate 16: Mosquitofish (*Gambusia holbrooki*) captured during fish survey

Swordtail (*Xiphophorus helleri*)

Seven *X. helleri* were captured during the fish survey. *X. helleri* is a small tropical/sub-tropical freshwater fish species native to North and Central America. The species is a popular small aquarium fish species. They have established populations at a number of discrete locations across a broad geographical range in Australia. It is likely that the species was released into the lake as unwanted aquarium fish.

There are records (Corfield *et al.*, 2008; NSW DPI, Undated (a)) as well as anecdotal reports of *X. helleri* being captured in the lake previously. They have only been recorded in one other location in NSW, Burringbar Creek. The small numbers captured in this survey indicate that the population is likely to be relatively low compared to the other small-bodied species (*G. holbrooki* and *H. galii*) in the lake. However, given that a number of apparently pregnant females were captured in the survey and the time since previous reports of the species indicate that the species is successfully breeding in the lake.

Interestingly, all *X. helleri* individuals were captured adjacent to emergent aquatic macrophytes along the southern bank with the majority caught from underneath blue-green algae slicks. Large numbers of other small fish were also caught from beneath the algae slicks. It appears in this instance the algae was providing habitat cover for these small-bodied fish species. In addition, electrofishing effectiveness may have been increased by the ability of the electrofishing operators to ambush fish taking refuge under the algae. There were no ill effects observed in any fish captured in the vicinity of the algae slicks.

NSW DPI (2019) note that here have been no studies on the impacts of *X. helleri* on NSW aquatic ecosystems however the species has been linked to negative impacts including suppression and displacement of native fish species in other parts of Australia (Arthington, 1989; Kailoa, 2000; Morgan *et al.*, 2004). Characteristics such as its omnivorous diet, its fast breeding capacity, lack of environmental constraints and especially its ability to coexist with *G. holbrooki* have been attributed to its success as an introduced species.

Plate 17: Swordtail (*Xiphophorus helleri*) captured during fish survey

5.1.3 Incidental captures

Incidental captures are those species captured that were not being targeted in the survey. Two incidental species were captured in the survey, both non-endemic, Redclaw crayfish (*Cherax quadricarinatus*) and juvenile Cane toads (*Rhinella marina*).

Redclaw crayfish (*Cherax quadricarinatus*)

Fifteen *C. quadricarinatus* were captured during the survey with many more sighted. This is a considerable number given that electrofishing is generally inefficient for the capture of crayfish. The size of individuals varied widely from approximately 2 to 20 cm.

C. quadricarinatus are native to tropical northern Australia however are considered a pest species outside of their natural range including NSW and many other parts of the world. *C. quadricarinatus* have large growth rates, superior fecundity and can withstand a wide range of environmental conditions allowing them to out-compete native species and establish populations.

C. quadricarinatus has been previously recorded in Lake Ainsworth (NSW DPI, undated (b); Leland *et al.*, 2012; Tierney *et al.*, 2019), is one of only a few recorded locations of *C. quadricarinatus* occuring in NSW and represents its southern most extent of its translocated range in Australia (Leland *et al.*, (2012). Leland *et al.*, (2012) note that the probable pathway of introduction of the species to the lake was by human action including “bait-bucket” transfer, aquarium discards and intentional (and illegal) translocation/stocking by recreational fishers, rather than natural dispersal from previous sites of introduction. The population of the species in the lake was reported as large, well established and self-sustaining by Leland *et al.*, (2012). Results from this survey indicate a high abundance of the species in the lake concurring with the Leland *et al.*, (2012) conclusion.

Despite a large number of *C. quadricarinatus* being captured in this survey, no endemic native crayfish were captured in the lake. Endemic native crayfish species that would typically be expected to occur in Lake Ainsworth include *Cherax cuspidatus* and *Tenuibranchiurus sp*. However, despite extensive targeted crayfish surveys by Leland *et al.*, (2012) that study also did not detect any native crayfish species in the lake. Interestingly, that study did report the presence of *Cherax cuspidatus* and *Tenuibranchiurus sp*. within adjacent Melaleuca swamps to the north of the lake where *C. quadricarinatus* was not recorded. Leland *et al.*, (2012) suggested that *C. quadricarinatus* maybe displacing the smaller native species or that they simply avoiding traps due to the presence of C. quadricarinatus. Although no endemic native species were recorded in the current survey, the presence of these species in the lake cannot discounted.

Plate 18: *Cherax quadricarinatus* captured during the survey.

Cane toad (*Rhinella marina*) tadpoles

R. marina were present in large numbers, but were intentionally avoided during the electrofishing survey in favour of better efficiency in capturing fish species. Despite, being actively avoided numerous individuals of *R. marina* were captured due to their high abundance. A large number of *R. marina* tadpoles and toadlets were observed around all margins of the lake. *R. marina* have been recorded previously in the lake since 1994 (Warren 1994; AWACS, 1996; MHL/Geolink 2002; and many anecdotal observations).

The history of cane toads in Australia is well known. They were originally introduced to North Queensland in the 1930s in an attempt to control beetle pests of sugar cane. The cane toad was ineffective in controlling the pests and soon became an environmental pest in their own right. They are now widespread throughout northern Australia.

Cane toads are considered a pest species in Australia because they:

- Compete with native fauna;
- Poison, injure and kill native fauna, mainly higher order predators such as snakes, large lizards and quolls;
- Poison, injure and kill pets;
- Prey on native fauna; and

- Potentially carry diseases that can be transmitted to native frogs and fishes.

Cane toads are listed as a key threatening process under Commonwealth and state biodiversity legislation.

The cane toad is highly adaptive and can tolerate a broad range of environmental conditions. It appears Lake Ainsworth provides favourable conditions for cane toads to breed with large numbers of tadpoles and toadlets observed around the lake. The current or historical abundance of cane toads at the lake is unknown however their current relative abundance appears to be high. High numbers of toadlets on the foreshore of the lake have also been recorded previously (AWACS, 1996).

The specific impacts of cane toads on the biodiversity of the lake is unknown with no specific studies on biodiversity conducted before, during or after the invasion to quantify impacts. It is likely that cane toads have impacted local frog and predator species in the lake. A recent study (Brown and Shine, 2016) on the impacts of cane toads on tropical native frog species over sixteen years found that the cane toads impacted the native species at the time of invasion however none of the native species declined over time and none of the species were less common at the end of the study than at the start. Further, when cane toads arrive in a new area they often impact frog-eating predators however over time the native species adapt to deal with the presence of cane toads.

Plate 19: *R. marina* toadlet on the shore of the lake amongst blue green algae.

5.1.4 Assessment of potential aquatic pest eradication techniques

Table 25 provides a summary of fish eradication techniques and their potential applicability to Lake Ainsworth. Many of the eradication options are likely to be unfeasible due to range of reasons including size of waterway, impacts on native fish and other fauna, impacts on public safety and public perception. The remaining options they are unlikely to be effective at eradicating or controlling pest fish populations.

Angling for *M. novemaculeata* has become popular in Lake Ainsworth and there is a significant possibility that any potential removal attempts, which are unlikely to be successful anyway, would be resisted by a proportion of the community.

Cognisant of this situation the most effective way of managing risks associated with pest fish species in the lake is likely to be containment and public education.

Table 26 provides a summary of cane toad control options and their potential applicability to Lake Ainsworth. It is very difficult to eradicate cane toads from a location, particularly behind the invasion front. However, there are potential population control methods available.

The implementation of any control options would have to be carefully considered, particularly in context of the current distribution of cane toads within Ballina Shire. It is unlikely one method alone would be effective but the implementation of a suite of methods may be effective at controlling cane toad numbers. For example, survival and recruitment could simultaneously be reduced by manual removal and trapping of both adults and tadpoles and discouraging breeding by increasing riparian vegetation, while applying suppressor pheromones and encouraging potential native predators of toads in and around the lake.

Table 25: Summary and assessment of pest fish eradication methods

Eradication Method	Advantages	Limitations	Potential applicability to Lake Ainsworth
Physical			
Netting, trapping, line fishing	• Minimal impact on non-target species and habitat • Requires minimal training • At least one method is suitable to most species	• Total eradication almost impossible • Labour intensive • Limited by access, depth, velocity, aquatic plant cover, woody debris, target species and avoidance behaviour by the targeted species	• Potentially effective at reducing Australian Bass biomass (not total eradication) however unlikely to be effective on small fish. • Use of netting unlikely to be accepted by the public due to potential impact on other fauna.
Electrofishing	• Selective with minimal impact on non-target species or habitat • Capable of removing a large range of fish sizes	• Total eradication is almost impossible • Only effective in shallow water	• Unlikely to be effective due to size of waterbody and deep water refuges.
Explosives	• Achieve eradication quickly	• Non selective • Large amounts of explosives are needed • Restricted to shallow water • Safety and structural issues	• Not feasible due to non-selective nature, public safety risk and likely to be considered unacceptable by the public.
Water drawdown	• High potential for achieving eradication • Highly efficient • Ability to be controlled • Selective process (if a holding area is available to non-target species)	• Potential for significant damage to aquatic vegetation • Only suitable for low flow water bodies (e.g. Pond or divert flow in a creek) • Need to have a suitable location for the disposal of pumped water • Labour intensive • Not suitable for larger waterbodies	• Not practical or desirable

Eradication Method	**Advantages**	**Limitations**	**Potential applicability to Lake Ainsworth**
Chemical			
Rotenone	• Total eradication achievable • Use is well developed • Ability to neutralise with potassium permanganate therefore can minimise downstream effects and 'revive' non-target species • Relatively successful history • Can be applied in a number of ways- liquid/powder, backpack/ vehicular/ aerial/ boat sprayed • Only Australian approved piscicide.	• Non selective • Labour intensive • Considerable site preparation- water drawdown, aquatic vegetation removal, calculations, potassium permanganate preparation, non-target fish holding area, flow diversion • Strenuous approvals process • Potentially negative public perception • Involve re-introduction of native species	Not feasible as it is non-selective and impractical for a large water body such as Lake Ainsworth
Other Chemicals	• Total eradication possible • Quick	• Some not approved for use in Australia • Some still in experimental stages • Similar issues to rotenone	Not feasible as it is non-selective and impractical for a large water body such as Lake Ainsworth
Biological			
Native predators	• Chemical free • Little labour	• Still in experimental stages • Effectiveness questionable • Complete eradication unlikely • Potentially cause other ecological issues	• Introduction of additional non-endemic fauna is not likely to be justifiable or desirable. • Unlikely to be effective on its own. Could be effective as a part of a broader control strategy rather than an eradication technique
Pathogens	• Can be species specific	• Still in experimental stages • Research dependent • Potentially cause other ecological issues • Potential negative public perception	• No known developed pathological techniques for identified pest species available. • May be applicable in the future if suitable pathogens are found.
Genetic techniques	• Species specific	• Still in experimental stages • Research dependent • Potentially cause other ecological issues	• No known techniques available.

Table 26: Cane toad control options potentially suitable for Lake Ainsworth

Control Method	Advantages	Limitations	Applicability to Lake Ainsworth
Manual removal	• Easily implemented, can be implemented by community groups • Good opportunity for community awareness and education	• Labour intensive. • Needs to be implemented in conjunction with other measures • Often ineffective behind the invasion front and unlikely to significantly reduce populations. • If ineffective it may create cynical public perception. • Potential for impacts on non-target species	• There is potential for implementation as part of a broader strategy • Would require significant community participation
Fencing	• Easy to implement • Can be very effective under suitable conditions	• Ineffective in wet climates. • Likely to be difficult to implement and ineffective in heavily vegetated and high public use areas.	• Unlikely to be feasible due to vegetation and high public use. • Potential for negative public perception due to perceived impacts on amenity and native fauna.
Adult trapping	• Easy to implement • Effective at capturing cane toads	• Labour intensive – needs to be monitored • Potential for impacts on non-target species	• There is potential for implementation as part of a broader strategy • Would require significant community participation
Tadpole trapping	• Easy to implement • Extremely efficient at removing a large number of tadpoles	• Still in developmental stages • Labour intensive – needs to be monitored • Potential for impacts on non-target species	• There is potential for implementation as part of a broader strategy in the future • Would require significant community participation
Suppression pheromones	• Potentially efficient at suppressing large populations in a water body	• Still in developmental stages.	• Potentially hard to implement in large water body such as Lake Ainsworth
Native predators	• Direct improvement to native biodiversity • Less labour intensive in the long term	• Unlikely to suppress populations in the short-term. • Likely to have a long lead time until effectiveness can be determined. • Would need to be part of a broader strategy	• There is potential for implementation as part of a broader vegetation and water quality management strategy

Containment and education

When populations of pest aquatic fauna species are discovered measures can be implemented to prevent the further spread of such populations. Such measures include lowering water levels in a water body to prevent flooding and further dispersal of a species and construction of physical or screen barriers between infested and un-infested areas of a waterway or catchment to prevent upstream/downstream migration of a pest species. These methods address containing natural spread of a pest species however, unfortunately the most common vector for the spread of pest species is human-induced dispersal. Therefore the most effective method of containment is often considered to be public education to discourage further dispersal of pest species.

In the context of Lake Ainsworth, one of the pest aquatic species (Mosquitofish) is so common, widespread and persistent in the area that containment is unlikely to be effective and two of the species (Swordtail and Redclaw crayfish) are quite unique to Lake Ainsworth, in that the lake is one of only a few locations that the species are present in NSW. Both of those species have been recorded in the lake for some time and if natural dispersal of the species from the lake was going to occur it is likely to have occurred already. Leland *et al.* (2012) noted that at the time of their study that no Redclaw crayfish had been captured in habitat adjacent to the lake.

Although it is now illegal to release exotic fish to the wild it is still a relatively common phenomenon, particular with aquarium fish. Swordtail and Redclaw crayfish are both valued aquarium species and the main risk of further dispersal of the species is via aquarium discards. Aquarium enthusiasts may capture individuals from the lake for use in an aquarium then deliberately or inadvertently release them into other waterways in the region. There is also potential for further invasive aquarium species to be released into the lake. The issue usually occurs when tank owners no longer want an aquarium or a particular species the fish either need to be relocated to another aquarium, returned to the pet shop or euthanased. Other tank owners and pet shops are often reluctant to accept unwanted fish due to the potential for disease transfer and therefore the release of these fish to (a good home) in the wild is often seen as the only alternative to the unpalatable euthanasia of the pet.

An educative program coupled with facilities for accepting unwanted aquarium fish would greatly mitigate the risk of further dispersal of pest species from the lake and new pest species into the lake. An educative program could include:

- Interpretative/educational signs at key locations around the lake;
- Distribution of relevant information to local pet/aquarium shops, local aquarium groups and online forums;
- An awareness campaign and distribution of relevant information through relevant Council communication techniques such as local newspaper, Council Facebook pages and newsletters.

Information could include relevant pest species identification information, impacts of aquarium fish releases to the wild, dumping of aquarium fish is prohibited and alternatives to dumping aquarium fish.

5.2 Aquatic Weeds

Exotic macrophytes are present within Lake Ainsworth and have previously been documented (MHL, 2001; GeoLINK, 2002; EnviTE 2007 & BSC, 2017b), these include Mexican Waterlily (*Nymphaea mexicana*), *Salvinia sp*., Water Primrose (*Ludwigia spp*.) and Water Hyacinth (*Eichhornia crassipes*). These weeds have been observed to occur throughout various sections of the lake. The waters of the northern section of the lake have been observed to be infested by Mexican Waterlily and Salvinia which can congest the waterbody and restrict flow between the far northern region and open water to the south (EnviTE, 2007). The north-western banks of the lake have been documented to have minimal infestation of exotic macrophyte species likely due to shading caused by paperbark trees. However an organic island in open water adjacent to these banks has been observed to contain Mexican Waterlilies. The western, south-western, southern and north-eastern sections of the lake have been observed to contain Water Primrose, Mexican Waterlily and Salvinia, while along the eastern section Water Hyacinth and Salvinia have been recorded. Water Hyacinth has also been observed along the western section and is of concern due to its ability to spread quickly and produce seeds which are viable for up to 20 years (BSC, 2017a).

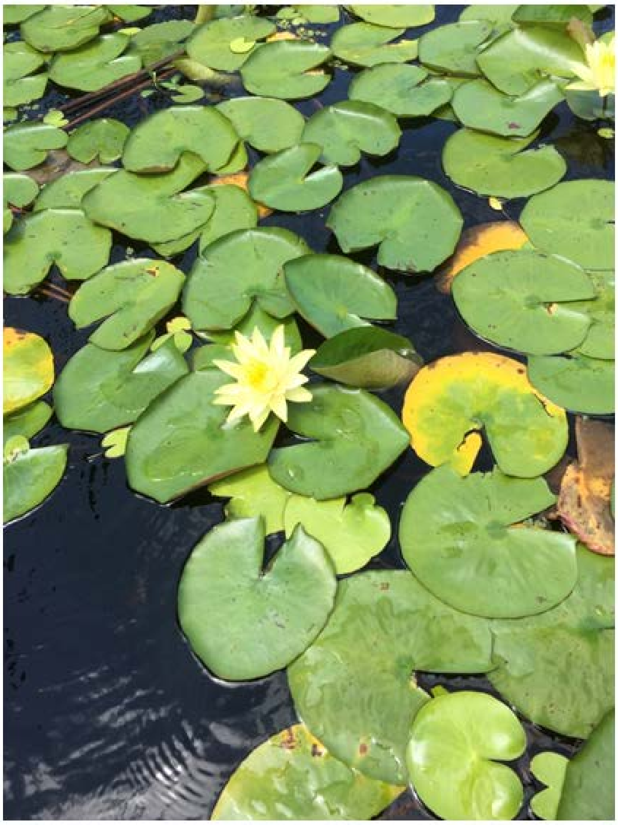



Plate 20: Left: Mexican Waterlily; and Right: Salvinia at Lake Ainsworth

5.2.1 Management Options

A variety of management techniques incorporating physical, biological and chemical controls have been implemented to address exotic macrophyte infestations within the lake.

Physical removal is labour intensive and generally relies on volunteer groups supported by Council. Lennox Head Landcare, supported by Council, undertakes frequent and regular manual removal of exotic macrophytes from the lake. During the summer of 2018/2019 Council and the Sport and Recreation Centre commenced an educational program with students attending the centre to target and remove aquatic weeds from the lake. Removal is typically completed using personal watercraft such as kayaks, canoes and SUP (stand up paddle) boards with the weeds stockpiled and removed to the northern end of the sporting fields at the Sport and Recreation Centre (outside of the lake catchment to prevent nutrient seepage back to the lake) to dry before being trucked to landfill for disposal. Council has hired an aquatic weed harvester in the past when the level of infestation was excessive. While effective at removing weeds, there were a large number of turtles and eels dragged up on the harvester which had to be manually removed to avoid injury, which in turn affected the speed of removal, and increased costs due to extra time required to hire the harvester. When required, a boom is used in the northern section of the lake to contain Salvinia to prevent this weed from choking the waterway until manual removal can be undertaken (EnviTE, 2007). Currently, the boom is broken and requires replacement.

The Salvinia weevil (*Cyrtobagous salviniae*), a biological control agent, is also routinely released at the lake to control Salvinia. Council partners with DPI and Rous County Council to deliver the control program, involving release during the summer months when water temperature is suitable. While the weevil is effective at controlling Salvinia, the growth rate of this weed in summer is faster than the rate of predation by the weevil. Therefore other management techniques are required in additional to this control method. The use of this biological control agent is ongoing and additional releases are undertaken annually.

Chemical control has been trialled in the lake with limited success. The key issues identified were that without removal of treated vegetation, this will sink and decompose, thus contributing to organic matter build up and releasing nutrients back to the water column. Additionally, this method is not likely to have community support.

Table 27 presents a summary of current management recommended by NSW DPI for species of concern at Lake Ainsworth. It also identifies landholder responsibilities under the *Biosecurity Act 2015* and its subordinate legislation for each species. In all cases, reducing the level of bioavailable nutrients in water is recommended to help control outbreaks of aquatic weeds.

Table 27: Summary of Biosecurity duty and control methods from NSW Weedwise (2019)

Name	Biosecurity duty under *Biosecurity Act 2015*	Control	Description	Effectiveness
Water hyacinth (*Eichhornia crassipes*)	*This weed must be eradicated where practicable, or as much of the weed destroyed as practicable, and any remaining weed suppressed. The local control authority must be notified of any new infestations of this weed within the Biosecurity Zone.*	Physical removal	Should be undertaken prior to flowering and seed set. Either by hand or by mechanical harvester. Mechanical harvesting of large infestations has been effective, although costly. As a guide, it takes between 600 and 900 hours to harvest one hectare of dense water hyacinth.	Manual removal is considered effective when the rate of removal is faster than the rate of regrowth. More effective in small systems. Manual removal is ongoing at Lake Ainsworth through community groups, Sport and Recreation Centre Programs and Council.
		Biological Control	Four insects from South America have been released by CSIRO since 1975 and are well established across NSW. There are two weevil species, *Neochetina eichhorniae* and *Neochetina bruchi*, and two moth species, *Niphograpta albiguttalis* and *Xubida infusellus*.	Biological control cannot be solely relied upon for effective control of water hyacinth in NSW.
		Chemical Control	A number of herbicides are registered for the control of water hyacinth in NSW. Application is through high volume spraying with hose and handgun power sprays either from a boat or from the banks.	Spraying an entire heavy infestation can cause the weed mat to sink and rot resulting in deoxygenation of the water, potentially killing fish. This can be avoided by spraying one third of the infestation at a time, or by physically removing as much of the weed as possible prior to spraying.
Salvinia (*Salvinia molesta*)	*General Biosecurity Duty: All plants are regulated with a general biosecurity duty to prevent, eliminate or minimise any biosecurity risk they may pose. Any person who deals with any plant, who knows (or ought to know) of any biosecurity risk, has a duty to ensure the risk is prevented,*	Mechanical Control	Floating booms or nets on waterways have been used to help contain Salvinia infestations and limit the spread of the plant to other areas or waterways. Mechanical removal possible for small infestations but expensive	Only offers short-term relief and are best used along with chemical control programs.

Name	Biosecurity duty under *Biosecurity Act 2015*	Control	Description	Effectiveness
	eliminated or minimised, so far as is reasonably practicable.	Biological Control	The Salvinia Weevil (*Cyrtobagous salviniae)* is originally from south-eastern Brazil and was introduced into Australia by the CSIRO in 1980 to combat the growing threat of Salvinia.	There have been cases in the Richmond and Clarence River systems where the *Cyrtobagous* weevil has provided effective control of Salvinia. These results have occurred within a six-month period over spring and summer with nutrient-rich water conditions. Control in Lake Ainsworth has been effective and should continue.
		Chemical Control	A number of herbicides are registered for the control of Salvinia in NSW.	Effective control depends on having good access to the weeds in well-defined waterways. Reedy banks and swampy backwater areas, protect the plant and reduce the effectiveness of chemical control. Reinfestation of a waterway can occur rapidly from these sites. Due to this regenerative ability, infestations of Salvinia should be controlled early to prevent them getting out of control. Dense, mature infestations are also difficult to control with herbicides. In this situation, it is difficult to gain effective herbicide contact with the plant due to the densely-folded and compact nature of the weed.
Water Primrose (*Ludwigia spp*.)	*Land managers should mitigate the risk of new weeds being introduced to their land. The plant should be eradicated from the land and the land kept free of the plant. The plant should not be bought, sold, grown, carried or released into the environment. Notify local control authority if found.*	Physical control	Small *Ludwigia* plants can be manually pulled or hoed from the ground. Remove as much of the root as possible. Larger infestations may be slashed and burnt. Follow up with herbicide may be required. Always take care not to spread seed.	Once mature plants are established the soil seed bank will ensure repeat growth of the weed. Follow up control will be necessary.
		Chemical control	Treat plants with a registered herbicide when actively growing and before flowering. Apply using foliar spray, cut stump or stem injection, depending upon the chosen herbicide.	
Mexican Water	*General Biosecurity Duty: All plants are regulated*	Physical	Mechanical harvest.	Once established this plant can be difficult to eradicate.

Name	**Biosecurity duty under *Biosecurity Act 2015***	**Control**	**Description**	**Effectiveness**
lily (*Nymphaea Mexicana*)	*with a general biosecurity duty to prevent, eliminate or minimise any biosecurity risk they may pose. Any person who deals with any plant, who knows (or ought to know) of any biosecurity risk, has a duty to ensure the risk is prevented, eliminated or minimised, so far as is reasonably practicable.*	control		Gold Coast City Council reported that harvesting the Mexican Water Lily is an unsustainable approach with rapid and thick re-growth of this lily observed in some patches in Robina South Lake shortly after harvest.
		Chemical control	A number of herbicides are registered for the control of waterlilies in NSW.	

5.3 Riparian Vegetation

Riparian vegetation is defined as vegetation growing on the water's edge and can include trees, shrubs, grasses and vines in a complex structure of groundcovers, understorey and canopy (DPI Fisheries, 2018). This vegetation zone provides ecosystem functions and values that include bank stability and maintenance of soil structural integrity, land use buffering, water quality filtering, lowering of water temperature (via shading), providing fisheries habitat (root masses and fallen logs/ trees), food source (from litter fall), providing terrestrial habitat, community/ recreational and intrinsic values, and scenic amenity. Riparian zones can also increase resilience to climate change by creating a buffer for development and by providing space for migration of vegetation communities impacted by sea level rise. The degradation of riparian communities can have detrimental effects on all of the ecosystem functions and values listed above.

5.3.1 Field Surveys

A field survey was undertaken for all riparian zones surrounding Lake Ainsworth in December 2018. The survey was undertaken concurrently with the bank erosion survey and sections were categorised in terms of the extent of riparian vegetation, degree of shading of the water and overall disturbance rating according to the classes described in Table 28.

Table 28: Riparian Vegetation categories assigned during field investigation (adapted from Parsons *et al.*, 2002)

Riparian Vegetation Disturbance Rating	Description
Extreme disturbance	Riparian vegetation absent or severely reduced. Vegetation is dominated by exotic species. Surrounding vegetation is cleared land and/or roads and plants present are virtually all exotic species.
High disturbance	Some riparian vegetation is present, but is extremely modified by human access or dominated by exotic species. Surrounding vegetation is cleared land and/or roads and plants present are virtually all exotic species.
Moderate disturbance	Riparian vegetation is native with canopy intact or native species are dominant. Surrounding vegetation is cleared land and/or roads and plants present are mix of native and exotic species.
Low disturbance	Riparian vegetation is in good condition with canopy intact and native species are dominant. Any disturbance is relatively minor. Surrounding vegetation is native with intact canopy and few exotic species

5.3.2 Riparian Vegetation Extent and Condition

Following the field investigation, the existing vegetation community mapping (BSC, 2004) was updated to reflect current vegetation extents (Figure 77). Only minor edits were required to extend sections of the Swamp Sclerophyll Forest and Woodland to current extents. The location of sites and resultant riparian disturbance rating is also indicated in Figure 77. Refer to Blackwood Ecological Services (2017) for a recent description of vegetation communities present at Lake Ainsworth.

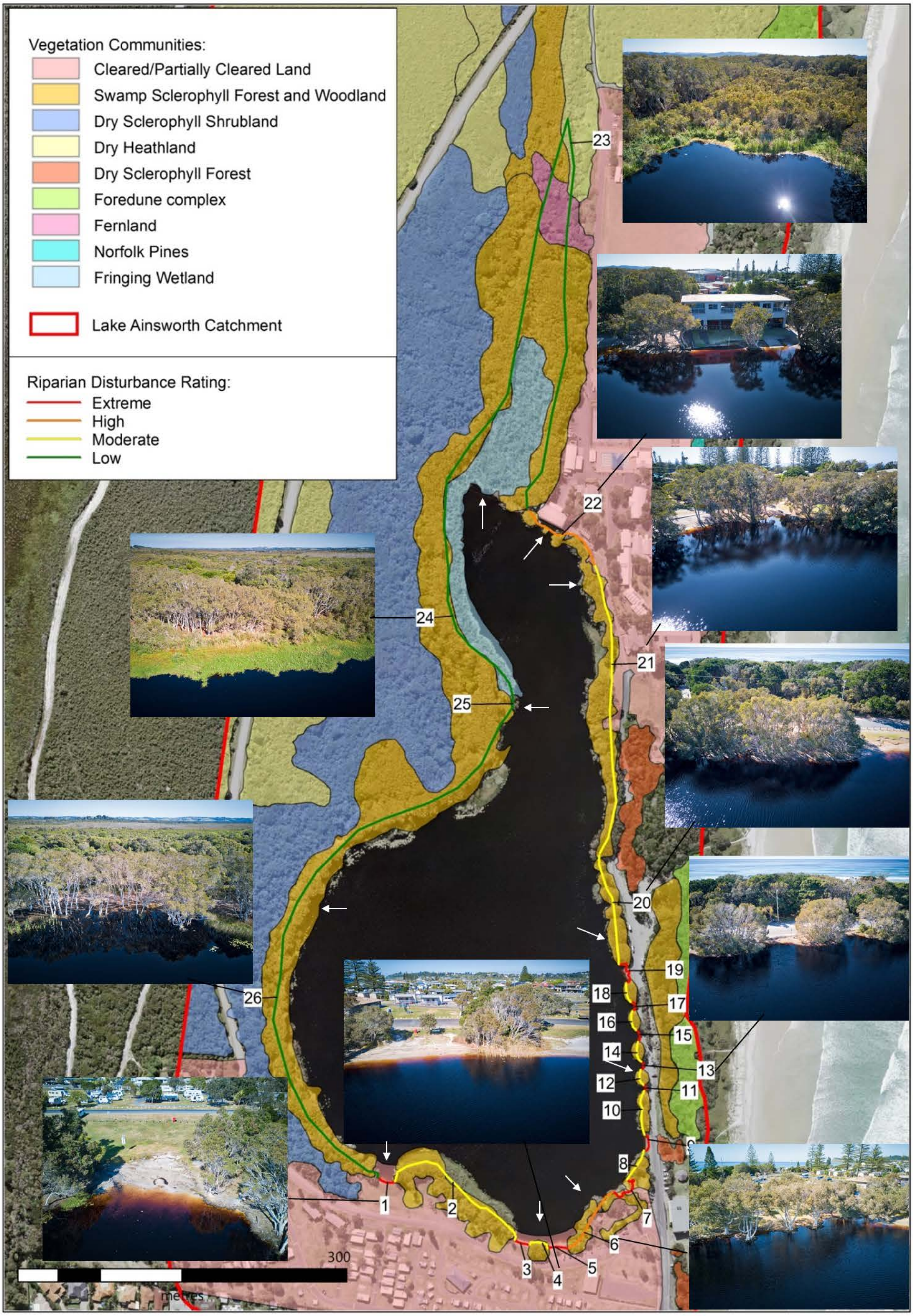


Figure 77: Lake Ainsworth Vegetation Communities (updated from BSC, 2004) and riparian vegetation disturbance rating 2018.

*Note: Drone images are shown for representative sites with photo direction shown as white arrow.

Riparian Vegetation Condition

A number of factors were noted as contributing to riparian vegetation disturbance at Lake Ainsworth. Areas classified as having extreme disturbance were typically located along the eastern road and southern foreshores at cleared access points, devoid of vegetation apart from exotic grassed areas. These sections had a high level of pedestrian traffic and were bordered by either cleared areas (mown exotic grassed areas) or roads.

Two sites were classified as having high disturbance. The first area was the popular south-eastern corner of the lake, which is also impacted by high levels of recreational use and has a high degree of exposed roots due to pedestrian traffic but retained a good native canopy cover due to the mature Broad-leaved Paperbark trees in this area. Some trees in this area were showing signs of poor health likely due to root exposure/erosion. The second area with high disturbance is along the northern foreshore at the main access point for the NSW Sport and Recreation Centre. There is also a high degree of foot traffic in this area as well as watercraft launching areas. Mature Broad-leaved Paperbark trees remain at this site with semi-continuous extent and 51-75% shading of the lake edges.

Moderate disturbance rating was assigned to 10 sites along the eastern and southern foreshores generally in between access points where generally there was continuous riparian vegetation in reasonable condition, often fenced-off and therefore had a lower degree of pedestrian traffic impacts. The western shore and northern tip of the lake displayed the least amount of riparian vegetation disturbance with continuous native vegetation, and very low exotic species present, bordered by native heathland vegetation in good condition.

Table 29 presents a summary of the results for Lake Ainsworth as total length of bank and % of bank classified in each vegetation disturbance category. Figure 78 presents the results graphically.

Table 29: Riparian Vegetation Disturbance rating summary for Lake Ainsworth

	Total length surveyed (m)	Extreme (m)	High (m)	Moderate (m)	Low (m)
Length of bank	2,521	174	151	683	1,513

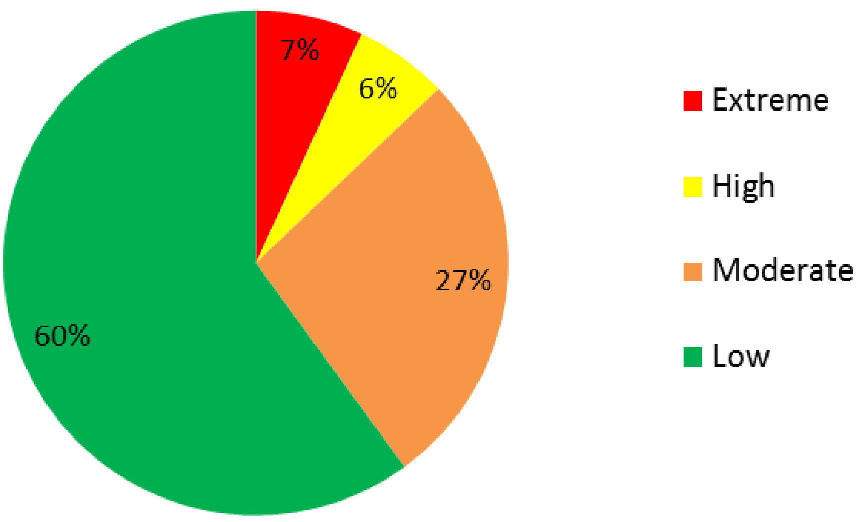


Figure 78: Proportion of riparian condition for Lake Ainsworth

Table 30: Riparian Vegetation Disturbance rating for Lake Ainsworth sites

Site (refer Figure 77)	Length (m)	Riparian Vegetation Disturbance Rating	Site Erosion Rating	Vegetation Communities
1	15.9	Extreme	Severe	Cleared/Partially Cleared Land
3	14.4	Extreme	Controlled	Cleared/Partially Cleared Land
5	18.0	Extreme	Controlled	Cleared/Partially Cleared Land
7	38.6	Extreme	Severe	Cleared/Partially Cleared Land
9	18.7	Extreme	Moderate	Cleared/Partially Cleared Land
11	6.6	Extreme	Moderate	Cleared/Partially Cleared Land
13	8.7	Extreme	Moderate	Cleared/Partially Cleared Land
15	11.9	Extreme	Moderate	Cleared/Partially Cleared Land
17	10.9	Extreme	Moderate	Cleared/Partially Cleared Land
19	29.9	Extreme	Moderate	Cleared/Partially Cleared Land
6	67.2	High	Moderate	Swamp Sclerophyll Forest and Woodland
22	83.8	High	Moderate	Swamp Sclerophyll Forest and Woodland
2	149.8	Moderate	Stable	Swamp Sclerophyll Forest and Woodland
4	20.5	Moderate	Stable	Swamp Sclerophyll Forest and Woodland
8	30.8	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
10	41.6	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
12	15.1	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
14	19.4	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
16	18.6	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
18	18.3	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
20	101.9	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
21	267.0	Moderate	Minor	Swamp Sclerophyll Forest and Woodland
23	717.4	Low	Stable	Swamp Sclerophyll Forest and Woodland, Fringing Wetland, Fernland, Dry Heathland
24	201.1	Low	Stable	Swamp Sclerophyll Forest and Woodland, Fringing Wetland,
25	46.3	Low	Minor	Swamp Sclerophyll Forest and Woodland
26	548.4	Low	Stable	Swamp Sclerophyll Forest and Woodland

6. COMMUNITY USES

Lake Ainsworth is an important asset utilised by the community and tourists for recreational, commercial and educational purposes. The lake is bordered by, or is in close proximity to, commercial and recreational facilities and businesses. The catchment area and these associated facilities and businesses provide a key destination for visitors to the region which in turn has a positive impact on the local economy.

6.1 Recreational Uses/ Activities

Lake Ainsworth is utilised by both the local community and tourists visiting the region for recreational purposes. The eastern and southern sides of the lake provide easy access to the water and contain recreational, picnic and parking facilities, while the western side contains informal walking tracks and additional access points to the waterbody. The lake and surrounding facilities are utilised on a regular basis for a variety of recreational activities, which include:

- Swimming;
- Sailing/ sailboarding;
- Surf lifesaving training and nippers;
- Canoeing/ kayaking/ ski paddling/ stand-up paddle boarding;
- Picnicking;
- BBQing;
- Bird watching;
- Walking/ jogging;
- Cycling;
- Dog walking (restrictions apply in relation to dogs around and in the lake)
- Camping (at the caravan park);
- Fishing (traps and nets not allowed); and
- Car parking for access to the lake and adjacent surf beach.

These activities are undertaken year round although the lake experiences peak periods during the warmer months, weekends and school holidays. Surveys undertaken during the preparation of the current *Lake Ainsworth Management Plan* (GeoLink, 2002) documented that the average number of vehicles visiting the lake was approximately 570 on Saturdays and 835 on Sundays. The total number of visitors on a Sunday was estimated at 3,100, with nearly 1,600 present at any one time (AWACS, 1996). These numbers have likely increased since the survey was undertaken, with suggestions that vehicle numbers have doubled during the Christmas/ New Year period. This is likely to be placing additional pressures on facilities and infrastructure as well as the lake and associated ecosystems. Foreshore erosion around access points has been exacerbated by high pedestrian traffic and in many places, severe erosion has restricted public access and/or created safety concerns (refer Section 1.3- Erosion Assessment and Section 6.6 – Public Safety Assessment). Such pressures can also adversely affect the ecology of these ecosystems (Butler *et al.*, 1996) and the level of ecosystem services provided by the study area.

Plate 21: Recreational use of the lake

6.2 Commercial Uses/ Activities

Lake Ainsworth is bordered by two commercial businesses, the Lake Ainsworth Caravan Park (Reflections Holiday Parks) and the Lake Ainsworth Sport and Recreation Centre. The Caravan Park is located on the southern shores of the lake and draws a substantial number of visitors to the area. Due to park reconfiguration, this facility has seen a reduction in capacity in recent years with average visitor numbers for 2017-2019 estimated at 715 people during 100% occupancy, a reduction from 1,200 people previously accommodated. The maximum current potential for the park is 1295 people at any one time (295 sites x 5 people per site) (pers.comm., D.Smith, 2019). The Sport and Recreational Centre borders the lake to the northeast and can accommodate approximately 210 people at any one time (Wagner, 2005). The Centre provides a variety of school camp options for primary and secondary students, offers holiday rental accommodation in the form of self-contained apartments, and caters for functions such as weddings and corporate events. Camp Drewe is also located in the northern reaches of the catchment area. This is a ministry of the Presbyterian Church with accommodation available for up to 96 people.

Prior to 2002, a commercial business providing lessons and rentals for sailboards, catamarans and skis was operating on the eastern shore of the lake (GeoLINK, 2002). Currently some surf schools and stand up paddle boarding schools are licensed by Council to operate in the lake.

6.3 Educational Uses/ Activities

Lake Ainsworth and the catchment area provide an important educational resource for the region. This area is utilised by the Sport and Recreation Centre to provide outdoor education programs to primary and secondary school children from all around Australia. Educational institutions, such as the Southern Cross University (SCU) and local primary and high schools use the lake and the surrounding dune systems to conduct research projects and educational programs with their students. This unique, freshwater lowland lake has also been the target of several research investigations (Timms 1982; Akhurst *et al.*, 2004 & Tibby *et al.*, 2008).

6.4 Community Engagement

A detailed program of community and stakeholder consultation was undertaken during Stage 2 of the CMP. Consultation activities included:

- Community online and paper-based survey – To engage the Lennox Head and broader community, an online and paper-based survey was open to the public for 12 weeks, between 22nd of October 2018 and 18th January 2019. There was a strong response to the survey with 327 on-line and 150 hard copy surveys (477 total surveys) completed. A copy of the survey is provided in Appendix 3;
- Project webpage – A project webpage was used to introduce the project, provide a link to the on-line community survey, project updates and contact details for further information. The webpage also contains a "Communication Portal" section where the public can provide information and feedback to the project team for consideration. The webpage address was communicated to community and stakeholders in media and other correspondence. The webpage will remain live for the duration of the project with regular updates and information provided to the community as it becomes available. It can be viewed at: www.hydrosphere.com.au/lakeainsworth;
- Media and advertising – various forms of media were utilised to advertise the project and encourage community involvement in the survey and stakeholder meetings. This included:
    - Posters promoting the survey and project webpage, put up at Council libraries and administration buildings and other key community outlets (Appendix 4).
    - Media releases resulting in newspaper articles and radio broadcast including introduction of the project and notification of the up-coming survey; launch of the community survey; and completion and survey and thank you to participants;
    - Social media posts (i.e. Council's Facebook page) providing key project information, updtaes and links; and
    - Articles in the Lennox Wave (local community magazine) and the Ballina Shire Council Community Connect distributed to Ballina Shire residents.
- Lennox Head market stall 9th December 2018 – the stall included information about the Lake Ainsworth CMP. Project staff were on hand to discuss the project with community members and answer questions. The community survey was also available at the stall for people to fill out.
- Targeted stakeholder consultation with key stakeholder groups. This included a phone call, email or letter informing stakeholders of the project, the community survey, webpage and inviting input. Notification letters/emails were sent to all stakeholders with known interest in the lake at the commencement of Stage 2. Follow-up meetings were held with stakeholders where necessary to discuss and clarify comments (written submissions provided by the community are provided in Appendix 5;
- A Community drop-in session was held at the Lennox Head SLSC in November 2018 to introduce the project; notify the public of the community survey and provide an opportunity for informal discussions between the community, stakeholders and the project team to discuss issues and obtain feedback.
- Meetings with the Project Steering Committee made up of the study area land managers and ongoing liaison as required. This group comprised representatives of BSC, Department of Lands, NSW Office of Sport, Office of Environment and Heritage, Reflections Holiday Park, and Lennox Head SLSC. The project team is scheduled to meet with the Project Steering Committee on eight occasions throughout the project at key milestones to ensure oversight and involvement at every stage;
- Notification, registration and face to face meetings with representatives of the local Aboriginal Community to discuss the CMP and to provide an opportunity for informal discussions between community members and the project team about the cultural significance of the lake and potential future management;

- Follow-up discussions with the relevant stakeholders were undertaken as necessary to clarify and/or obtain more information on submissions received.

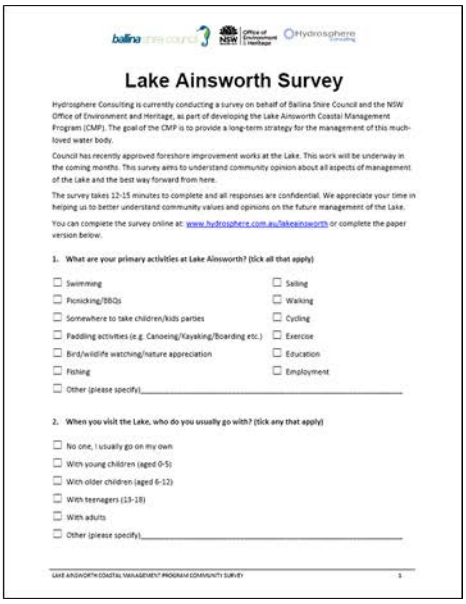
Further consultation will be undertaken throughout the course of the CMP including:

- Meetings with the Project Steering Committee;
- Media releases and advertising at key stages;
- Project web page and communication portal will remain live for the duration of the project;
- Public Display - The Final Draft CMP will be placed on public exhibition for 28 days during late 2019. Formal (written) submissions on the Draft CMP will be sought from the community and stakeholder groups. Submissions will be considered in the development of the Final CMP; and
- Community drop-in session will be held during public exhibition in late 2019. This will provide an opportunity for informal discussions between the community, stakeholders and the project team to discuss issues and obtain feedback prior to formal submissions on the Draft CMP.

6.4.1 Lake Ainsworth Community Survey

The Lake Ainsworth Survey received an excellent response with some 477 completed surveys by deadline. This comprised 327 surveys completed online, and 150 completed paper copies. The results of the survey provide a good snapshot of community opinion about the lake including: popular activities and locations of access; current issues; perceptions about lake health; management priorities; and the community's vision for the future of the lake.

A Community Survey Report has been prepared detailing the analysis and interpretation of survey data is included in Appendix 3. A summary of key findings is provided below.



Lake Ainsworth Survey

Hydrosphere Consulting is currently conducting a survey on behalf of Ballina Shire Council and the NSW Office of Environment and Heritage, as part of developing the Lake Ainsworth Coastal Management Program (CMP). The goal of the CMP is to provide a long-term strategy for the management of this much-loved water body.

Council has recently approved foreshore improvement works at the Lake. This work will be underway in the coming months. This survey aims to understand community opinion about all aspects of management of the Lake and the best way forward from here.

The survey takes 12-15 minutes to complete and all responses are confidential. We appreciate your time in helping us to better understand community values and opinions on the future management of the Lake.

You can complete the survey online at: www.hydrosphere.com.au/lakeainsworth or complete the paper version below.

1. What are your primary activities at Lake Ainsworth? (tick all that apply)

☐ Swimming ☐ Sailing
☐ Picnicking/BBQs ☐ Walking
☐ Somewhere to take children/kids parties ☐ Cycling
☐ Paddling activities (e.g. Canoeing/Kayaking/Boarding etc.) ☐ Exercise
☐ Bird/wildlife watching/nature appreciation ☐ Education
☐ Fishing ☐ Employment
☐ Other (please specify)________

2. When you visit the Lake, who do you usually go with? (tick any that apply)

☐ No one, I usually go on my own
☐ With young children (aged 0-5)
☐ With older children (aged 6-12)
☐ With teenagers (13-18)
☐ With adults
☐ Other (please specify)________

LAKE AINSWORTH COASTAL MANAGEMENT PROGRAM COMMUNITY SURVEY 1

Plate 22: Left: The community survey link provided on project webpage; and Right: The paper version of the survey (a copy of the survey is provided in the Community Survey Report)

Key messages coming out of the survey were:

- The lake is highly valued for its natural scenic beauty and as a place for relaxation and recreation.
- This natural setting provides an important recreational opportunity with swimming and picnicking/BBQs being the most popular activities followed by paddling activities

(canoeing/kayaking/boarding etc.), walking, a place for children/kids parties and wildlife watching/nature appreciation.

- Most survey respondents indicated they used multiple access points to the lake although the majority of people are most likely to access the lake in the south east corner and the southern end of the eastern road. Access via the Sport and Recreation Centre and western side of the lake were the least likely access points, however approximately 1 in 5 survey respondents indicated they were still likely to access the lake from these locations at some time.
- The lake is visited year-round at varying degrees with summer unsurprisingly being the most popular season, followed by spring and autumn. While winter was the least popular time, 38% (97) of respondents said they still visited the lake either every day or a few times a week in this season.
- When asked to rate the overall health of the lake, the community gave an average score of 54 out of 100, equating to just slightly better than "neither healthy or unhealthy" on the provided rating scale. The major factors believed to be affecting lake health were: cyanobacteria, water quality problems, overcrowding, sunscreen pollution, dogs, rubbish and litter, foreshore erosion and runoff. Many respondents noted that water quality issues and algal blooms were only a problem during summer when overcrowding/overuse and hot weather contributed to poor health.
- There are concerns about a number of issues that need to be managed to ensure the health and amenity of the lake into the future. In order of greatest concern, the issues were: algal blooms, foreshore erosion, litter, habitat loss, poor water quality, and overcrowding. Over three-quarters of the community provided details of "Other" concerns for management consideration including: increased use of western side into the future; dogs; low levels of understanding and respect for the lake ecosystem and Aboriginal heritage; lack of education and effective signage; impact of catchment land use; caravan park tenants using lake parking; anti-social behaviour; not enough garbage bins; population growth pressures; lack of management action; concerns about future changes to lake's natural beauty etc.
- Management priorities matched the main issues perceived by the community with the highest priorities being (in order of priority): Improving water quality; protecting/improving natural habitats/wildlife; better public education about protection of the lake's sensitive ecosystem; addressing foreshore erosion; stormwater treatment; and reducing amount of litter/rubbish. Of slightly lower priority were: improving vegetation/weed removal (on land), reducing aquatic weeds, and improving amenity value. Improving public access, improving parking, improving recreational facilities and planning for climate change/sea level rise threats were considered of lowest priority.
- When asked to imagine the lake in 10 years' time, survey respondents overwhelmingly (89%) expressed a strong desire for good water quality (no cyanobacteria, no surface scums/ safe to swim). Stable foreshore (no erosion) (50%), healthy vegetation (47%) and scenic beauty (45%) and abundant wildlife (40%) were also highly desirable. Built infrastructure aspects were less important with improved public facilities (22%), and improved access (21%) scoring much less than natural attributes. More space/ less crowding and more active water-based recreation features were the least selected attributes with (19% and 14% assigned respectively).
- Over half of the survey respondents (278) provided their vision for the lake in 10 years' in their own words. There were a wide range of responses provided, with the most frequently mentioned aspects being related to maintaining and preserving the natural beauty of the lake; improved water quality; no erosion; and having a safe, clean and family friendly place accessible to all to enjoy nature in peace. Many respondents expressed a desire for the lake to remain as close to nature as possible without major changes to the current aesthetics and feel of the area. There was a desire for improvements to enhance the natural attributes and address key issues (e.g. water quality, foreshore erosion, algal blooms etc.). There was a broad spectrum of visions for the lake with regard to future access from

those wanting to see access increased with more parking; to those wanting no change or reduced parking to help control overcrowding and negative social and environmental impacts. Others envisioned encouragement of alternative transport options such as cycling, walking and shuttle bus services to reduce congestion. Figure 79 below is a word cloud which has been generated from the 278 responses received to this question. The larger the word in the cloud, the more frequently it was mentioned in responses.

- Many survey questions gave the opportunity for the community to provide open-ended responses. Over 1600 open-ended responses were collected across the survey, equating to over 30,000 words. The feedback varied broadly, with many issues or concerns raised, some relating stories and memories of the lake in the past and others providing suggestions and ideas for management of issues. The high level of community input is testament to the significance of this much-loved lake in the everyday lives of the community.
- The survey did not directly address aspects relating to the Lake Ainsworth Foreshore Improvement Works including the eastern road closure however, community members did express concern regarding potential future parking issues. Given the high peak visitation rates and the constrained nature of the site, it would be appropriate to further consider this specific issue in Stage 3 of the CMP
- Certain demographic patterns emerged from the survey that may assist in tailoring management actions to key user groups:
    - Younger people (aged <40) were more likely to use the lake primarily for swimming and picnicking/ BBQs, while older respondents were more likely to select a broader range of activities;
    - Unsurprisingly, respondents who lived in Lennox Head were far more likely to visit the lake more often and throughout the year than people who lived elsewhere. The older the respondent was, the more likely they were to visit the lake in all seasons but particularly in the Winter and Autumn compared to younger demographics;
    - Respondents who lived in Lennox Head tended to rate lake health lower than respondents living further away which was attributed to more frequent use, expose to range of conditions and closer connection to the lake than visitors;
    - The older age groups (>40) tended to be more concerned about foreshore erosion, access difficulties as well as aquatic weeds and habitat degradation compared to younger age groups. Algal blooms and water quality were of greatest concern to younger age groups (<40) compared to other issues; and
    - In general, female respondents tended to rank most issues as higher concern/priority than male respondents, except for access difficulties which was rated of more concern by male respondents.

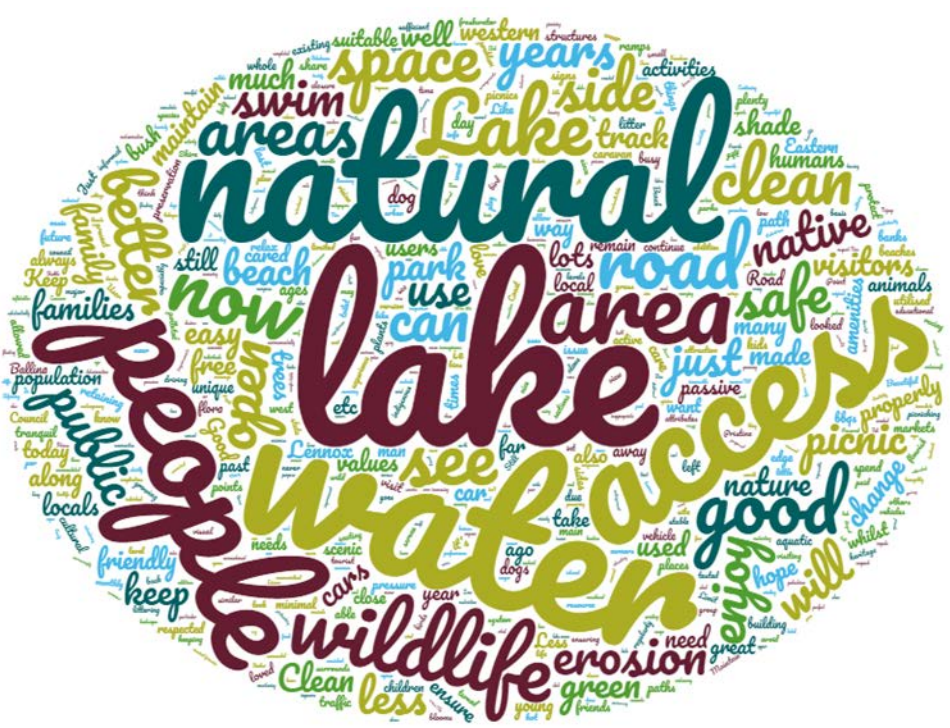


Figure 79: Word cloud generated from responses to Questions 13: If you would like to use your own words, please describe your vision of Lake Ainsworth as you would like to see it in 10 years

6.4.2 Community Organisations and Groups

There is a very active community with interest in Lake Ainsworth.

Lennox Head Landcare

Lennox Head Landcare has been actively involved in vegetation management at Lake Ainsworth for many years. This work is ongoing an includes monitoring of western side to identify and address weed outbreaks to prevent reinfestation; native vegetation plantings along south western corner to replace Lantana infestation; and periodic removal of Water hyacinth from the lake. Lennox Head Landcare provided a position paper on Lake Ainsworth to the project team (attached Appendix 5). The group identified the following issues as essential to water quality and environmental quality:

- Closure of eastern road to all but emergency vehicles;
- Stormwater treatment incorporating WSUD principles;
- Provision of appropriate riparian vegetation;
- Use of suitably durable grass type for high use areas (couch proven inadequate) with effective weed guard to separate grassed areas from native vegetation;
- Underground replacement or relocation of power lines between Sport and Recreation Centre and Lennox Surf Club to reduce vegetation damage from ongoing maintenance;
- Maintenance of existing buffer between Camp Drewe Road and Lake Ainsworth with modifications to rationalise access tracks (1 track only), restore fencing to protect lake edges, remove parking space along road, manage road runoff and provision of signage to explain lake sensitivities and restrictions to protect the lake.
- Investigation of introduced flora and fauna species in the lake and identification of management actions to address impacts;

- Establishment of management structure to coordinate all agencies contributing to the lake and immediate surrounds;
- Effective signage/notice boards to educate and promote understanding of the natural attributes of the lake, sensitivities and key issues and encouraging low-impact use/practices to protect the lake.

The Lennox Head Residents Association and Lennox Head Landcare with support from Ballina Shire Council produced a kids activity booklet called Lake Wildlife Spotters in 2018 (Plate 23) to raise awareness of the lake's wildlife and introduced pests. The booklet has been well-received in the community with several re-prints required to keep up with demand. This shows there is a desire for this type of education material and this format could be expanded to include education of a number of other issues at the lake (e.g. water quality, sunscreen impacts etc.).

Plate 23: Lake Wildlife Spotters kids activity booklet produced by the Lennox Head Residents Association and Lennox Head Landcare with support from Ballina Shire Council.

Lake Ainsworth Wildlife Watch Lennox Head

The Lake Ainsworth Wildlife Watch Lennox Head are a group dedicated to preserving the wildlife at Lake Ainsworth and maintaining a healthy lake environment and ecosystems. The key concerns for this group are:

- The closure of the Eastern Road will divert more traffic to Camp Drewe Road, causing more road kill and particularly putting turtles at risk which are known to cross the road to access the lake. Vehicles speeding along the road is of concern, particularly with road sealing and current lack of posted speed limits. The group call for traffic management including a suitable speed limit to mitigate impacts;
- Water quality including algae and the effects of sunscreen on wildlife that drink the water.
- Litter build up and particularly plastics affecting turtles and other wildlife.
- A lack of research into wildlife populations at Lake Ainsworth.

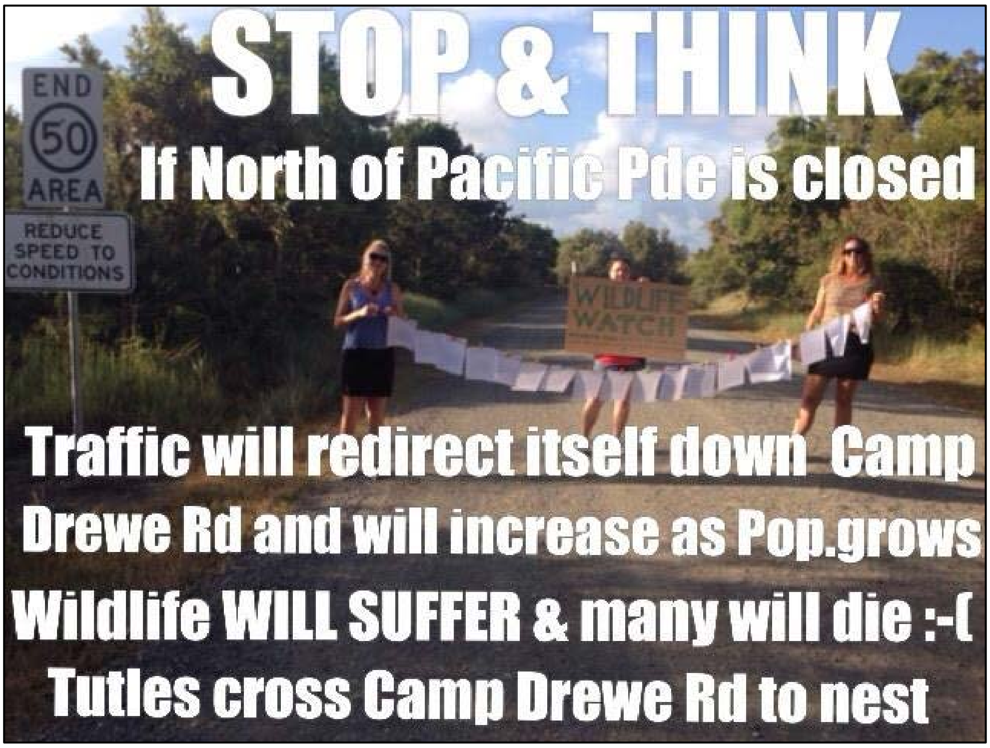


Plate 24: Lake Ainsworth Wildlife Watch Lennox Head facebook page post August 2018

Lake Ainsworth Interest Group (LAIG)

Lake Ainsworth Interest Group (LAIG) is a body that represents the views of three community organisations:

- Ballina Environment Society
- Lennox Head Residents' Association and
- Lennox Head Landcare

Their submission is provided in Appendix 5. Key concerns for the group include:

- Cause of increasing phosphate concentrations in the lake;
- Links between introduced species such as Bass, their predation and blue-green algae outbreaks;
- Predicted impacts of all known users and best practice management strategies to minimise impacts;
- Need for a management body comprising all stakeholders to oversee lake management;
- Defining areas of acceptable uses (e.g. boat launching, swimming etc.);
- Western side increasing use and changes to use creating greater impact from that side with no provision for access, stormwater, vegetation management etc.;
- Appropriate signage/education (e.g. appropriate behaviour, aboriginal heritage, keep sunscreens out, litter, name plates for trees and shrubs etc.);
- Parking – caravan parking in public foreshore areas, consider no parking overnight around lake Foreshore, potential to look at other times parking conrols, provide better walking paths from new Ross St parking areas to lake; provision for mobility vehicle parking; and
- Overcrowding – concerns regarding the planned return of markets to the lake foreshore once foreshore improvement works are complete (e.g. litter, access, loading on top of stormwater swales etc.)

Plate 25: Informal access to western side of the lake

Preserving Lake Ainsworth Inc.

Preserving Lake Ainsworth Inc. is a community group with strong opposition to the planned closure of the eastern road connecting Pacific Parade to the access point to Seven Mile Beach and the Sport and Recreation Centre. A submission regarding the CMP was received by BSC and is included in Appendix 5. Key issues raised by the group include:

- Concern about restriction of public access to the lake through closure of the eastern road affecting public use, amenity and social and cultural values;
- A need for a holistic view of the lake precinct and restoration of the lake, specifically complete foreshore restoration (negating the need to remove the road and restores open space);
- A lack of information from Council about the significant issue that cannot be mitigated which resulted in the closure of the eastern road;
- A desire to be involved in all stages of the CMP development including initial scope setting, identification of stakeholders, and identification of issues affecting the whole lake area.

6.4.3 Aboriginal community engagement

The following consultation activities were undertaken in accordance with the *Aboriginal Cultural Heritage Consultation Requirements for Proponents* (OEH, 2010):

- Stage 1: Notification of project and registration of interest – Aboriginal people who hold cultural knowledge relevant to determining the cultural significance of the area were identified, notified and registered. This involved making contact (in writing) with the following:

  - The OEH regional office;
  - Jali Aboriginal Land Council;
  - The Registrar, *Aboriginal Land Rights Act 1983* for a list of Aboriginal Owners;
  - The National Native Title Tribunal for a list of registered native title claimants, native title holders and registered Indigenous Land Use Agreements;
  - Native Title Services Corporation Limited (NTSCORP Limited);
  - The relevant local council (Ballina Shire Council);
  - the relevant catchment management authority (North Coast Local Land Services) for contact details of any established Aboriginal reference group.
- A public notice was published in the Northern Star on 21st July 2018 inviting members of the Aboriginal community with cultural knowledge relevant to Lake Ainsworth to register their interest.
- Notification letters were sent to members of the Aboriginal community who had been involved in previous consultation activities associated with the lake, inviting them to register their interest.
- A record of the names of each Aboriginal person who registered an interest was made.
- Stage 2: Presentation of information about the proposed project - the registered Aboriginal parties were provided with information about the CMP through:
  - Initial information sent as part of the notification letter including the project flyer and website address for the project with details of the CMP process, key documents and contact information;
  - Face to face meeting with registered parties to discuss the project, aims, milestones and deliverables and relevant cultural knowledge, concerns and perspectives.
- Stage 3: Gathering information about cultural significance through face to face meetings with registered parties and follow up communication.

All feedback received from registered parties was documented to help inform decision making as part of the CMP. Due to request from registered parties, the information has not been made public at this stage.

Aboriginal Land Claims

A search of the Register of Aboriginal Land Claims database was conducted for the Lake Ainsworth catchment in July 2018. No properties in the catchment were identified as being affected by Aboriginal Land Claims pursuant to sections 36 and 37 of the *Aboriginal Land Rights Act 1983*. A copy of the search result from the Office of the Registrar is provided in Appendix 6.

BSC has provided advice that there is an undetermined Aboriginal Land Claim on Lot 7001 DP 1052251, which is located in the coastal dunes immediately east of the beach access point to Seven Mile Beach, south of the Sport and Recreation Centre (refer map in Appendix 6).

Native Title Search

A search of the Native Title Register was undertaken for the Lake Ainsworth catchment in July 2018. There are no registered native title claimants, native title holders or registered Indigenous Land Use Agreements within the study area. However, it will be necessary to seek BSC Native Title Manager advice in relation to works proposed as part of the CMP that are on Crown Land that Council is the Crown Land Manager for. In some instances, prior to works taking place there is a requirement for Council to notify NTS Corp and providing an opportunity to comment (there is a time frame of 28 days for NTS Corp to respond).

6.5 Carrying Capacity

Carrying capacity is defined by Liu (2003), as the maximum number of visitors an area could accommodate without there being excessive deterioration of the environment or declining visitor satisfaction. Carrying capacity can also be defined as the point at which a destination or attraction starts experiencing adverse effects as a result of the number of visitors. There is no fixed value for carrying capacity as it is very much dependent on the location, setting, type of activities undertaken, environmental sensitivity and the expectations of visitors. The use of carrying capacity as a management tool is largely out-dated today due to issues with the conceptual assumptions made and its limited practical application. However considering carrying capacity as a process and the calculated limits as guidance can be useful in considering management options to address overuse issues.

The social carrying capacity of Lake Ainsworth was estimated by Jones (1988) as approximately 560 people at any one time for Lake Ainsworth. This includes a number of different categories including picnicking, sunbathing, swimming, and passive water craft use as shown in Table 31. There have not been any major changes to infrastructure or the size of recreational areas and beaches at the lake since 1988, and therefore these figures remain relevant today. AWACS (1996) reported peak usage rates at Lake Ainsworth 4-5 times the carrying capacity calculated by Jones. In 2017 local recreational traffic counts assessed by BSC (2017b) indicated that peak usage days may now exceed 10 times the estimated carrying capacity, assuming two people per car, not accounting for visitors on foot (**Error! Reference source not found.**, Figure **80**).

Table 31: Estimated Social Carrying Capacity (adapted from Jones, 1988)

Activity	Estimated Social Carrying Capacity
Picnicking	160
Sunbathing	38
Swimming	240
Sailboarding	120
Sailing	5
Total	**563**

Table 32: Average Daily Traffic (ADT) volume (both directions) (23/3/2017 – 3/5/2017) (Source: BSC, 2017b)

3.3 Location	3.4 Existing			3.5 Proposed		
	Off Peak Period	Peak Period	Period Daily Maximum	Off Peak Period	Peak Period	Period Daily Maximum
Pacific Parade – Total (Counter 1)	1640	2280	3230	1640	2280	3230
Local Recreational Traffic	1240	1670	2540	1240	1670	2540
Eastern Road Through to Lake A Sport and Recreation Centre	220	340	700	-	-	-
Camp Drewe Road	190	280	460	400	610	1120

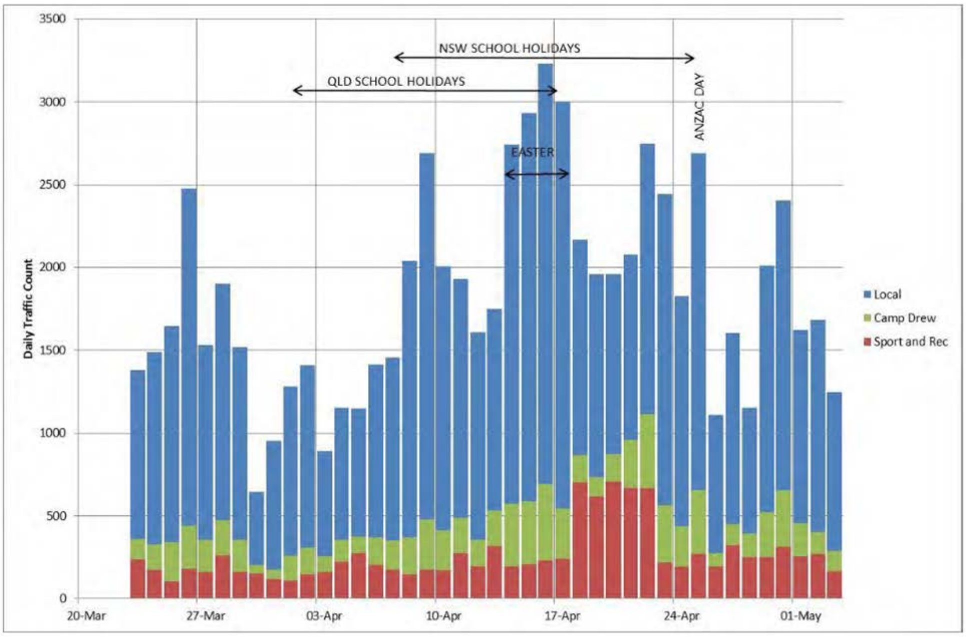


Figure 80: Daily traffic count for Lake Ainsworth (23/3/2017 – 3/5/2017) (Source: BSC, 2017b)

6.6 Public Safety Assessment

There is an ongoing need to provide safe and enjoyable access by matching strategies, infrastructure location and design of access and recreational facilities to environmental and community needs. Public access safety was assessed as part of the bank erosion assessment in December 2018. Results are presented below.

6.6.1 Public Access Safety Risk Assessment

Field survey was undertaken for all banks of Lake Ainsworth in December 2018. Banks were divided into sections corresponding to the erosion survey which was completed concurrently. The location of sites and resultant safety risk rating is indicated in Figure 82.

The public safety risk assessment involved the following process at each site:

1. Identify hazards – find out what could cause harm; and
2. Assess risks – understand the nature of the harm that could be caused by the hazard, how serious the harm could be and the likelihood of it happening.

Table 33 shows the risk assessment matrix used to classify the identified hazards at each site. Where such risks are regarded as high or very high, these issues and recommended measures to address these risks are to be developed as part of the CMP.

It should be noted that the assessment was based on the current situation at the time of survey. Council's future works program includes modification of public access arrangements and foreshore treatment which will influence public safety risks and other factors which will be considered in detail as part of Stage 3 of the CMP process: Response indication and evaluation.

Table 33: Public Safety Risk Assessment Matrix

			Potential Consequences				
			Minor injuries or discomfort. No medical treatment or measureable physical effects	Injuries or illness requiring medical treatment. Temporary impairment.	Injuries or illness requiring hospital admission	Injury or illness resulting in permanent impairment	Fatality
			Not significant	**Minor**	**Moderate**	**Major**	**Severe**
Likelihood	Expected to occur regularly under normal circumstances	**Almost certain**	Medium	High	Very High	Very High	Very High
	Expected to occur at some time	**Likely**	Medium	High	High	Very High	Very High
	May occur at some time	**Possible**	Low	Medium	High	High	Very High
	Not likely to occur in normal circumstances	**Unlikely**	Low	Low	Medium	Medium	High
	Could happen, but probably never will	**Rare**	Low	Low	Low	Low	Medium

A number of safety hazards were identified in the vicinity of access points to Lake Ainsworth. The 'Very High' safety risks resulted from the close proximity of several access points to the Eastern Road where the top of the eroded bank was within 0.5m of the public road with very little if any separation between cars and swimmers/pedestrians. Other hazards included potential for falls and trips due to erosion creating vertical drops up to 0.8m, exposed roots and uneven ground.

The location and classification of foreshore access safety risk for each site is shown in Figure 82. Corresponding details for each labelled section can be found in the bank erosion database (Appendix 1). Table 34 presents a summary of the results for Lake Ainsworth as total length of bank and percentage of bank classified in each erosion category. Figure 81 presents the results graphically.

Although not assessed specifically as part of the survey, it was noted that public access to the water would be limited under certain water levels conditions for people with poor mobility. It is noted that Council's current works program includes establishment of least one access ramp on the eastern foreshore to cater for disabled access, however no assessment of likely access safety for future works has been undertaken. It is recommended that a review of this safety risk assessment is undertaken once the Lake Ainsworth Foreshore Improvement Works program has been finalised.

Table 34: Foreshore Access Safety Risk summary for Lake Ainsworth

	Total length surveyed (m)	Low (m)	Medium (m)	High (m)	Very High (m)
Lake Ainsworth	2,521	1,648 (65%)	581 (23%)	205 (8%)	87 (3%)

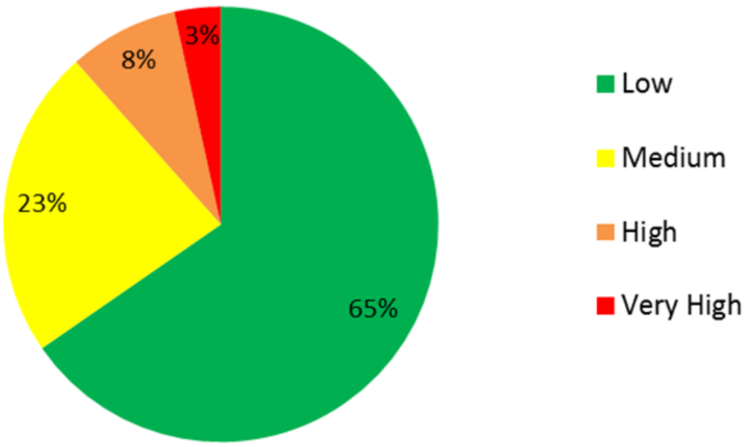


Figure 81: Proportion of foreshore access safety risk for Lake Ainsworth

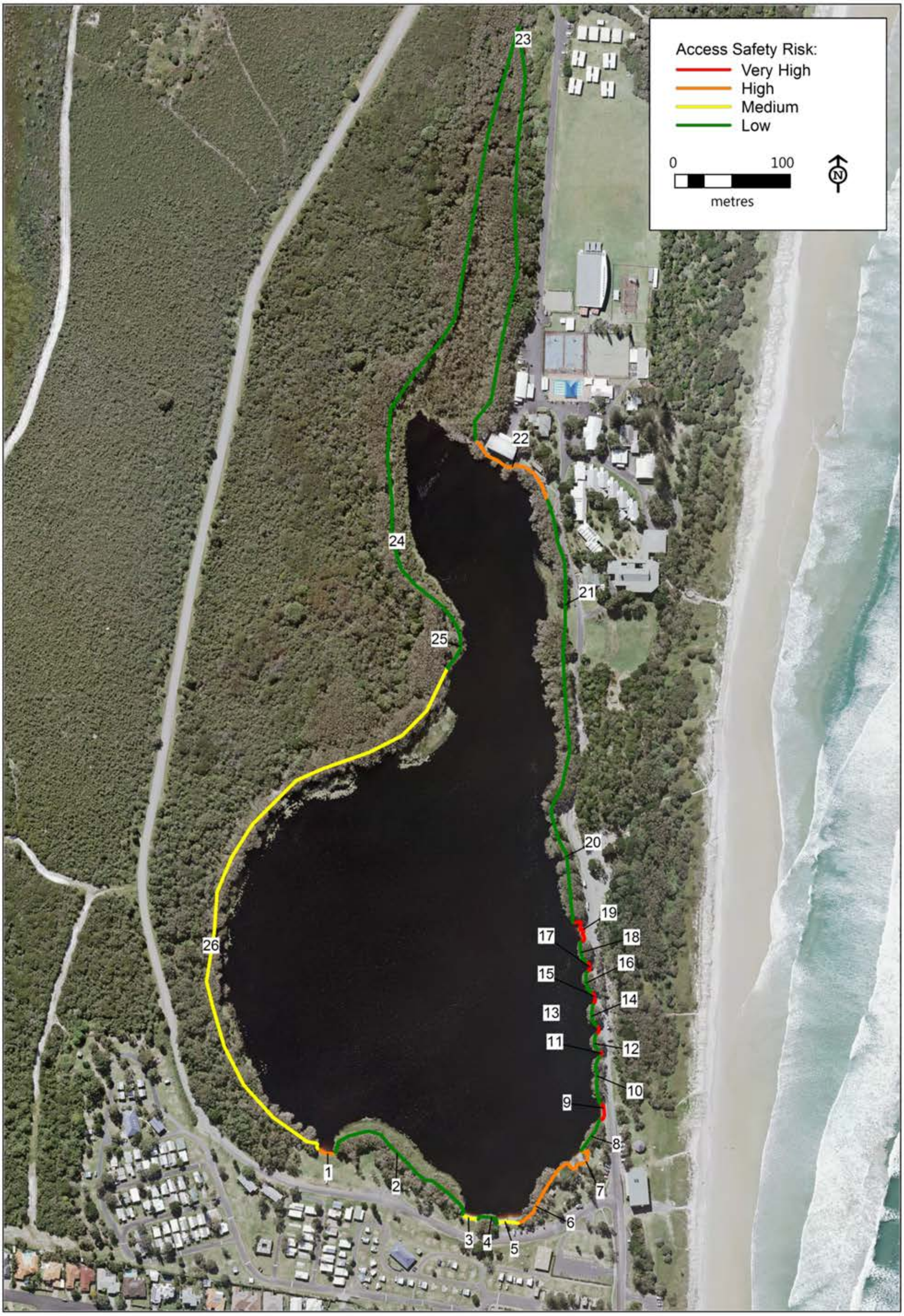


Figure 82: Foreshore Access Public Safety Risk sites and ratings December 2018

7. PRELIMINARY ASSESSMENT OF MANAGEMENT OPTIONS

A preliminary assessment of potential management options is provided in Table 35. This assessment is based on the current understanding of management options to address the key issues identified by this study. A description of each management option is provided along with a summary of benefits and limitations and details of any relevant past investigations either at Lake Ainsworth or elsewhere to help inform decision making. Finally, a recommendation is made as to whether the option has merit, and should be considered further. Options recommended for further consideration will be assessed in detail as part of Stage 3 of the CMP: Response Identification and Evaluation. Note that Stage 3 may incorporate additional options and is not limited to those listed in Table 35.

Table 35: Preliminary Assessment of Management Options

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
Coastal Hazards						
1.	Sea wall construction/ enhancement to protect against ocean shoreline recession	Extension of current sea walls to provide continuous shoreline protection as recommended in the coastline CZMP. Consider most easterly placement practical	Consistent with existing certified CZMP Provides certainty for management of the eastern foreshore and lake ecosystem for the medium term Provides for protection of littoral rainforest and dune vegetation	Expensive Timing of works needs to be optimised Potential for damage to dune vegetation Potential for beach erosion in front of wall. Sand nourishment is also likely to be required to maintain public amenity and beach condition	Coastline CZMP Hazard Definition Study Seawall Upgrade Study Ground penetrating radar study to locate existing buried sea defences	Yes – considered the best option for long-term protection of Lake Ainsworth
2.	Strategy to address wave run-up risks at the Surf Club	Develop a strategy for emergency/short-term mitigation of potential wave over-wash risks at the Surf Club	Addresses a potential risk to foreshore facilities, lawns and bank erosion Compatible with other protection measures likely to be considered for the Surf Club itself	Nil	Nil	Yes – potential to be incorporated either in Lake Ainsworth CMP or future coastline CMP

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
Coastal Hazards - Bank Erosion						
3.	Beach nourishment	Nourishment of the recreational beaches with clean sand to ameliorate erosion, and re-instate safe access to the water. This option combines engineering solutions described in Section 1.3.6:battering, renourishment, and reshaping	Provides recreational beach width under most water level conditions Coarser material more stable under wave action Minimal turbidity issues during construction as there is minimal disturbance of lake sediments Infill of exposed tree roots to improve tree health	Maximum beach width will be limited in areas constrained by roads Nourishment material vulnerable to offshore loss particularly in a locations with a steep offshore bank slope. Cost to import nourishment material	Nil	Not recommended in isolation in areas with steep offshore bank slope– sand likely to be lost from beach quickly without retaining structures and therefore should be considered in concert with other options Potentially suitable in isolation for other areas
4.	Beach nourishment with a geofabric container beach sill	As for option 3 with installation of geofabric containers along the beach face (i.e. parallel to the shoreline) to act as sills to maintain minimum beach levels and reduce the rate of sediment loss from the beach This option combines engineering solutions described in Section 1.3.6:armouring, battering, renourishment, and reshaping.	As for option 3 Nourishment life extended over that of nourishment on its own Nourishment less vulnerable to onshore-offshore loss	Cost to import nourishment material Sill(s) provide a potential trip hazard and a hazard to swimmers (sudden small drop off resulting in unexpected submergence) when water levels are very low.	Trials currently underway at the lake	Yes - considered a 'user-friendly' option to minimise sediment loss on recreational beaches along deep frontages. Size and placement depth of geofabric containers requires further design.

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
5.	Beach nourishment with timber retaining structure	As for option 3 with installation of a timber retaining structure to contain sand nourishment and reduce sediment loss. This option combines engineering solutions described in Section 1.3.6:armouring, battering, renourishment, and reshaping.	As for option 3 & 4 Nourishment life extended over that of nourishment on its own Nourishment less vulnerable to onshore-offshore loss above the retaining structure	Cost to import nourishment material Minor reduction in beach aesthetics Retaining structures provide a potential trip hazard and a hazard to swimmers (sudden small drop off resulting in unexpected submergence) and are much more prominent then submerged beach sill. Timber susceptible to rapid deterioration in the aquatic environment unless properly specified and treated. Chemically treated timber is undesirable due to risk to water quality.	Nil	Wooden retaining has been used in the past but is should be avoided in favour of other bank treatments.
6.	Beach nourishment with rock revetment	As for option 3 with installation of a rock retaining structure to contain sand nourishment and reduce sediment loss.	As for option 3 & 4 Nourishment life extended over that of nourishment on its own Nourishment less vulnerable to onshore-offshore loss above the retaining structure	Cost to import nourishment material Minor reduction in beach aesthetics Retaining structures provide a potential trip hazard and a hazard to swimmers (sudden small drop off resulting in unexpected submergence) and are much more prominent then submerged beach sill.	Nil	Rock retaining is considered to be out of character for the lake and is not recommended.

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
7.	Manage access	Rationalising and formalising pedestrian access (e.g. direct foot traffic to areas designed to withstand impacts). May involve fencing or other structures (i.e. maintenance/ restoration of existing or new structures)	Reduce erosion due to pedestrian access Protect vegetation and vulnerable areas	Cost Vandalism Visual impact if materials/design not in keeping with current aesthetics	Nil	Yes – considered a key part of overall management
8.	Access ramps	Allows for concentrated pedestrian access to the lower beach	Allows for more effective riparian vegetation- reduced impact on vegetation Disabled access	Subject to erosion and will need careful design and ongoing maintenance Visual impact if materials/design not in keeping with current aesthetics	Nil	Yes - will be location dependent Design//materials selected to minimise risks
9.	Riparian vegetation	Enhancement/expansion of riparian vegetation as primary bank erosion control.	Natural bank protection Shown to be effective in areas of intact vegetation at the lake Enhance ecological values (e.g. habitat, shading etc.) Provides separation of beaches and provides a sense of more secluded areas	On the less expansive beaches this may create a more closed in feel, less visual connection between parkland areas and the water. Greater concentration of pedestrian impacts in non-vegetated areas. Could be mitigated with access ramps to cater for this increased impact.	Nil	Yes- will be location dependent and need to balance access requirements with bank protection and ecological values
10.	Managed Retreat	Permits bank erosion to continue, while managing any safety or environmental concerns	Low cost, 'natural' process allowed to proceed	Only viable where there is room for this to occur without negative impacts on recreational use, access, infrastructure etc. (i.e. only viable on western/northern shorelines)	Nil	Yes - further consideration only where there is space (e.g. western/northern shorelines)

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
11.	Monitoring and maintenance	Monitor the performance of erosion controls and conduct timely maintenance as required. Also need to monitor future access pressure on the western side following closure of the eastern road to minimise/mitigate any worsening of erosion.	Address small issues before they get bigger Maintain safe access at all times	Nil	Nil	Yes - considered a key part of overall management
Coastal Hazards - Flooding						
12.	Flood Planning	Future development and actions to consider potential future flood risk	Development is suitable for location/ adaptive	Nil	This study	Yes
13.	Draining nutrient-rich benthic waters	See option 27	See option 27	See option 27	See option 27	See option 27
14.	Enhance flushing	See option 28	See option 28	See option 28	See option 28	See option 28
Coastal Hazards - Hydrology/Groundwater						
15.	Draining nutrient rich-benthic waters	See option 27	See option 27	See option 27	See option 27	See option 27
16.	Enhance flushing	See option 28	See option 28	See option 28	See option 28	See option 28
17.	Monitoring	Continue to monitor sediment extent and groundwater outflows, particularly if management actions implemented reduce algal blooms. Monitoring of actual groundwater flows.	Provide information about relative rates of sedimentation over time and if reductions in algal blooms reduce rates of sedimentation Provide groundwater flow data directly	Cost – set up/monitoring of groundwater bores could be high	Processes Study (AWACS 1996), This study	Yes- incorporate into monitoring program for CMP

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
Water Quality - Cyanobacteria Blooms/Nutrient Enrichment						
18.	Continue use of bubble plume aerators	Aim to completely mix the entire water column using compressed air released into bottom waters. Currently operated between spring and autumn at Lake Ainsworth for 12 hours in a 24 hour cycle.	Aerators break down stratification. DO is maintained at reasonable levels throughout the water column Low running cost (already set up)	No evidence that aerators are reducing algal blooms (blooms continue at unacceptable levels despite operation of aerators for over 20 years). The community has identified algal blooms as the issue of highest concern for the lake in 2018. Aerators may be facilitating nutrient cycling from sediments to surface waters thus fuelling continued eutrophication and algal growth.	Results of this study indicate that the aerators do break down stratification and maintain DO at reasonable levels throughout the water column. However, the results also show that the aerators do not affect the anoxia occurring at the sediment/water interface and phosphorus release from sediments is still occurring. The aerators have been shown to continually transport nutrients released in bottom waters to the surface where algae grow.	Yes – even though negative effects have been identified, the risk of a major anoxia event (see option 19) occurring in absence of aeration should be carefully considered at Stage 3 and if risks are considered too high, it may be appropriate to continue aeration (or a modified program of aeration).
19.	Stop artificial aeration (trial)	Trial turning off aerators for a period of time (e.g. one year to assess seasonal changes). During the trial it will be necessary to carefully monitor water quality in the lake including development of anoxic zones.	The short trial conducted in 2018/2019 (this study) shows allowing stratification to develop reduced nutrients and improved DO in surface waters. No operational or energy cost.	Without regular aeration, and during warm, still conditions stratification is likely to develop creating anoxic bottom waters. A naturally occurring mixing event (due to severe wind/rainfall event) may cause a large DO crash if large volume of anoxic water is brought to the surface. The level of impacts are unknown, however they could be significant with regard to aquatic ecology (e.g. potential for fish kill as a worst case scenario)	As above	Yes- requires assessment of key risks. Key risks are DO depletion and natural turnover events

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
20.	Vertical mechanical mixers/surface mixers	A large impeller mounted on a raft draws water from the surface and transports it through a tube to desired depth. The aim is to transport cyanobacteria into deeper water thereby inducing light limitation.	Directly addresses blooms and therefore should have immediate effect. Doesn't rely on reducing nutrients Only used when there is a bloom developing so decreased operational costs.	Start-up costs likely to be high. Ongoing operational requirements and costs Safety risks - usually used in dams not recreational lakes. BGA dies and sinks to the bottom where nutrients may be recycled again to water column. Uncertain whether toxins produced by BGA are also transported to bottom and locked-up.	Brookes *et al.* (2008) SA dam - found to be effective at controlling blooms	Potential – further risk and feasibility assessment required
21.	Pure oxygen injection	Injection of pure oxygen to bottom waters to prevent nutrient release from sediments. Stratification is preserved and surface layer would remain intact	Potential advantage over bubble plume aerators that they increase DO but nutrients from bottom waters are not transported to surface.	Require on-site oxygen tanks, likely to be expensive, potentially hazardous	Gachter and Wehrli (1998) study of Switzerland lakes, found no change in P-cycling.	Potential – further risk and feasibility assessment required
22.	Fountains	Enhances surface mixing to prevent buoyant blooms.	May prevent buoyant surface blooms near mixing area.	May not be effective outside of area where surface mixing is occurring. Waste a lot of energy relative to their effects on mixing surface waters. Maintenance requirements high Noise/aesthetics may not be acceptable in natural setting	Nil	Potential – further risk and feasibility assessment required

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
23.	Bio-Manipulation	Enhance populations of cyanobacteria predators. 'Top-down' control: reduce feeding pressure of fish on zooplankton, allowing zooplankton to dominate and control phytoplankton levels	"Natural" solution (not introducing chemicals)	Very complex and hard to manage. Risk of ecosystem side-effects	Some success in northern hemisphere but native Australian zooplankton do not have the same capacity to control noxious cyanobacteria (Boon *et al.*, 1994)	Not recommended- not likely to be effective
24.	Biological treatments	Bacterial seeding and nutrient supplementation	"Natural" solution (not introducing chemicals)	These treatments do not remove nutrients. There is no indication that they can provide adequate bacterial stock to increase breakdown of organic matter at lake-scale. Better suited to wastewater ponds.	Burford *et al.* (2018)	Not recommended- not likely to be effective
25.	Booms	Physical 'trap' on surface to concentrate algae and allow for removal by truck-mounted suction truck hose or other means.	Direct removal of visible surface scums when blooms occur	May only target small (floating) fraction of total BGA population. Limited locations for truck access along shore and dependence on scum location (no western side access). Disposal of scum may be problematic due to high water content and potential presence of cyanotoxins. Risks for recreational use associated with booms that may be hard to see on surface	Burford *et al.* (2018)	Not recommended- not likely to be effective
26.	Water skimming and filtration system	Mechanical device that skims top 20cm of water and remove algae	Direct removal of algae	Examples elsewhere ineffective. Disposal of toxic algae problematic	2001 Management Study/Plan (DPWS, 2001) mentions but not much detail	Not recommended- not likely to be effective

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
27.	Draining and /or treatment of nutrient rich-benthic waters	Removal and/or treatment of nutrient-rich hypolimnetic (bottom waters) water during thermal stratified conditions. Treatment may involve pumping of water through treatment medium, or separate harvestable macrophyte beds	Direct removal of nutrient laden waters Reduced water levels may mitigate climate change/flooding impacts depending on timing	Method to extract water unknown. Requires careful monitoring and timing. If water to be removed, disposal method for water unknown. Ocean disposal unlikely to be suitable particularly into adjacent Cape Byron Marine Park. Lack of space for potential treatment areas nearby Reduced water levels may affect biology	Klapper (2003) examined water quality control using selective take-off of nutrient-rich water via outlets, siphon pipes and variable intake pipes.	Potential - risk and feasibility assessment required
28.	Enhance flushing	Spillway or drain pipe(s)/piezometers to allow for drainage of high water levels to the sea (suggested by community)	Will remove some nutrient dissolved in water through enhanced outflows. Reduced water levels may mitigate climate change/flooding impacts depending on timing.	May allow seawater ingress back to lake. Not effective when high tides/seas	Nil	Potential - risk and feasibility assessment required

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
29.	Alum/Gypsum dosing	Dosing lake with Alum and gypsum to reduce turbidity and phosphorus	Reduces water column turbidity, nutrients and algae	These chemicals works as flocculating agents, meaning they won't remove phosphorus unless associated with turbidity. Turbidity is low in the lake therefore unlikely to be effective. Changes to pH and other unknown changes could be detrimental to system Unlikely to have community support	2001 Management Study/Plan (DPWS, 2001)	Not recommended
30.	Algacide dosing (copper sulphate)	Dosing lake with an algacide to kill algae directly	Kills algae directly	Harmful to aquatic organisms Potentially harmful to public health/recreational users Potential for unforeseen ecological changes due to altered nutrient uptake pathways Unlikely to have community support	2001 Management Study/Plan (DPWS, 2001)	Not recommended
31.	Floating wetlands	In-lake floating wetlands, harvested to remove nutrients from system.	Once established can be left (except for harvesting requirement) Potential to reduce erosion depending on placement Provide habitat	High cost Use by birds could increase faecal contamination and nutrients. Potential safety risks. Large area required to reduce high nutrient load. High effort and cost associated with continued harvesting.	Lake Hugh Muntz (SE QLD) – recent evaluation study found them to be a poor investment for nutrient attenuation (GHD, 2016)	Not recommended- not likely to be effective

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
32.	Aquatic plant harvesting (reeds, water hyacinth etc.)	Harvest aquatic plants to remove nutrients. Water hyacinth is currently removed from lake by Landcare Group	'Natural' method of nutrient removal	Unlikely to be adequate biomass and plant replenishment to maintain nutrient control at high levels Requires high level of effort to harvest and dispose of plants (currently done by volunteers). Potential for negative aesthetic and habitat impacts on naturally occurring native species	Kings Bay, Florida	Potential - estimate area required to be harvested to achieve adequate nutrient removal
33.	Reed bed enhancement	Cultivate further reed beds/wetland areas either along foreshore or as separate treatment areas and harvest regularly to remove nutrients from system	Reduce nutrients in water through uptake and harvest. Reduce erosion Provide habitat	Could restrict recreational access May not make any real impact on nutrient levels Species dependent (e.g. Typha known to shed a lot of organic material into the surrounding sediments). Nutrient uptake rates low in still water (non-flowing). Efficiency may be increased if water could be pumped from lake through separate constructed wetland system. Lack of space in catchment for this option.	2001 Management Study/Plan (DPWS, 2001)	Potential - estimate area required to be harvested to achieve adequate nutrient removal

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
Sediments						
34.	Sediment capping using Bauxsol, bentonite clay	A chemical agent is used to provide a physical barrier over sediments, with the aim of blocking the release of nutrients into the water column.	Directly addresses sediment source Also takes nutrients out of the water column	Repeat dosing required to maintain capping – only short term option. Chemicals used may have 'side-effects' on aquatic ecosystem health	Two capping agents were investigated by Akhurst *et al*. (2004): bentonite clay and Bauxsol. The bentonite clay was highly effective at reducing plant available P in anoxic/oxic conditions, but levels of dissolved Fe were enhanced with its use. Bauxsol not recommended in anoxic waters, although use as suspension in oxic waters warrants further study (Akhurst *et al*. (2004)	Yes- further consideration of Bauxsol as suspension as suggested by study (Akhurst *et al*. (2004)
35.	Geochemical compounds (e.g. alum, Phoslock^{TM,} Aqual-P etc.)	Dosing of water column and/or sediment capping to bind phosphorus and make in unavailable for plant/algae uptake. Could dose in-lake or stormwater in-flows.	Can be highly effective at locking up phosphorus under appropriate conditions and doses.	Small risk of legacy effects (chemicals remain in sediments) Careful dose-response needed Possible effects on visual clarity of water	Burford *et al.* 2018 – Lake Hugh Muntz trial currently underway for Phoslock^{TM} (2019)	Yes - risk and feasibility assessment required Keep watch current Lake Hugh Muntz Phoslock trial
36.	Sediment capping using clean sands	Establish a layer (approx. 5-10cm) of clean sand over the nutrient rich muds located in the deepest parts of the lake. Aim is to prevent sediments releasing nutrients back to water column.	'Natural' solution (no chemical dosing).	Potentially high cost, depending on volume of sand required and local availability. Unknown effectiveness and longevity of treatment with bioturbation etc. Technical difficulty in providing a consistent coverage at the required thickness to be effective	Burford *et al*., 2018	Potential - requires consideration of volumes required to guarantee coverage, sedimentation rates, bioturbation and groundwater influence to examine longevity of treatment

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
37.	Sediment removal (dredging)	Dredging of nutrient rich (sludge) layers from deep sections of lake	Directly addresses sediment source Removes historical nutrient load	High costs ($100,000/ha for small lakes estimated by Hamilton and Dada, 2006) Disposal of dredged sediments likely to be high cost. EPA approval required. Resuspension of sediments during removal (short-term) resulting in release of nutrients and effects on biota. Potential for interfering with groundwater processes, compromise 'perched' layer etc. Slurry needs to be dewatered requiring designated bunded area nearby. Limited space available for this purpose locally. Leachate likely to be nutrient rich and could return to lake through seepage etc.	2001 Management Study/Plan (DPWS, 2001) estimated removal of 120,000m^3 sediment required. Cost estimate $800,000 in 2001 not including deposition area construction.	Potential although significant risks identified previously- risk and feasibility assessment required
38.	Review blue green algae alert/ lake closure signage	Review the current signage including text, images, symbols as well as placement and sizing to ensure effective communication of public health risks.	Better communication of risks associated with blooms with a view to reducing those swimming during high risk periods	Nil	Nil	Yes – considered necessary, no risks identified

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
Catchment Management						
39.	Stormwater treatment/ improvement	Constructed wetlands/ bioretention/ GPTs/ filters/ swales etc. to slow stormwater flows and treat water before reaching the lake	Reduce inputs of nutrients/ pollutants (source control) Reduce erosive potential of stormwater to reduce erosion rates.	Cost to retrofit existing infrastructure	Eastern Road redevelopment proposes stormwater treatment devices along east and southern foreshores.	Yes – consider further for all areas including Sport and Recreation Centre and Caravan Park
40.	Community education campaign	Education about fertiliser use/ garden waste management/ compost etc. Sensitivity of lake Groundwater/ surface water interactions Flyers, website, community connect. Types of fertiliser, application rates, timing with rainfall etc.	Community pro-active Low cost	Can only provide information to improve knowledge. Success relies on community will to improve practices. May not reach all stakeholders.	2001 Management Study/Plan (DPWS, 2001)	Yes
41.	Litter/recycling	Ensure adequate provision/emptying of general waste bins. Provision of recycling bins Consider Gross Pollutant Traps (GPTs) for stormwater outlets	Reduce litter impacting on amenity, water quality and wildlife Increase recycling opportunities	Nil	Nil	Yes
Water Quality - Sunscreen pollution						
42.	Investigations of sunscreen pollution at Lake Ainsworth	Lake water testing for chemicals of concern, nutrients from sunscreen etc.	Helps to better understand the level of the problem and priority for management.	Cost	Examples world-wide, very little on nutrient input, no study in the lake to date.	Yes – aims and scope of investigations to be fleshed out

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
43.	Community education campaign - sunscreen	Education to encourage swimmers to: Use more environmentally friendly sunscreen; wear UV resistant clothes instead (e.g. rash shirt etc.); avoid hottest part of day; apply sunscreen 20mins before swimming	Low cost Targeting the source	Uncertainty about level of issue (no local testing data) Potential for public health risk due to UV exposure if sunscreen or alternative protection not used Potentially greater cost to public for 'environmentally friendly' sunscreens and alternative sun protection clothing.	No local studies, but a growing body of Australian and international studies to warrant consideration of the issue at the lake	Yes - considered a key part of overall management
44.	Install shade over foreshores	Community suggested option to provide sun protection and negate need for sunscreen	Reduces need for sunscreen Family friendly, particularly for young children	Not in keeping with natural environment aesthetics Limited areas, concentration of users contributing to crowding Costs and maintenance – potentially difficult to install Vandalism Damage from high winds/hail etc.	Nil	Potential – benefits and risks to be assessed further
Water Quality - Recreational						
45.	Investigate sources of Enterococci	Determine whether wildlife/dogs or human waste is source of faecal matter to Lake	Target source	If not timed to include a range of weather events, sample error may occur	None at lake to date. Many examples of source tracking elsewhere.	Yes- robust sample design required to cover a range of rainfall conditions (wet and dry)

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
Flora and Fauna						
46.	Containment and education of pest fish species	An educative program coupled with facilities for accepting unwanted aquarium fish. Information could include relevant pest species identification information, impacts of aquarium fish releases to the wild, dumping of aquarium fish is prohibited and alternatives to dumping aquarium fish.	Mitigate the risk of further dispersal of pest species from the lake and new pest species into the lake.	May not be effective/ may not engage those responsible for fish release Costs	Nil	Yes – incorporate into CMP education campaign
47.	Develop local Cane Toad management strategy	Assessment of cane toad management options	Reduce impacts of Cane Toad	Ineffective management despite high level of effort	Discussed in Section 5.1	Yes – a review of feasibility/ realistic chance of success required
48.	Riparian vegetation	Enhancement/ maintenance/ restoration of natural fringing vegetation around lake through protection of sensitive areas and weed management	Intercept diffuse surface runoff Protects banks against erosion Enhance habitat/ aesthetic values	Balance between ecological and aesthetic benefit and providing access to water	Nil	Yes – requires careful consideration of target areas to balance access requirements, amenity and environmental values
49.	Backfill exposed tree roots	Backfill exposed roots of Paperbark trees along foreshore with suitable sediment	Improve tree health / prevent dieback Enhance habitat/ aesthetic values	Sediment lost over time through ongoing foot traffic /erosion (ongoing monitoring and maintenance required)	Nil	Yes- considered a priority to protect trees currently at risk
50.	Grass species selection for open space areas to minimise bare areas	Use of suitably durable grass type for high use areas (couch proven inadequate) with effective weed guard to separate grassed areas from native vegetation	Grass cover maintained for enhances aesthetics and recreational use Reduced erosion Reduced invasion of native vegetation areas	Unlikely to achieve grass cover in all scenarios (e.g. drought)	Lennox Landcare conducted intial research suggesting *Empire Zoysia* or *Kenda Kikuyu* might be more suitable	Yes – considered important to maximise amenity and environmental values

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
51.	Underground replacement or relocation of power lines between Sport and Recreation Centre and Lennox Surf Club.	Liaise with power authorities	Reduce vegetation damage from ongoing maintenance Reduce fire risk	Previous requests to Essential Energy unsuccessful due to prohibitive costs	Previous requests made	Yes – warrants further effort
52.	Assessment of impact of introduced flora and fauna species	Flora and fauna assessment of catchment Identification of key issues and management actions to address impacts	Provides information on this issue	Cost	Exotic aquatic fauna assessment completed as part of this study	Yes- aims and scope of investigations to be fleshed out
53.	Assessment of turtle populations and impact of Camp Drewe Road	Monitoring of turtle sightings/ fatalities	Provides information on this issue	Cost	Nil	Yes- aims and scope of investigations to be fleshed out
54.	Set appropriate speed limit for Camp Drewe Road	Consider wildlife, public safety	Slows traffic to reduce road-kill incidents and public safety concerns	Nil	Nil	Yes – requires liaison with raod authorities
55.	Wildlife/ turtle crossing warning signs on Camp Drewe Road	Crossing signs to alert drivers of potential wildlife crossing at known locations	Slows traffic to reduce road-kill incidents Raise awareness	Requires information on wildlife crossing areas for most effective sign placement	Community provided information	Yes
56.	Manual harvest of water hyacinth by volunteer groups	Currently Lennox Head Landcare volunteers and students at the Sport and Recreation Centre harvest water hyacinth by hand from the lake when outbreaks occur.	Direct removal of weed Some nutrient removal if plants are removed from catchment	Weeds can harbour contaminants Disposal of weeds to registered waste facility required. If left to decompose on lake shore, can create aesthetic issues (odour, visual) and nutrients re-introduced to lake. Transport/handling costs Reliance on volunteers, cannot guarantee continued effort	Nil	Yes – investigate further assistance (e.g. disposal, transport) as required

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
57.	Aquatic weed harvester	Barge-mounted aquatic weed harvesters, compactors and removal services	Efficient removal of large areas of weeds Offload directly to compactor truck without contact with ground Bulk waste reduced as water squeezed out by compactor loading process	Costs to hire equipment, transport and disposal Risks to aquatic fauna, specifically eels and turtles that were encountered in large numbers during previous use of cutting conveyor belt harvester model. Removal of fauna also reduced efficiency d increased cost of hire.	Harvester used previously with moderate success due to aquatic fauna entrapment.	Yes - investigate different models of harvester that may be less likely to impact aquatic fauna and feasibility/risks at the lake
58.	Aquatic herbicide	Application of herbicide to kill aquatic weeds	Directly kills infestations	May not treat all seed sources and recurrent blooms may occur. Impacts of residual herbicide on non-target species unknown. Ecosystem effects unknown. Removal of biomass required or nutrients and organic matter returned to lake. Costs of application and removal Unlikely to have community support	Used previously in the lake with limited success due to decaying vegetation adding to nutrient load.	Not recommended
59.	Biological Control	Salvinia weevil (*Cyrtobagous salviniae*), is released at the lake as needed and is an ongoing management tool.	'Natural control' of problem	No negative side-effects identified to date	Ongoing use at the lake in partnership with DPI. Deemed to be successful but cannot control Salvinia in isolation during high growth periods. Physical removal also required for effective management	Yes - considered important for ongoing control

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
60.	Replace boom used in aquatic weed management	The boom in place at the lake is current damaged and needs to be replaced.	Allows for containment of exotic macrophytes facilitating removal	Nil	Nil	Yes – maintenance/replacements
Community Uses						
61.	Defining areas of acceptable uses	Separate key use areas such as swimming; boarding; sailing; fishing etc.	Reduce conflict between uses Reduce safety risk	May not have wide community acceptance Implementation may be difficult/ effective signage etc.	2001 Management Study/Plan (DPWS, 2001)	Potential – investigate practicalities of this approach
62.	Public access safety improvements	Address identified public safety risks by improving access and addressing erosion (see erosion options). The Lake Ainsworth Foreshore Improvement Works program will address the majority of risks identified.	Reduced public safety risk	Costs Access restriction in some cases	Lake Ainsworth Foreshore Improvement Works	Yes – considered a priority to reduce current safety risks
63.	Review of public safety risk assessment	Review of the risk assessment undertaken as part of this study once the Lake Ainsworth Foreshore Improvement Works program has been finalised	Reassess risk level Identify any residual risks	Nil	This study	Yes – necessary to update risks and identify any remaining risk areas

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
64.	Educational campaign (e.g. "Keep the Lake Clean")	Multi-faceted campaign to educate and promote understanding of the natural attributes of the lake, sensitivities and key issues and encouraging low-impact use/practices to protect the lake. May involve: installation of attractive and engaging signage at key locations; leaflets/flyers; webpage; posters; information days/activities; school programs; educational videos etc. Include information on health risks of exposure to cyanobacteria blooms.	Education leading to positive change in behaviour Educational opportunities for school groups etc.	May not be effective/ may not engage majority of lake users Costs	Nil	Yes - considered a key part of overall management
65.	Greater acknowledgement of Aboriginal Heritage	Work with traditional owners to identify culturally appropriate ways to better acknowledge the indigenous history of the lake. May include signage and be linked to education campaign.	Improve understanding of indigenous history Educational opportunities for school groups etc.	Getting agreement on appropriate actions between different stakeholders has been difficult in other local projects.	Remnant Archaeology (2017) *Aboriginal Cultural Heritage Assessment Lake Ainsworth Foreshore Improvements*	Yes - considered a key part of overall management
66.	Manage increasing use of Western side of lake	Community concern that changes to eastern road will mean increased use of western side, management will need to address impacts	Preserve relatively 'untouched' ecosystem	Difficult to 'lock-up' completely Any structures put in place to restrict access may be subject to vandalism Largely out of sight on western side – difficult to regulate	Nil	Yes- further investigation of options including formalising access/signage/education, parking, discouraging access to certain areas or whole western side.

No.	Management Option	Description	Benefits	Limitations/Risks	Previous investigations	Further consideration
67.	Restrict overnight parking along foreshore	Explore options to restrict parking between hours of 1am and 5am along the lake foreshores including: signage; ranger policing; and lake CCTV surveillance.	Discourage long-term parking and free-up public parking spots for lake users Discourage Caravan park customers from parking in public spaces along foreshore Discourage illegal camping along foreshore.	May be difficult to enforce, outside of normal working hours for rangers. Potentially expensive with ongoing out of hours surveillance and/or CCTV monitoring Vandalism	Nil	Yes - risk and feasibility assessment required
68.	Encourage alternative transport to the lake	Provide facilities/services to encourage alternative transport to cars (e.g. improved cycling, walking pathways connecting town to lake; bike racks, mobility scooter parking; provide a shuttle bus service through town to the lake)	Reduced congestion Reduced parking pressure Reduced vehicle use meaning lower carbon emissions, pollution and increased safety Encourages exercise, increased health benefits	Generally only effective for residents of Lennox Head. Visitors from elsewhere will still drive to lake.	Nil	Yes – could incorporate into Community Education Campaign
69.	Consideration of management of future parking arrangements	Address continued community concern regarding lack of sufficient parking spaces during peak times	Reduced parking pressure	Limited space for additional parking	Lake Ainsworth Foreshore Improvement Works and associated investigations	Yes - considered a key part of overall management

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GLOSSARY AND ABBREVIATIONS

Aerobic respiration	The process of producing cellular energy involving oxygen.
Algal bloom	The rapid growth of phytoplankton resulting in a high biomass in the water column.
Allocthonous	Derived from terrestrial sources
Amenity	A desirable or useful feature or facility of a building or place
Ammonia (NH_3 & NH_4^+)	A measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4^+). Nitrogen is an essential plant nutrient and although ammonia is only a small component of the nitrogen cycle, it contributes to the trophic status of a body of water. Natural waters typically have ammonia concentrations less than 0.1 mg/L. Excess ammonia contributes to eutrophication of water bodies and at high concentrations is toxic to aquatic life.
Anaerobic	Living without air
Anoxic	A total depletion in the level of oxygen in water.
Anthropogenic	Any phenomenon caused by human activities
Aquatic	Living or growing in water, not on land.
Bathymetry	Measurement of water depth in lakes, oceans and seas. In other words, bathymetry is the underwater equivalent to topography.
Bio-available	Nutrient forms (usually inorganic) available for plant growth.
BOM	Bureau of Meteorology
BSC	Ballina Shire Council
Catadromous	Born in brackish/estuarine water, migrate to freshwater then migrate back downstream to spawn
CBMP	Cape Byron Marine Park
Chlorophyll a	The green pigment in plants used to capture and use energy from sunlight to form organic matter (see photosynthesis). Concentrations of Chlorophyll a in the water column are used as an indicator for phytoplankton and benthic algae biomass. It provides a useful proxy indicator of the amount of nutrients incorporated into phytoplankton biomass, because phytoplankton have predictable nutrient-to-chlorophyll ratios
CMP	Coastal Management Program
CZMP	Coastal Zone Management Plan
Diffuse Source Pollution	Non-point source pollution such as sediment or nutrients from catchment runoff or groundwater inputs.
DIN	Dissolved Inorganic Nitrogen (DIN) is the sum of nitrate, nitrite and ammonium. It comprises the forms of nitrogen available for plant growth.
DIP	Dissolved Inorganic Phosphorus (PO_4-P) is the form of phosphorus required by plants for growth and is the form readily available in aquatic environments for algal uptake. In freshwater, Ortho-P is often the limiting factor for algal growth, where light is not limiting. Ortho-Phosphate. See Ortho-P below.

Diurnal	During the day
Dissolved Oxygen. (DO)	A measure of the amount of oxygen dissolved in water. Typically the concentration of dissolved oxygen in surface water is less than 10 mg/L. Although tolerance varies between species, the level considered suitable for most forms of aquatic life is above 6mg/L or above 80%saturation. The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. The maximum solubility of oxygen (fully saturated) ranges from approximately 15 mg/L at 0°C to 8 mg/L at 25°C (at sea level). Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Natural re-aeration of waterways can take place in areas of waterfalls, riffles and rapids. Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments.
DPI Fisheries	NSW Department of Primary Industries – Fishing and Aquaculture
DPI	Department of Primary Industries
Ecology	The interactions between organisms and their environment
Ecosystem	Refers to all the biological and physical parts of a biological unit (e.g. an estuary, forest, or planet) and their interconnections.
Estuarine	Part of the river channel with a mix of fresh water and salt (tidal) water
Euphotic zone	The zone closest to the surface of water that receives enough light for photosynthesis to occur
Eutrophication	The process of nutrient enrichment of a water body resulting in the increase in plant biomass (algal blooms) and bacterial decay (heterotrophic activity). Often results in a reduction in species diversity, visual amenity, and the prevalence of toxic algal species.
Foreshore	That part of the shore that lies between the mean high tide mark and the mean low tide mark
Hydrographic	Refers to topographic/bathymetric features of a water body (depth and morphology)
Hydrology	The study of water and its properties, including precipitation onto land and returning to oceans
ICOLL	Intermittently Closed and Open Lake and Lagoon
Inter-annual variation	Variation observed between years.
Lentic	Relating to, or living actively in still waters (such as lakes, ponds or swamps)
Lotic	Relating to, or living actively in flowing water
Macroinvertebrate	Animal lacking a backbone
MHL	Mainly Hydraulics Laboratory
Nitrate (NO_3^-)	The measurement of the most oxidized and stable form of nitrogen in a water body. Nitrate is the principle form of combined nitrogen found in natural waters. It results from the complete oxidation of nitrogen compounds. Nitrate is the primary form of nitrogen used by plants as a nutrient to stimulate growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations. At high levels it is toxic to infants. Without anthropogenic inputs, most surface waters have less than 0.3 mg/L of nitrate.
Nitrite (NO_2^-)	A measure of a form of nitrogen that occurs as an intermediate in the nitrogen cycle. It is an unstable form that is either rapidly oxidized to

	nitrate (nitrification) or reduced to nitrogen gas (de-nitrification). This form of nitrogen can also be used as a source of nutrients for plants. It is normally present in only minute quantities in surface waters (<0.001 mg/L). Nitrite is toxic to aquatic life at relatively low concentrations.
OEH	Office of Environment and Heritage
Organic Nitrogen	A measure of that portion of nitrogen that is organically bound. Organic nitrogen includes all organic compounds such as proteins, polypeptides, amino acids, and urea. Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs.
Oxidised Nitrogen (NOx)	The sum of nitrite and nitrate. Oxidised nitrogen is immediately available to plants.
pH	The measurement of the hydrogen-ion concentration in the water.
Photosynthesis	the process by which plants, some bacteria and some protistans use the energy from sunlight to produce glucose from carbon dioxide and water. Oxygen is also produced.
Physico-chemical	Physical properties dependent on and influencing chemical structure, properties and reactions
Phytoplankton	Single-celled organisms of lakes, streams and oceans that make their own food from sunlight through photosynthesis (e.g. microscopic algae)
Piscivore	A carnivorous animal that eats primarily fish
Point Source Pollution	A single point of pollutant discharge. For example, effluent from a sewage treatment plant.
REF	Review of Environmental Factors
Riparian	Of, on or relating to the banks of a watercourse or waterbody
Salinity	The level of salt dissolved in the water
SCU	Southern Cross University
Sedimentation	The deposition or accumulation of sediment
SLSC	Surf Life Saving Club
Terrestrial	Living or growing on land (not aquatic)
Thermocline	The transition layer between warmer mixed water at the surface and cooler deep water below. Generally when a thermocline is present there is very little if any mixing between the surface waters and deeper waters below the thermocline.
Total Nitrogen (TN)	A measure of all forms of nitrogen (organic and inorganic). Nitrogen is an essential plant element and is often the limiting nutrient in marine waters. The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present, be it ammonia, nitrite, nitrate, or organic nitrogen.
Total Phosphorus (TP)	A measure of both inorganic and organic forms of phosphorus. Phosphorus can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. It is rarely found in significant concentrations in surface waters.
Turbid	Cloudy or dirty (not clear)
Turbidity	A measure of the amount of light-attenuating particles in a water body.
WSUD	Water Sensitive Urban Design – a land planning and engineering design approach which integrates the urban water cycle, including stormwater, groundwater and wastewater management and water

	supply, into urban design to minimise environmental degradation and improve aesthetic and recreational appeal.
Zooplankton	Small floating or weakly swimming organisms consisting of small animals and the immature stages of larger animals in water