Summary report prepared for the Department of Environment, Water and Natural Resources

Coorong, Lower Lakes and Murray Mouth water quality monitoring program

2009 – 2016

South Australia

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p.4 The Murray mouth Credit: South Australian Tourism Commission (Adam Bruzzone)

Coorong, Lower Lakes and Murray Mouth
water quality monitoring program
2009—2016
Summary report

Authors
Dylan Stone[1], David Palmer[1], Ben Hamilton[1],
Cathy Cooney[1] and Luke Mosley[2]

[1]South Australian Environment Protection Authority
GPO Box 2607,
Adelaide, SA 5001
Australia

[2]University of Adelaide
Waite Campus, PMB 1
Glen Osmond, SA 5064
Australia

For further information please contact:
Information Officer
Environment Protection Authority
GPO Box 2607
Adelaide SA 5001
Telephone: (08) 8204 2004
Facsimile: (08) 8124 4670
Free call (country): 1800 623 445
Website: www.epa.sa.gov.au
Email: epainfo@epa.sa.gov.au

Cover photo Lake Albert, Credit: DEWNR

Previous page, Bird life,
Credit: South Australian Tourism Commission
(Craig Ingram)

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Executive summary

The water quality of the Coorong, Lower Lakes and Murray Mouth (CLLMM) region is a significant component of this internationally important, Ramsar-listed, wetland ecosystem. A water quality monitoring program was undertaken by the Environment Protection Authority (on behalf of the Department of Environment, Water and Natural Resources) between 2009 and 2016 as part of the CLLMM Murray Futures program. Its purpose was to assess changes during and after the extreme drought period (2007 to 2010) in order to improve the environmental values (ecosystems and human uses) of the region.

This report provides a summary of the monitoring program as a whole, synthesising previously published data and new results. It outlines how the use of the data and knowledge gathered helped to inform management decisions across the region during the program. Recommendations for future water quality monitoring — to help inform decision makers about suitable management responses aimed to help protect environmental, cultural, social and economic values across this important region of the state and the Murray–Darling Basin — are provided.

Major findings

- The lack of freshwater inflows during the Millennium Drought (2002 to 2010) resulted in very poor water quality across the Lower Lakes compared to historical conditions. There was no lake flushing from 2007 to 2009 as no discharge occurred over the barrages to the Coorong and Murray Mouth. Salinity increases were very large, particularly in Lake Albert and the southern regions of Lake Alexandrina. As a consequence, major losses of freshwater species occurred and the lake water became unsuitable for irrigation. The lack of flushing also resulted in high concentrations of nutrients and algae, and increasing dominance by cyanobacteria. The Lower Lakes were hyper-eutrophic before the drought (chlorophyll *a* >15 µg/L) and this condition substantially worsened during the low flow period (ie chlorophyll *a* increased to 50-200 µg/L from pre-drought level of approximately 20-50 µg/L). Turbidity also increased during the drought period, particularly in Lake Albert, due to concentration of particulate material and effects caused by wind resuspension from the sediments.

- Several surface water acidification events occurred between 2008 and 2010 over a total area of approximately 2,173 ha, or about 3% of the Lower Lakes. In some areas acidic conditions (pH<6.5, ANZECC guideline) prevailed for weeks to months, and in others it remains an ongoing issue. Neutralisation of acidification developed in some areas naturally through the effects of dilution and alkalinity input following a rapid rise in lake levels when upstream floodwater entered the lakes during 2010.

- Treatment of acidification via aerial limestone addition to water bodies occurred in Currency Creek and Boggy Lake, and was successful in achieving neutralisation over large areas. Additional limestone barriers were placed in the acidified regions upstream in Finniss River. There have been ongoing low levels of acidity (eg dissolved metals) at some previously acidified locations such as Boggy and Hunter's creeks, likely caused by diffusion from the acidic sediments below the water column.

- In the Coorong, salinity, total nitrogen and total phosphorus increased significantly from 2004 to 2010. Chlorophyll *a* and turbidity were lower from 2007 to 2010, probably due to lack of nutrient supply for algal production and high salinities promoting particle aggregation. The return of higher River Murray flows and water releases through the barrages in late 2010 resulted in decreasing salinity, total nitrogen and total phosphorus, while chlorophyll *a* and turbidity increased in the recovery period (2011 to 2016).

- The release of water from Morella Basin to the Coorong did not appear to have any negative water quality effects. In contrast, in the most comprehensive dataset collected in 2014, there were indications of significant improvements in water quality for nutrients, chlorophyll and salinity along the South Lagoon. Modelling and hydrological data suggests this is due to the Salt Creek inflows (with lower salinity and total nutrient and algal levels) driving export of water from the South Lagoon into the North Lagoon. Increase in dissolved nutrients only occurred in the immediate mixing zone, less than 2 km from where Salt Creek enters the Coorong, whereas total nutrients were diluted in this zone. While the data collected in 2013 was quite limited, and the total release volume in 2015 was quite low, similar patterns to those expressed in 2014 were evident.

- Acidic groundwater (of pH 3–5) was recorded at three of the four monitoring locations (Point Sturt, Currency Creek and Campbell Park). The acidic groundwater at these sites (0.5–2 m below lake bed) is likely to have originated from vertical transport of acid from the upper oxidised acid sulfate soil materials formed during the drought. High soluble metal (iron, aluminium and manganese) levels were also recorded at acidic locations. Groundwater hydraulic head gradients on exposed sediments were low, indicating there was limited potential for groundwater flux to the lake, although gradients temporarily increased during high rainfall events. The hydraulic gradients at all locations were dynamic, with complex relationships along the nearshore environment. Acidic shallow groundwater has persisted at many sites for over five years following re-inundation post-drought.

Management implications

- The CLLMM water quality monitoring program successfully delivered critical information for management of the region, including information for assessment and management of acidification, provision of data to various key stakeholders (including the community), ecological risk assessment projects, assessment of changes to water quality in the extreme drought and long-term trends, modelling future management scenarios, impacts of drought mitigation measures, assessment of the benefits of environmental water releases, and adding to the scientific knowledge base of the region.

- The extreme low flow period from 2007 to 2010 resulted in a severe decline in water quality across the CLLMM region resulting in major negative impacts on aquatic ecosystems and socio-economic values. The water quality changes in this period in the Lower Lakes exceeded all values in the (over 40-year) historical record for many parameters. This highlights the importance of improved environmental flows and water security under the Basin Plan to prevent such impacts occurring again in the future.

- Recovery of surface water quality to pre-drought conditions was relatively quick (months) in Lake Alexandrina as it is a flow through system, receiving inflow from the Murray River and outflow through the barrages. Recovery has been much slower in Lake Albert as it is a terminal lake with restricted water exchange via the Narrung Narrows. Poorer water quality has persisted untill 2016, with elevated salinity, nutrients and chlorophyll *a*. Aquatic ecosystems and socio-economic values (e.g. irrigated agriculture) were impacted for a much longer period in Lake Albert.

- The Coorong's water quality declined during the extreme drought period due to a lack of barrage outflows (to the Murray Mouth and North Lagoon) and Morella Basin inflows (to South Lagoon). Event-based monitoring showed releases from Morella Basin improved water quality in the South Lagoon in the 2013 to 2015 period.

- Groundwater acidification, arising from acid sulfate soil exposure, occurred during the drought and has persisted to the present at some sites. Minor amounts of acidity have continued to be detected for many years post-drought in the surface waters of some areas (e.g. Boggy and Hunter's creeks). This highlights the importance of environmental flows and management strategies to prevent or minimise these types of prolonged water quality impacts in the future.

- It is necessary to consider the water quality in various CLLMM regions (e.g. Lake Albert, Lake Alexandrina, North and South Coorong Lagoons) individually due to differing morphology, hydrological regime and ecology, as well as taking a whole-of-system approach for future management.

Recommendations

The Department of Environment, Water and Natural Resources and other key stakeholders should consider the following recommendations:

- Ambient water quality monitoring should be continued at historical sites and increased in frequency, parameters (e.g. add metals and acidity) and site number during low flow or lake drawdown events.
- At-risk areas identified in this report should be first priority for monitoring in future low flow or lake drawdown events.
- Annual assessment of previously and currently acidified sites for sediment, surface and ground water quality (e.g. Boggy and Hunter's creeks, Currency Creek, Point Sturt, Campbell Park) should be undertaken.
- Existing CLLMM water quality triggers should be revised and included in the Basin Plan and state guidelines. These need to consider the deterioration in water quality that has been observed over time and the ecological impacts.

In summary

The water quality monitoring program has been successful in addressing essential information needs to underpin the management of ecological and socio-economic values in the CLLMM region. The Millennium Drought had major negative effects on water quality with increased salinity, nutrients and acidification. Recovery from the drought has been prolonged and an ongoing water quality issue for many parts of the region, particularly Lake Albert and acidified groundwater sites. The water quality monitoring program was critical for informing management decisions and helped keep local communities up-to-date about water quality in their region. The program filled critical knowledge gaps relating to water quality interactions and processes in the region. Continuing a long-term water quality monitoring program would help protect and manage the CLLMM region in the future.

Mundoo Station
Credit: Beth Nixon

1 Introduction

1.1 Physical description of study area

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region is located at the terminal end of the Murray–Darling Basin.

The Lower Murray region area monitored in the CLLMM program comprised the lower reaches of the Murray River below Wellington, Lake Alexandrina and Lake Albert (collectively known as the Lower Lakes), two lower tributary regions (Currency Creek and Finniss River) that flow into the Goolwa Channel (Figure 1a), and the Coorong (Figure 1b). The two lakes are connected via the Narrung Narrows, a shallow channel with restricted flow capacity.

The CLLMM area comprises the lowest-elevation portion of the Murray—Darling Basin, which has a total catchment area of 1,061,469 km^2 (equivalent to 14% of Australia's total area) and is a highly regulated river system with a series of locks, weirs and storages. The river channel discharges into the Lower Lakes (821.7 km^2 total surface area). Under sufficient flows, water exits from the Lower Lakes through a series of barrages separating the lakes from the Coorong (a coastal lagoon), and into the Coorong and Murray Mouth out to the Southern Ocean (Figure 1).

The barrages are gated structures completed in the late 1940s to prevent seawater intrusion into the lakes, as water resource development in the Murray–Darling Basin began to exacerbate this effect. The barrage operations typically maintain the Lower Lakes at near full capacity at approximately +0.75 m AHD (Australian Height Datum, corresponding approximately to mean sea level).

The Coorong region study area stretches approximately 110 km from Goolwa Barrage in the north, then south-eastwards past the Murray Mouth and various other barrages in the Mundoo Channel and Coorong, along the North Lagoon, and ends about 3 km south of Salt Creek in the South Lagoon. The total area of the Coorong and Murray Mouth region (downstream of the barrages) is approximately 216 km^2. At zero metres AHD, the average widths of the North and South lagoons are 1.5 and 2.5 km respectively, whereas the average depths are 1.2 and 1.4 m respectively (Webster 2007). In its northern region, significant amounts of fresh water only enter the system when released through the barrages.

The Coorong is connected to the Southern Ocean via the Murray Mouth. This narrow and dynamic connection can close in low flow conditions and was kept open artificially by the use of a dredge from 2002 through to the end of the Millennium Drought in late 2010. Dredging commenced again in January 2015 and is ongoing to ensure the connection to the Southern Ocean is kept open. In the South Lagoon, the Coorong receives some drainage water inputs (lower in salinity than the Coorong water) from Salt Creek. These inflows are from water collected in the Morella Basin, made up largely of surface run-off and subsurface drainage from agricultural land in the south east of South Australia, which is then channelled through a network of constructed drains into Salt Creek.

Beneath the surface waters of the Lower Lakes and Coorong are soils containing appreciable concentrations of reduced inorganic sulfides, principally in the form of the mineral pyrite (FeS2) [Fitzpatrick *et al* 2008, 2009; Grealish *et al* 2010]. These types of soils are also known as acid sulfate soils as they may acidify upon exposure to oxygen (Dent 1986). Acid sulfate soils form under waterlogged conditions where there is a supply of sulfate, the presence of organic matter that can be metabolised, and iron containing minerals. Under reducing conditions sulfate is bacterially reduced to sulfide, which reacts with reduced iron to form iron sulfide minerals. These sulfide minerals are generally stable under reducing conditions, however, on exposure to the atmosphere the acidity produced from sulfide oxidation can impact on water quality, aquatic ecosystems, crop production, and can corrode concrete and steel structures. The consequences of the exposure of acid sulfate soils to water quality in the CLLMM region is discussed further below in this report.

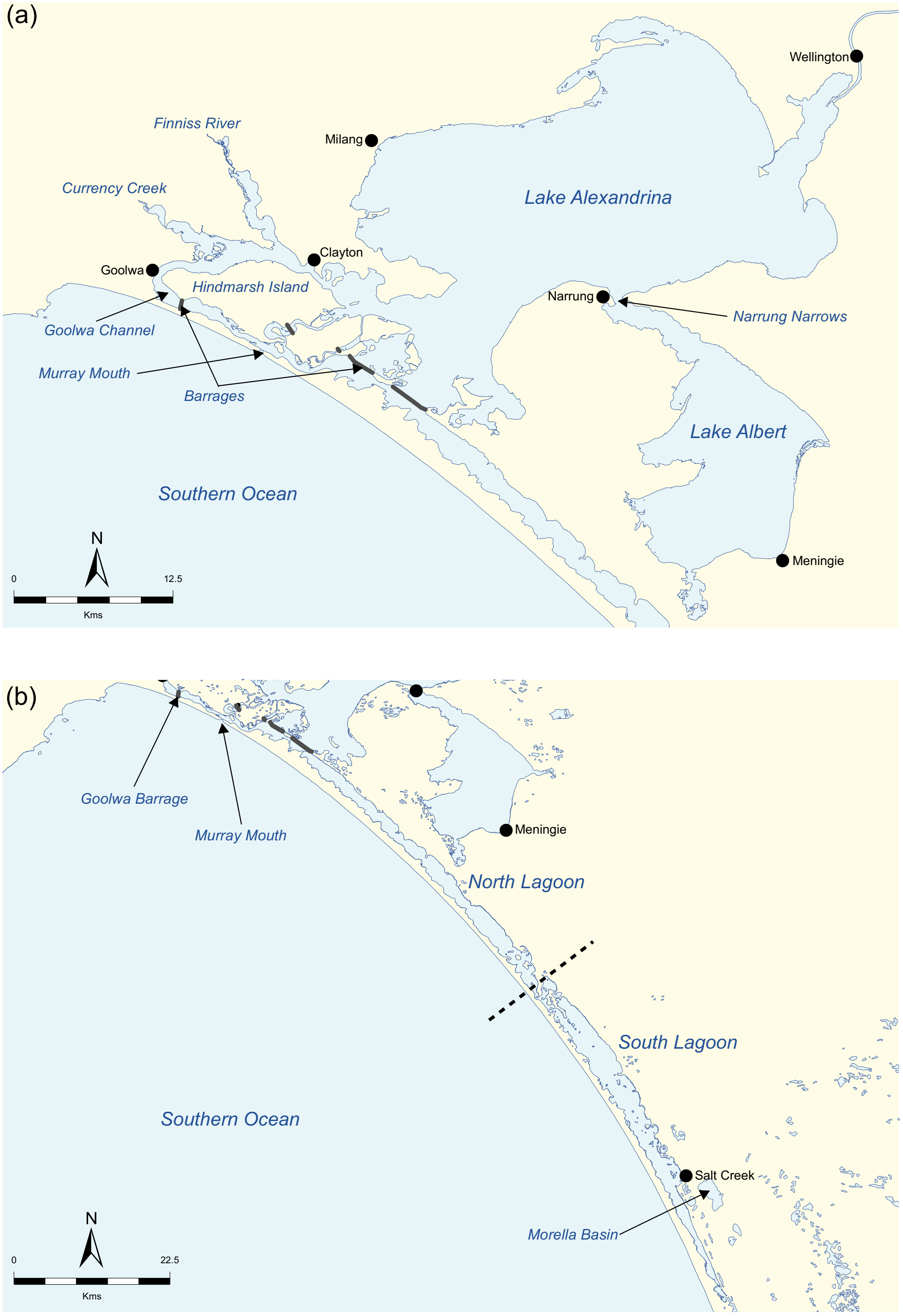

Figure 1 - Sampling region (a) the Lower Lakes and Tributaries and (b) the Coorong, together forming the CLLMM study area (the dotted line is the approximate division of the north and south lagoon of the Coorong).

1.2 Importance of water quality in the CLLMM region

The protection of the ecosystem and human use values of the CLLMM region depends on maintaining suitable water quality. The region has several important cultural, socio-economic and aquatic ecosystem values, termed environmental values.

The aquatic ecosystems are recognised as one of Australia's most significant ecological assets and the CLLMM region is designated a wetland of international importance under the Ramsar Convention (Australian Government 2010). This region contains the townships of Goolwa, Milang and Meningie and other smaller communities. It also contains several large irrigated agricultural areas, including major vineyards (Langhorne and Currency creeks), cropping, and dairy farming. The lakes are also an important recreational area for activities such as sightseeing, boating, fishing and bird watching. This area is of high cultural importance, particularly for the indigenous Ngarrindjeri people (Ngarrindjeri 2006).

'The aquatic ecosystems are recognised as one of Australia's most significant ecological assets'

p.14 Pelicans- Credit: South Australian Tourism Commission (Mike Haines)

1.3 Historical water quality monitoring and drivers of water quality in the CLLMM region

The water quality in the Lower Lakes has been studied for well over a century. Documented reports of algal scums and discoloured water go back to at least 1853, with the first detailed scientific account of toxic cyanobacteria appearing in the scientific journal Nature (Francis 1878).

It reported hundreds of stock deaths at Milang on the shores of Lake Alexandrina, and through careful analysis attributed these deaths to the ingestion and toxicity of scums of the cyanobacterium *Nodularia spumigena* (see Codd *et al* 1994 for further information on this and other toxic algae events in the Lower Lakes).

Long-term water quality monitoring data has been collected at selected sites in the Lower Lakes and Coorong since the 1970s. The long-term dataset has originated from (a) initially the lakes being a drinking water supply for the local townships of Milang and Meningie, and tested regularly in the 1970s, (b) a Murray—Darling Basin wide monitoring program initiated in the early 1980s by the (now) Murray—Darling Basin Authority for the Goolwa and Milang sites and (c) Environment Protection Authority (EPA) monitoring at Meningie and Poltalloch since the late 1990s. The (now) Department of Environment Water and Natural Resources (DEWNR) collected water quality samples in the Coorong from the late 1990s to present.

The CLLMM water quality monitoring program from 2009 to 2016 supplemented the long-term dataset and added substantially more data spatially and temporally during and after the Millennium Drought.

Many research reports and papers have been published on the water quality of the Lower Lakes and Coorong. Briefly, these indicate the lakes are hyper-eutrophic and have very high algal, total nitrogen and phosphorus levels (Geddes 1984, 1988). Dissolved nutrients however, are generally at very low levels in the lakes and Coorong (Geddes 1984; Ford 2007; Mosley *et al* 2012), which has been attributed to rapid uptake by algae (Ford 2007; Mosley *et al* 2012, 2015). A large proportion of the nutrient inputs from the River Murray are retained within the lake system in organic forms and not exported (Cook *et al* 2009).

The lakes are also highly turbid and this results in rapid light absorption and attenuation, influencing phytoplankton community structure (Geddes *et al* 1998, 1988). Turbidity is variable and changes according to the upstream basin source of flow (e.g. more turbid Darling water versus less turbid Murray water, Geddes 1988) and wind-driven resuspension on the shallow lakes (Mosley *et al* 2012; Skinner *et al* 2014). The Coorong is less turbid due to its marine nature resulting in aggregation and settling of particles, but is also eutrophic to hyper-eutrophic (Mosley 2015). Detailed nutrient flux and budget information can be found in Haese *et al* (2009), Grigg *et al* (2009) and Grigg and Oliver (2012).

In terms of phytoplankton, Geddes (1984) showed there was a dominance of green algae in the Lower Lakes, although there has been a more recent shift in dominance by cyanobacteria (Mosley *et al* 2012; Oliver *et al* 2013, 2014, 2015).

As mentioned above, toxic cyanobacterial blooms have been a not too infrequent feature of the Lower Lakes history (Codd *et al* 1994). Diatoms have been found to dominate the phytoplankton community in the South Lagoon of the Coorong (Jendyk *et al* 2014; Leterme *et al* 2014). In the North Lagoon chlorophytes (green algae) have been found to be dominant up to a salinity of 20 g/L, but over this diatoms dominated the community (Leterme *et al* 2014). The concentration of chlorophyll *a* in the Coorong shows a pronounced spatial variation increasing from the northern end to the southern end where concentrations often exceed 100 µg/L (Ford 2007).

Paleolimnological and other evidence demonstrated the Lower Lakes have historically been a predominantly freshwater system (Fluin *et al* 2007). Seawater intrusions up from the barrages into the lakes can occur during periods of low flows (Aldridge *et al* 2011) or storm surge events if the barrages are open.

Sampling groundwater from beneath the surface of Lake Alexandrina after the return of water to the region. Credit: EPA

1.4 Key publications from the CLLMM water quality monitoring program

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Many of the publications that have arisen directly from the CLLMM water quality monitoring program are discussed and referenced within this report. Below is a list of these specific publications:

Hamilton B, Mosley LM, Stone D and Zammit B 2014a, *Measurement of sediment acidity fluxes to Boggy and Hunters Creeks*, Environment Protection Authority, Adelaide, 23 May 2016. www.epa.sa.gov.au/xstd_files/Water/Report/fluxes_boggy_hunters_creeks.pdf

Hamilton B, Mosley LM, Fradley K, Stone D and Mettam P 2014b, *Lower Lakes groundwater acidification risk project: monitoring report 2012—14*. Environment Protection Authority, Adelaide, 23 May 2016. www.epa.sa.gov.au/xstd_files/Water/Report/lower_lakes_acid_1214.pdf

Leyden E, Cook F, Hamilton B, Zammit B, Barnett L, Lush AM, Stone D and Mosley LM 2016, 'Nearshore groundwater acidification during and after a hydrological drought in the Lower Lakes, South Australia', *Journal of Contaminant Hydrology*, doi:10.1016/j.jconhyd.2016.03.008.

Mosley LM, Zammit B, Leyden E, Heneker TM, Hipsey MR, Skinner D and Aldridge KT 2012, 'The impact of extreme low flows on the water quality of the Lower Murray River and Lakes (South Australia)', *Water Resources Management* 26:3923–3946.

Mosley LM, Barnett L, Leyden E, Fradley K, Iacopetta J, Jolley AM, Mettam P, Natt A, Palmer D, Scott P, Spencer J, Stone D and Zammit B 2013, *Water quality in the Lower Lakes during a hydrological drought: water quality monitoring report*, Environment Protection Authority, Adelaide. www.epa.sa.gov.au/xstd_files/Water/Report/lower_lakes_WQ.pdf

Mosley LM, Zammit B, Jolley A and Barnett L 2014a, 'Acidification of lake water due to drought', *Journal of Hydrology* 511:484–493.

Mosley LM, Shand P, Self P and Fitzpatrick R 2014b, 'The geochemistry during management of lake acidification caused by the rewetting of sulfuric (pH<4) acid sulfate soils', *Applied Geochemistry* 41:49–56.

Mosley LM, Zammit B, Jolley A, Barnett L and Fitzpatrick R 2014c, 'Monitoring and assessment of surface water acidification following rewetting of oxidised acid sulfate soils', *Environmental Monitoring and Assessment* 186:1–18.

Mosley LM 2015, *Assessment of the effects of the 2013—2015 Morella Basin releases on Coorong water quality*, Report to the Department for Environment, Water and Natural Resources (DEWNR), University of Adelaide.

Mosley LM 2016, *Barrage release optimisation trial August 2015; assessment of environmental outcomes and achievement of management objectives*, Report to SA Water, University of Adelaide.

Natt A, Mosley LM, Barnett L, and Corkhill E 2011, *Acidification as a result of severe drought conditions and over allocation in the Murray—Darling Basin: a case study of monitoring and management of Currency Creek*, River Symposium conference. Perth.

Oliver R, Lorenz Z, Nielsen DL, Shiel RJ and Aldridge K 2014, *Report on the Coorong, Lower Lakes and Murray Mouth 2012—13 microalgae and water quality monitoring data: a multivariate analysis in the context of the Millennium Drought*, Report prepared for the Department of Environment and Natural Resources, Adelaide, 50pp.

Oliver RL, Lorenz Z, Nielsen DL and Shiel RJ 2013, *Multivariate analyses of the microalgae, zooplankton and water quality monitoring data from the Coorong, Lower Lakes and Murray Mouth: analysing environmental perturbations in a connected river, lake and estuarine system*, Report prepared for the Department of Environment and Natural Resources, Adelaide, 94 pp. incl. appendices.

Oliver R and Mosley LM 2015, *An Assessment of the Coorong, Lower Lakes and Murray Mouth Water Quality and Microalgae – A preliminary evaluation of water quality trigger values associated with the Ecological Character Description*, CSIRO Land and Water Flagship, Australia.

Shiel RJ and Tan LW 2013a, *Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth October 2011–April 2012*. Final report to Department of Environment, Water & Natural Resources, Adelaide, 49 pp. incl. appendices, DOI: 10.13140/2.1.4129.3440.

Shiel RJ and Tan LW 2013b, *Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth September 2012–March 2013*, Final report to Department of Environment Water & Natural Resources, Adelaide, 41 pp. incl. appendices, DOI: 10.13140/2.1.3080.7685

1.5 Components of the monitoring program

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The EPA and the Department of Environment, Water and Natural Resources (DEWNR) designed and implemented a water quality monitoring program in 2009 under the Murray Futures program.

The program was initially implemented to assess changes during the extreme period of the Millennium Drought (2007 to 2010) in order to better understand and protect the ecological and human uses of the region from acidification and salinisation. The program evolved over time to encompass other objectives and has been continued post-drought to monitor water quality recovery in the region. Where possible, newer components of the program were designed to overlap with existing monitoring to more efficiently collect and build on existing data records.

The three main components of the program were:

- Surface water quality monitoring at regular intervals in the CLLMM region (ambient program).
- Surface water quality monitoring for targeted issues (event-based program).
- Groundwater quality monitoring on exposed (drought) and then resubmerged (post-drought) areas known to contain acid sulfate soils on the margins of the Lower Lakes and tributaries.

The water quality monitoring program's broad objectives were to:

- Provide early warning of changes to water quality and ecology that indicate imminent acidification.
- Assess the impacts of low water inflows and acid sulfate soils on the ecological communities in the region.
- Examine the effectiveness or any impacts of implemented management actions.

Exposed and cracked acid sulfate soils during the drought
Credit: EPA

1.6 Aims of the report

The aims of this report are to:

- Summarise the water quality monitoring program as a whole, synthesising previous and new findings.

- Describe how the use of the water quality data and knowledge gathered during the program helped to inform management decisions

- Inform future water quality monitoring and management decisions across the region.

The Narrung bund installed as an emergency measure in the drought to maintain water levels (via pumping) in Lake Albert. A 100 meter section of the bund was breached in September 2010, and the bund was fully removed in 2011

1.7 Water quality parameters

A wide range of water quality parameters were monitored across the CLLMM region with key parameters reported herein being pH, alkalinity, acidity, salinity, turbidity, nutrients (total nitrogen and total phosphorus), chlorophyll *a* and metals (aluminium, manganese and iron). A brief description of these parameters is provided below:

- **pH** is an indicator of acidity or alkalinity. pH is a logarithmic scale and an increase or decrease of one pH unit is a 10-fold change. Neutral water has a pH of 7, acidic solutions have lower pH and alkaline solutions higher pH.

- **Alkalinity** is a measure of the buffering capacity of water, or the capacity of the water to neutralise acids and resist pH change. Alkalinity within water bodies is consumed as acid is released from acid sulfate soils. Adding limestone contributes alkalinity to waters, helping to neutralise any acid released from the sediments.

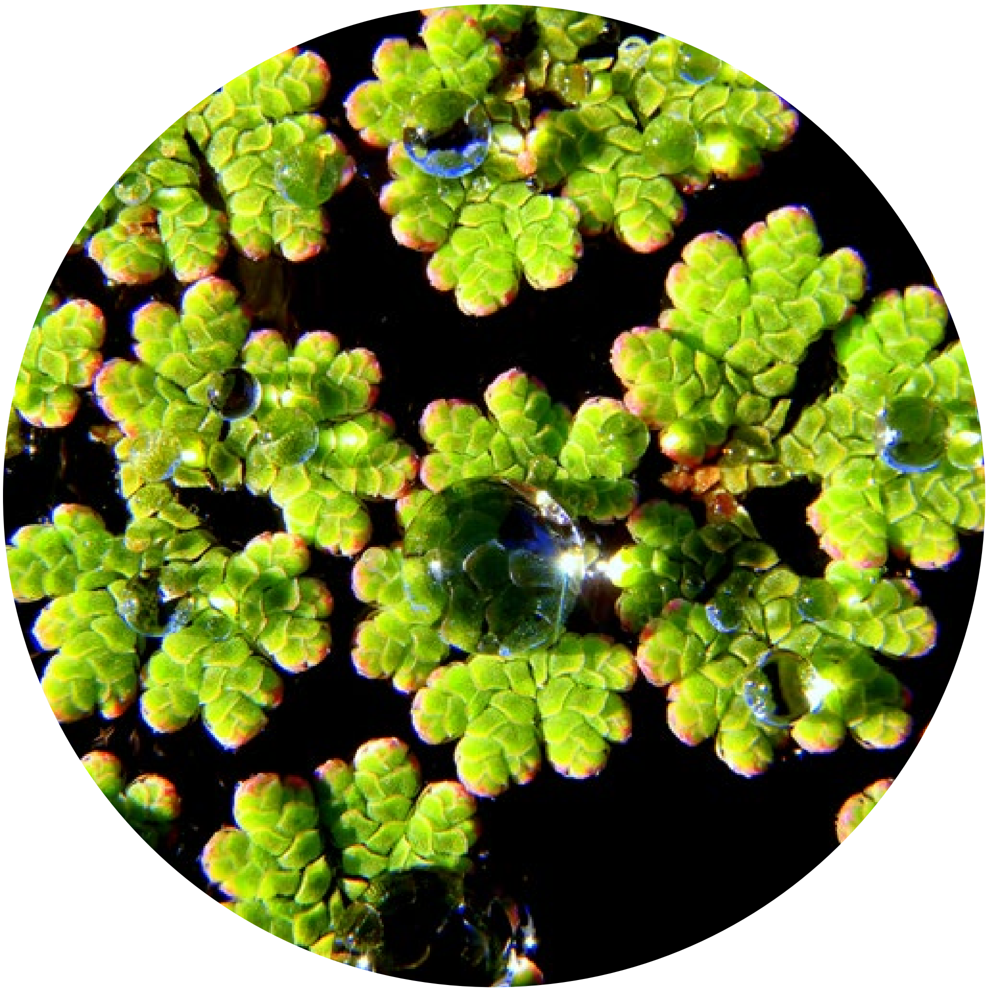
- **Acidity** is a measure of the combined concentrations of acid (protons, H^+) and dissolved metals (that may generate protons upon oxidation and hydrolysis). Normally there is little detectable acidity present in surface waters, but run-off and drainage from acid sulfate soils can contain significant amounts.

- **Salinity** is a measure of the amount of dissolved salts in the water. Saline water conducts electricity more readily than freshwater, so electrical conductivity (EC) is routinely used to measure salinity. As salinity increases, it may become toxic to plants and animals and be unsuitable for irrigation.

- **Turbidity** is a measure of the cloudiness or haziness in water caused by suspended solids (e.g. sediment, algae). Turbidity is expressed in nephelometric turbidity units (NTU) and is measured using a relationship of light reflected from a given sample. Turbidity in the Lower Lakes is very variable and influenced primarily by wind events and turbidity levels of entering river water.

- **Nutrients–nitrogen and phosphorus** are essential nutrients for growth of plants in water. Nitrogen can be present in different forms (e.g. organic nitrogen in plant material, ammonia, nitrate and nitrite). Phosphorus can also be present in different forms (e.g. organic phosphorus, phosphate). High concentrations of dissolved nutrients or total phosphorus (TP) and total nitrogen (TN) can result in or indicate excessive growth of aquatic plants such as cyanobacteria, phytoplankton, macrophytes and filamentous algae.

- **Chlorophyll *a* & *b*** are the main photosynthetic pigments in green algae. The concentration of chlorophyll gives an indication of the volume of aquatic algae present in the water column. Levels in excess of 15 µg/L are considered very high (hyper-eutrophic) and nuisance algae and plant growth can occur (ANZECC 2000).



Azolla sp. from the Finniss region.
Credit: Goolwa to Wellington Local Action Planning Association

- **Metals** are naturally occurring elements (e.g. iron, manganese, aluminium, etc) that can be dissolved or associated with particulates in the water and sediment. Where acid sulfate soils are present, as the sediments acidify and the pH is reduced, metals that have been previously bound to sediment can be released to the water. An increase in dissolved metal concentration can be used as an indicator of acid sulfate soil impacts. Dissolved metals can harm biological systems, and are generally more bio-available and toxic to aquatic organisms than particulate forms.

- **Dissolved oxygen** is a measure of the quantity of oxygen present in water. Aquatic animals, plants and aerobic bacteria depend on dissolved oxygen for respiration as well as for some chemical reactions. High concentrations of organic matter can result in depletion of dissolved oxygen due to microbial consumption. The concentration of dissolved oxygen is an important indicator of the health of the aquatic ecosystem. Persistently low dissolved oxygen (less than 5 mg/L) will harm aquatic life. Oxygen is replenished via exchange with the atmosphere and photosynthesis.

- The water quality program also collected samples of **phytoplankton and zooplankton** from across the CLLMM region for identification and use by the University of Adelaide. This data is explored in reports by Oliver *et al* (2013, 2015) and Shiel *et al* (2013a, b).

All laboratory sample results presented in this report were analysed in a National Association of Testing Authorities (NATA) accredited laboratory (the Australian Water Quality Centre) using standard methods (APHA 2005). Strict quality control procedures are applied as part of the NATA system. Field parameters were collected using handheld YSITM instruments that were calibrated on a weekly basis or immediately prior to sampling. Water quality data collected was stored in and extracted from the EPA's database.

1.8 Lower Lakes and Coorong hydrology

Long-term flows over Lock 1 (after which the river forms a connected pool through to the Lower Lakes barrages) and water levels are shown in Figure 2.

Up until the mid to late 1990s there were regular winter and spring flow pulses of high magnitude (greater than 40,000 ML/day) over Lock 1. Beginning in the early 2000s (the start of the Millennium Drought), there was a transition to a sustained period of low flows, averaging less than 10,000 ML/day. From 2006 to 2010 flows decreased to the lowest on record, at less than 1,000 ML/day for sustained periods in 2009. Heavy rainfall and flooding across the Murray—Darling Basin occurred in 2010 resulting in higher flows in the Murray River, with an average daily flow over Lock 1 of 34,454 ML. These high flow levels continued through 2011 to 2012. Flows have decreased since then averaging 8,624 ML/day in 2013, 5,816 ML/day in 2014 and 5,585 ML/day in 2015. Water levels downstream of Lock 1 show similar patterns, with the lowest water levels downstream of Lock 1 in nearly 100 years of records occurring during the Millennium Drought (Figure 2).

'Water levels downstream of Lock 1 show similar patterns, with the lowest water levels downstream of Lock 1 in nearly 100 years of records occurring during the Millennium Drought'

Water levels in the Lower Lakes over the period water quality data is available (1975 to 2016) are shown in Figure 3. Average lake levels (–0.38 m AHD in Lake Alexandrina, –0.19 m AHD in Lake Albert) in the 2007 to 2009 drought period were approximately 1 m lower than the long-term average (0.7 m AHD) and represented 35% and 55% reductions in water volume respectively (Mosley *et al* 2012). During this period Lake Alexandrina levels fell below mean sea level, reversing the usual positive hydraulic gradient from the lake to the sea and resulting in seawater seepage through the barrages into the lake. The lowest water levels (–1.05 m AHD in Lake Alexandrina, –0.55 m AHD in Lake Albert) during the drought were reached in April 2009, and represented 64% and 73% reductions in lake volume respectively (Mosley *et al* 2012). Water levels recovered to pre-drought levels in September 2010 when high inflows rapidly occurred and removal of the various drought-mitigation bunds was begun.

Barrage outflows were high and regular from the start of records in the 1950s to the early 2000s, prior to the beginning of the Millennium Drought. During the extreme drought period (2007 to 2010) the low river inflows and correspondingly low lake levels (Figure 3) meant there was no barrage outflow (Figure 4). Water levels in the North and South Lagoons of the Coorong were at their lowest during the Millennium Drought period (Figure 4).

Water levels were high and similar in both lagoons during the 2011 to 2012 period of high river and barrage flows. Water levels typically decrease in both lagoons during summer, and during lower flow periods the decrease in the South Lagoon is often larger. Morella Basin releases are also shown in Figure 4, with more regular and higher volume releases occurring after 2010.

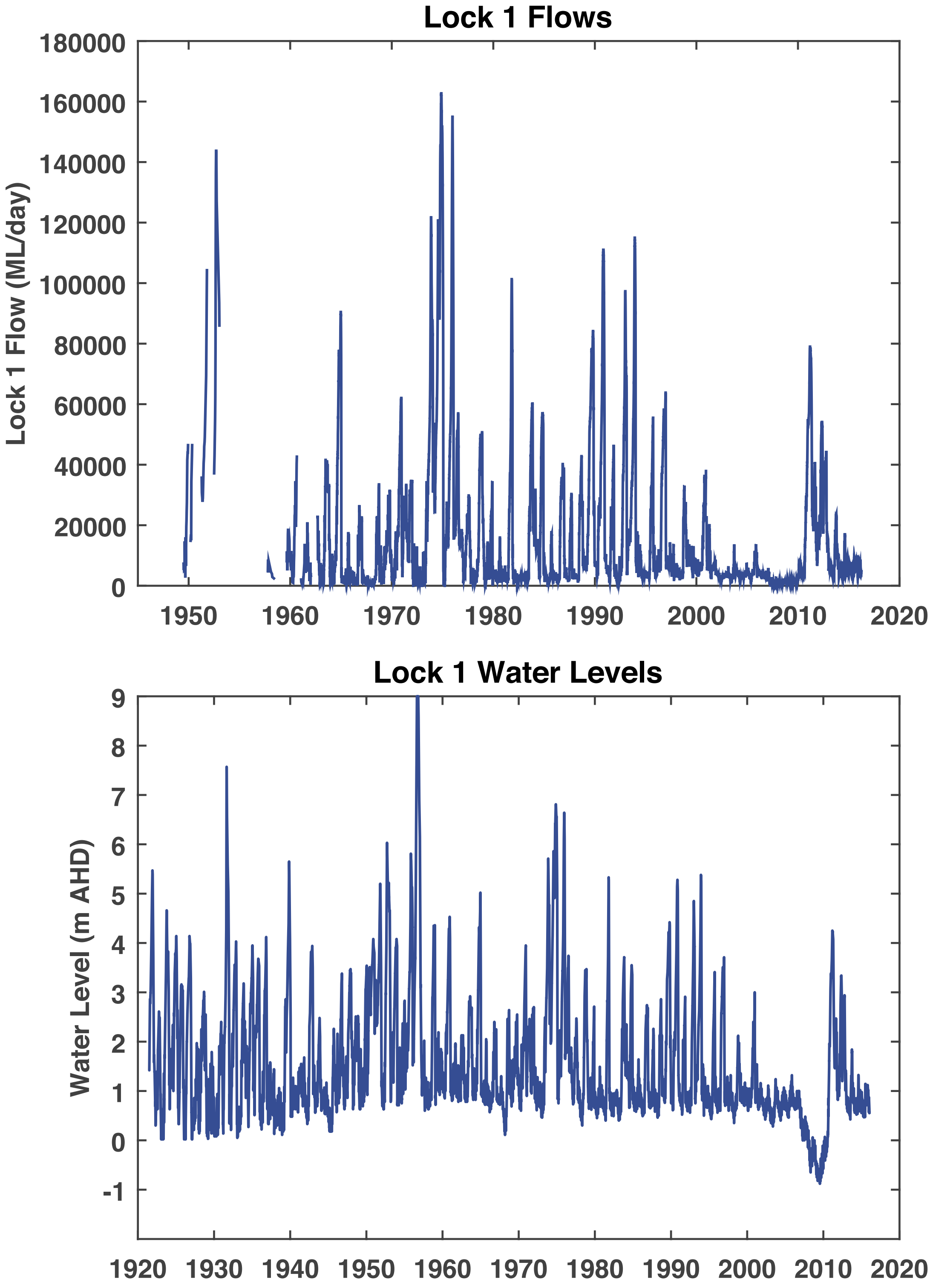
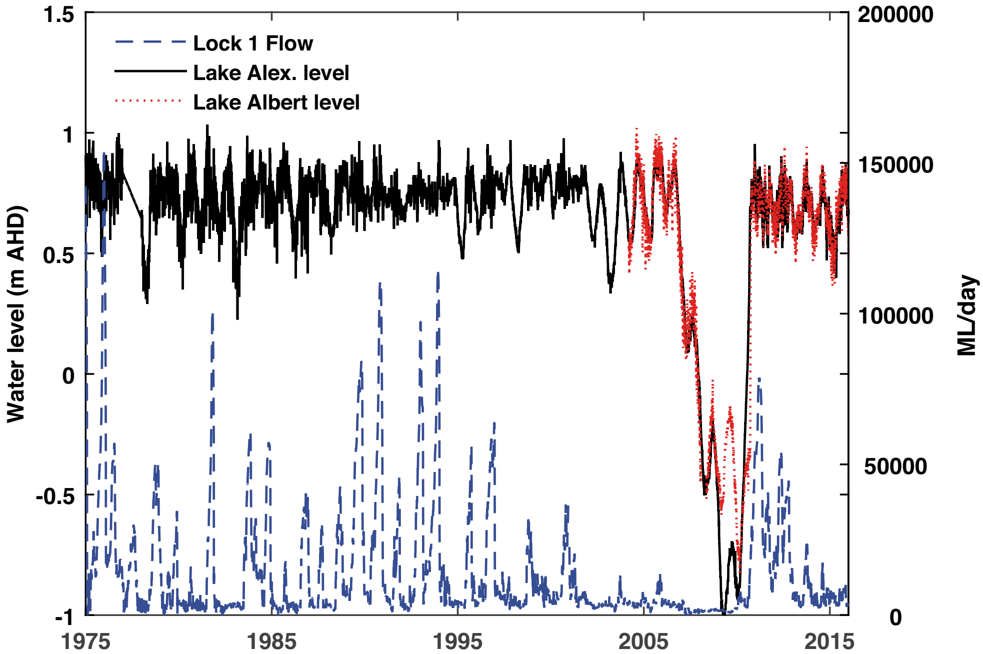


Figure 2
–
Long term River Murray flow (top, 1950-2016) and water levels (bottom, 1920-2016) downstream of Lock 1 (Station A4260903).

Figure 3
–
Lake Alexandrina and Lake Albert water levels (average daily levels from multiple stations) from 1975 to 2016. The River Murray flow downstream of Lock 1 (Station A4260903) is also shown on the right hand side in ML/day. There was pumping from Lake Alexandrina to Lake Albert in 2009-10 to maintain minimum water levels to prevent acid sulfate soil exposure. This resulted in the difference observed in water levels between the two lakes during this period.



The Coorong and Murray Mouth when the first water flows following the Millennium Drought exited the mouth to the Southern Ocean, causing large discolouration along the coast.

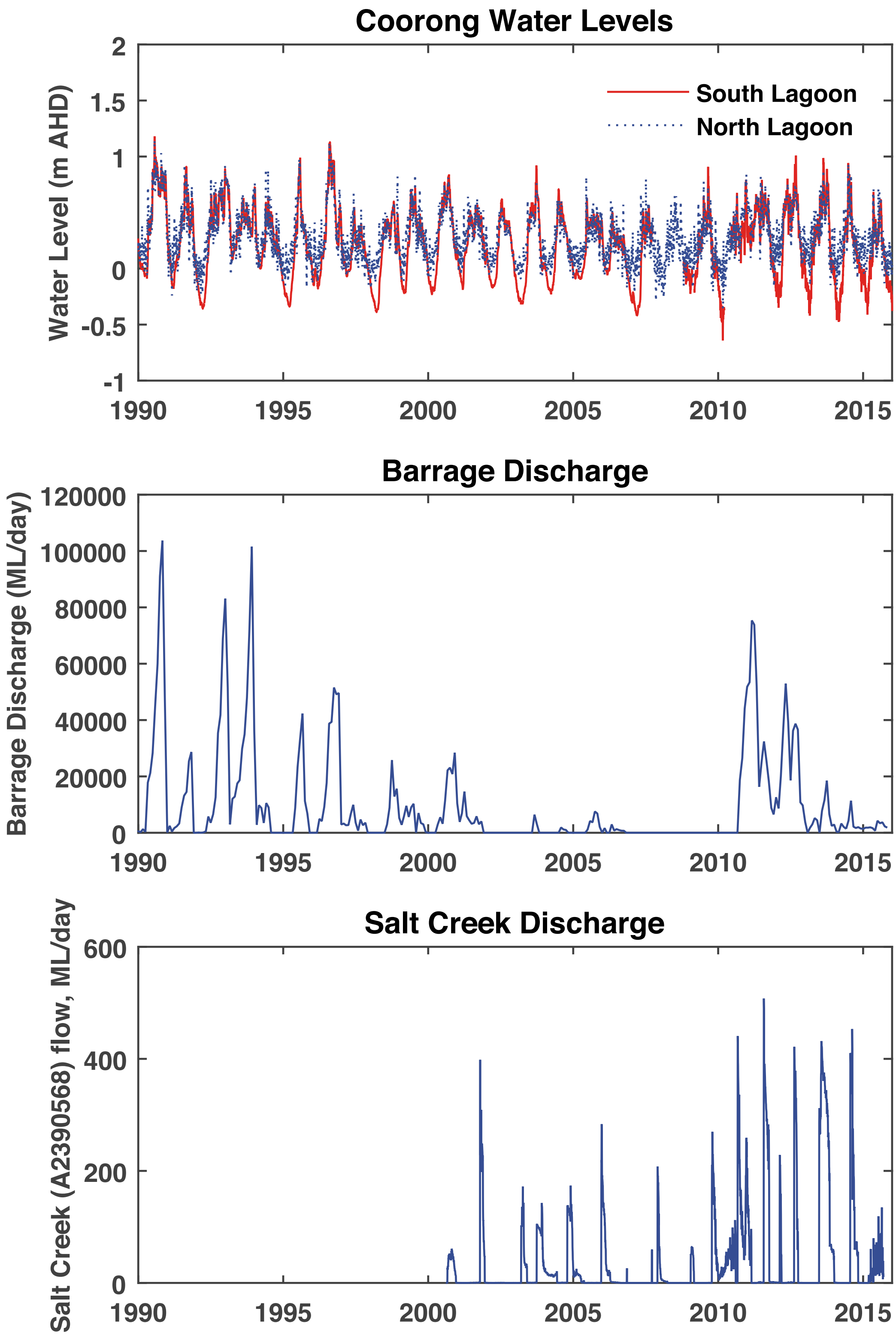


Figure 4 – Coorong North and South Lagoons water levels (top, includes modelled data from CSIRO pre-2008), barrage outflows (middle, estimated barrage flow data from DEWNR), and Salt Creek/Morella Basin outflows (bottom) from 1998 to 2016 (no previous data available).

2 Monitoring program component summary

A summary of the water quality monitoring program components, their aims, methods and key findings.

2.1 Lower Lakes and Tributaries – ambient monitoring

Aim

To assess ambient water quality across the lakes and tributaries, particularly in the drought in regard to acidification risks, and to monitor ongoing recovery of water quality across the region.

Methods

The main ambient water quality monitoring sites in the Lower Lakes from 2009 to 2016 are shown in Figure 5. Monitoring occurred on a fortnightly to monthly basis from 2009 to 2010. Sampling with field analysis occurred fortnightly in Lake Alexandrina with laboratory analysis being carried out monthly. In Lake Albert monitoring occurred monthly when pumping from Lake Alexandrina was not occurring (winter) and fortnightly when pumping was occurring (summer) with laboratory and field analysis carried out each time. In the tributary region laboratory and field analysis occurred fortnightly.

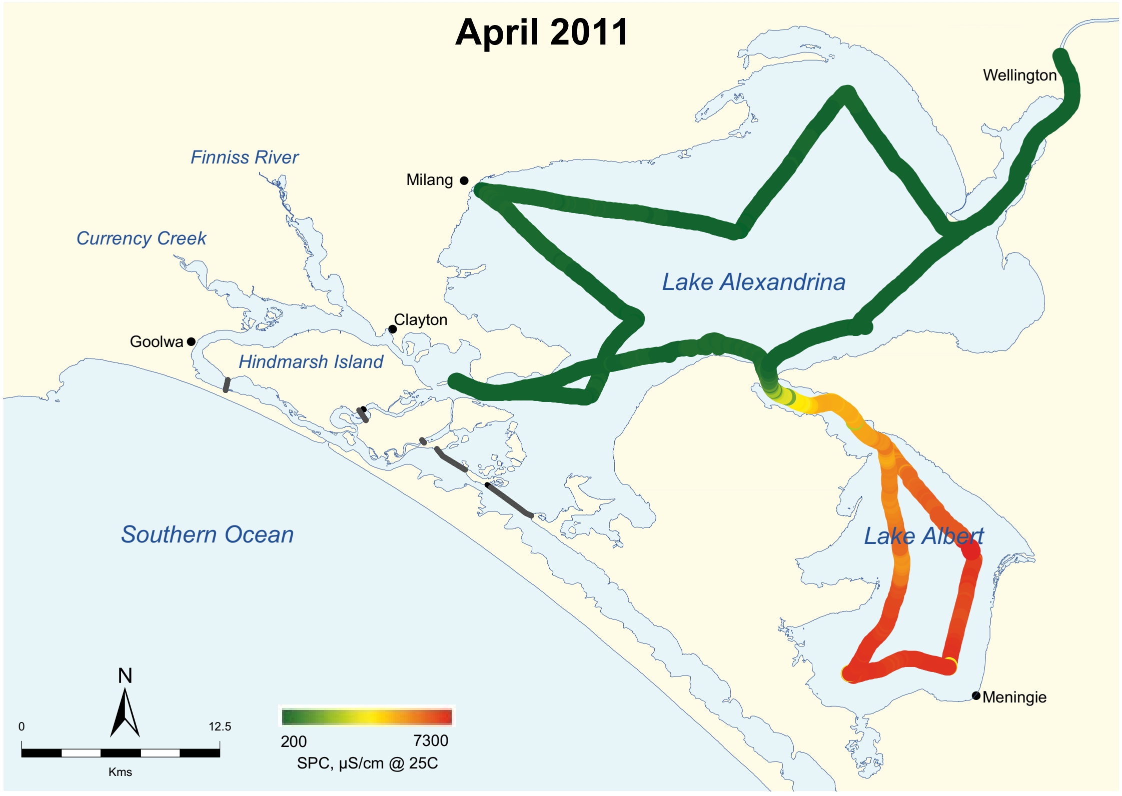
With return of inflows to the Lakes in late 2010, monitoring in Lake Alexandrina and Lake Albert became monthly with laboratory and field analysis carried out each run.

The tributaries continued to be monitored fortnightly with monthly laboratory analysis. In July 2013 the Lakes and tributaries monitoring changed to quarterly laboratory and field analysis, with the final monitoring occurring in February 2016.

When sampling was undertaken by boat in the lakes, some water quality parameters were recorded continuously in conjunction with GPS location to enable the creation of transect maps that show the spatial variation of surface water quality across the Lower Lakes. This was achieved at first by building a stainless steel water off-take tube that was connected to the boat just below the water surface, facing forward (adapted later to draw water via a pump). Water was forced through the tube into a chamber that was connected to a water quality meter which recorded the water quality data and GPS location every 10 seconds. From this data, maps showing salinity levels and mixing across the lakes were created (Figure 6). This method of continuous data collection was later adapted for use in other components of the monitoring program.

For the list of parameters analysed please see Appendix 1.

Figure 5 – Map of Lower Lakes ambient monitoring sites.



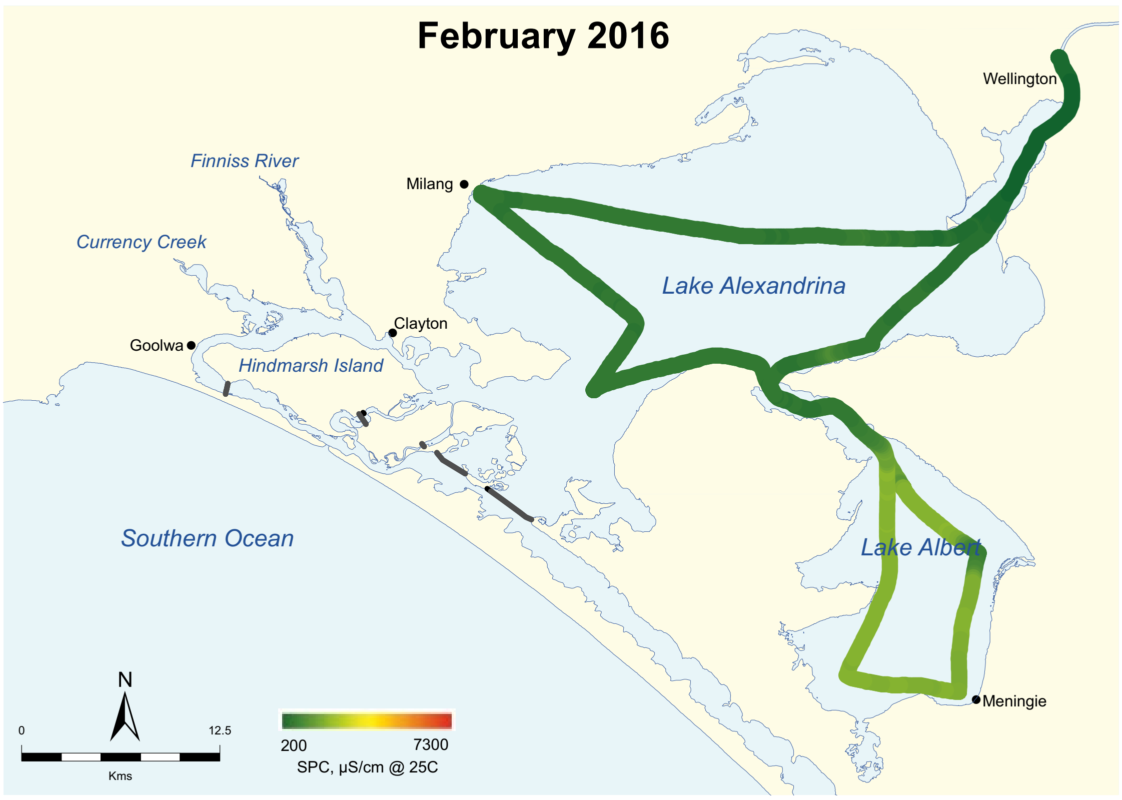


Figure 6
–
Salinity transect maps from 2011 (top) and 2016 (bottom). The slower dilution of salinity in Lake Albert is very clear in 2011, and in 2016 salinity is still higher than Lake Alexandrina and pre-drought Lake Albert levels.

Findings

- The Millennium Drought resulted in very poor water quality across the Lower Lakes compared to historical pre-drought levels (Figures 7 and 8). There was a complete lack of lake flushing between 2007 and 2009 as no discharge occurred over the barrages to the Coorong and Murray Mouth. This resulted in a concentration of dissolved and particulate material in the lakes, driven by evaporation and the associated large reductions in lake volume (Mosley *et al* 2012; 2013). Salinity increases were very large, particularly in the southern regions of the lake furthest from the river inflow and closest to the barrages, which leaked seawater into the lakes due to sea levels being higher than the lakes for much of the drought period. The lack of lake flushing also resulted in the observation of very high concentration of nutrients (e.g. TN and TP in Figures 7 and 8). Algal levels also increased (Chlorophyll *a*) with increasing dominance of cyanobacteria (Oliver *et al* 2015). Turbidity also increased during the drought period due to concentration of particulate material and increased wind resuspension (Mosley *et al* 2012).

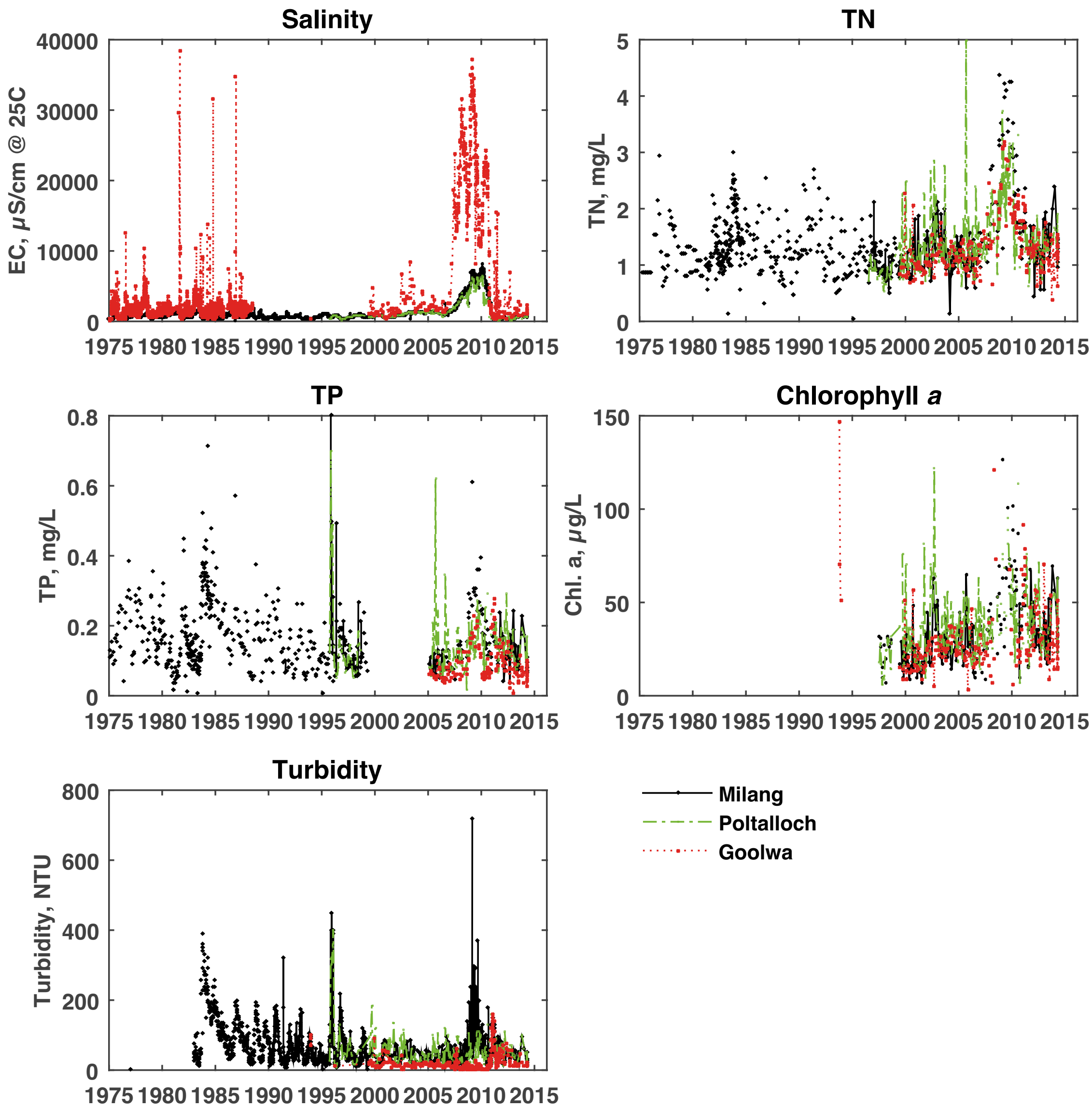


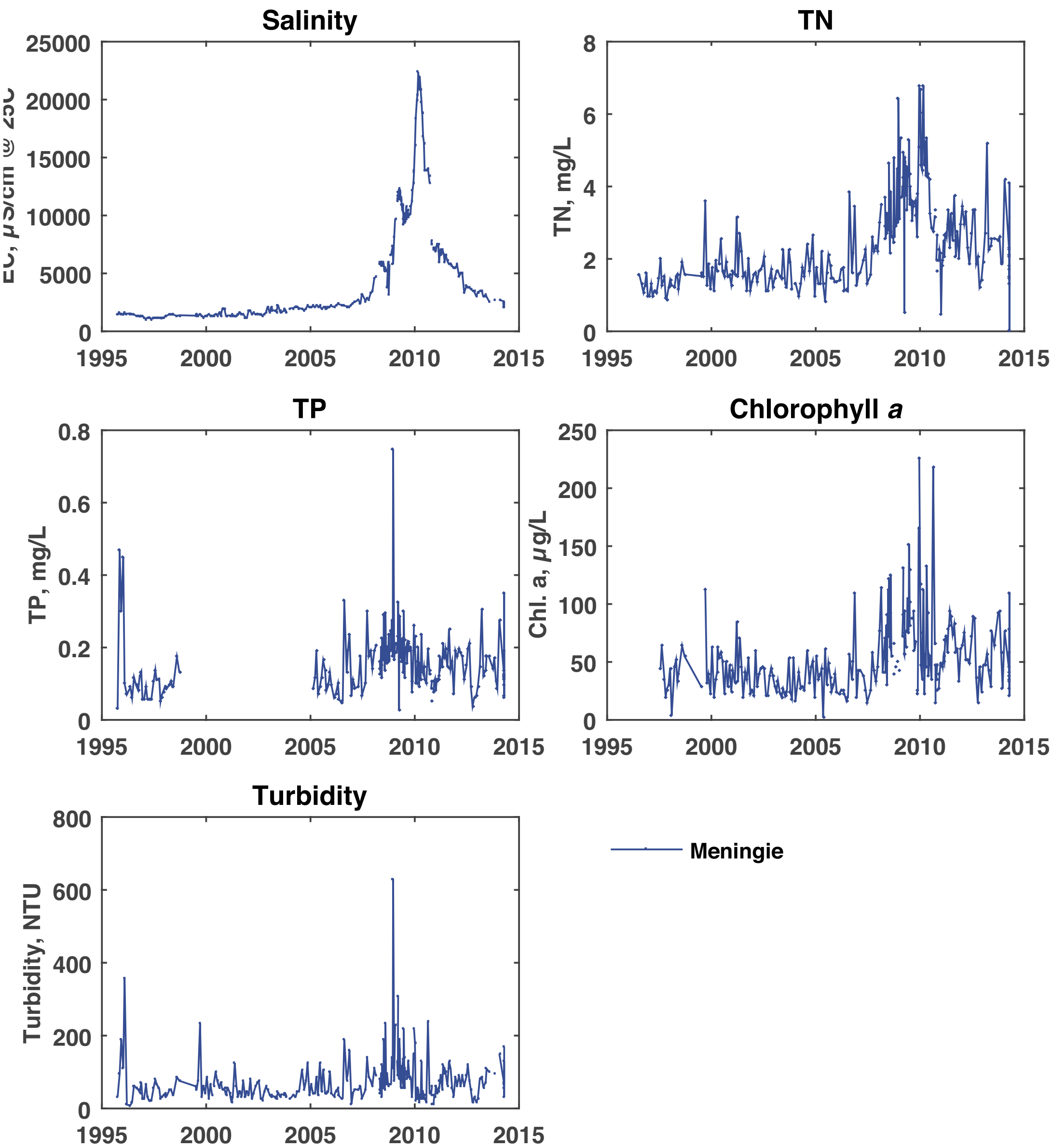
Figure 7 – Electrical conductivity, TN, TP, turbidity, chlorophyll *a*, and pH in Lake Alexandrina (Milang, Goolwa, and Poltalloch) from 1975 to 2016.

- Lake Alexandrina water quality recovered quite quickly with the return of inflows in late 2010 as it is a flow-through system (Figure 7). There was very slow recovery of Lake Albert water quality following the end of the drought (Figure 8), its reconnection to Lake Alexandrina, and return of lake levels to normal in late 2010. For example, salinity in Lake Alexandrina returned to pre-Millennium Drought levels in February 2011 (Figure 7), but Lake Albert has still not returned to pre-drought levels as of February 2016 (Figure 8). The slow recovery of Lake Albert is influenced by the terminal nature of the lake which limits water exchanges, leaving it reliant on seiching and diffusion to and from Lake Alexandrina.

'Over the long term (post-1975) there have been increasing trends in salinity, TN and chlorophyll a in the Lower Lakes (Oliver et al 2015)'

Over the long term (post-1975) there have been increasing trends in salinity, TN and chlorophyll *a* in the Lower Lakes (Oliver *et al* 2015). This may reflect increasing land development for agriculture in the Murray–Darling Basin and lower total amount and frequency of higher flows that flush the lakes.

Figure 8 – Electrical conductivity, total nitrogen (TN) and phosphorus (TP), turbidity, chlorophyll *a*, and pH in Lake Albert (Meningie) from 1995 to 2016.



2.2 Lower Lakes and Tributaries – event based monitoring

Aims

- To assess presence of acidification 'hotspots' and effectiveness of acidification management actions during the drought.
- To monitor the region for ongoing signs of acidification in previously determined 'hotspot' locations.
- To undertake investigation of targeted issues such as salt transport and mixing through the Narrung Narrows.

Methods

Event-based water quality sampling was undertaken at targeted areas that experienced acidification or were at risk of acidification (see DENR 2010; Grealish *et al* 2010). The selection of sites was based upon previous acid sulfate soil risk assessments, in accordance with available data on the distribution of sulfidic and sulfuric materials, and research and modelling into potential acidity fluxes. High risk locations were initially screened to identify the presence and extent of any acidity, and the frequency of further monitoring was determined from these results. An overview of the main locations is shown in Figure 9 and included key locations such as Currency Creek, Finniss River, Boggy Lake, Dog Lake, Boggy and Hunter's creeks, Loveday Bay, Dunn's Lagoon, Bascombe Bay, and the western margin of Lake Albert.

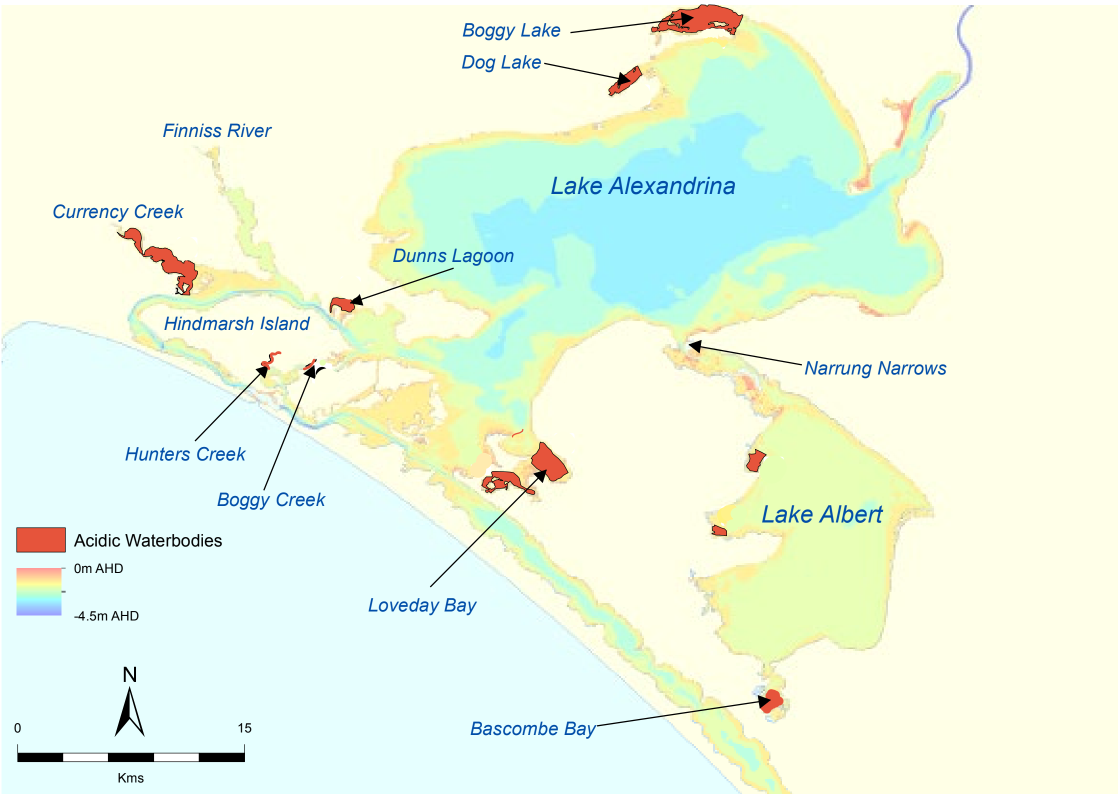
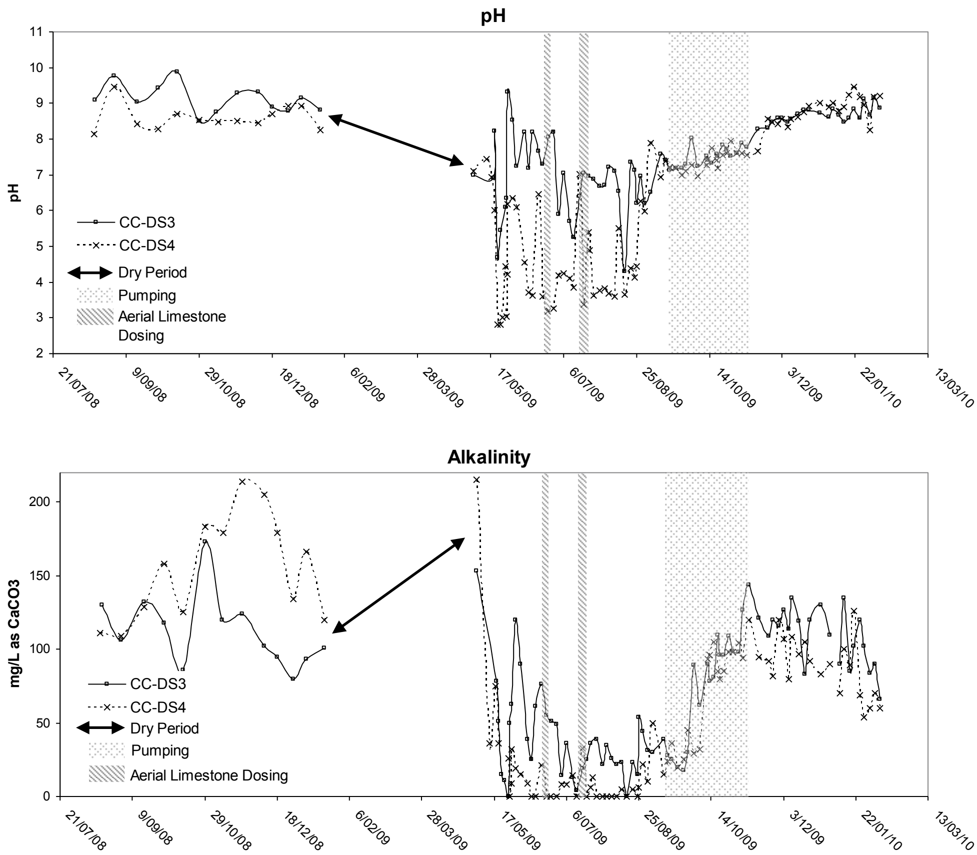


Figure 9
Map of Lower Lakes event-based acidic monitoring sites showing regions (red shaded areas) that experienced surface water acidification during 2008-10 (adapted from Mosley *et al* 2014a).

'Community interest in water quality in the region was very strong so the data collected was published fortnightly in reports on the EPA website'

Figure 10 – Effect of limestone dosing on water pH in Currency Creek (from Natt *et al* 2010). The timing of two aerial limestone additions is shown.



The water quality information collected was used to determine the need for, and effectiveness of, management actions such as limestone dosing, which occurred in Currency Creek, Finniss River and Boggy Lake in 2009 and 2010. In these early days of the program, field testing at sites that had turned acidic such as Currency Creek was conducted up to four times a week to track movement of acidic water and general water quality. Laboratory testing was also carried out regularly (weekly to fortnightly) at targeted locations. Community interest in water quality in the region was very strong so the data collected was published fortnightly in reports on the EPA website (EPA 2015).

Boggy and Hunter's creeks on Hindmarsh Island were both identified as at-risk areas due to the presence of acid sulfate soils. Both creeks were regularly monitored from July 2010 to June 2015. The frequency of monitoring varied, starting out at weekly, then moving to fortnightly, monthly, then quarterly. Laboratory and field analyses were undertaken at multiple sites along both creeks. Two sites in particular (Boggy 6 and Hunters 1) regularly recorded acidity in the water body so laboratory testing at these two sites was continued post-drought, while the other sites which had stable water quality and no acidity were field tested only.

Additional event-based sampling was undertaken in the Narrung Narrows to understand salinity transport and dilution between the two lakes during recovery from the drought. Measurement of field-based parameters, primarily salinity, was undertaken by boat along a transect through the Narrows. Depth profiling was also conducted.

For the list of parameters analysed please see Appendix 1.

Removal of the Clayton Bay regulator. Credit:EPA

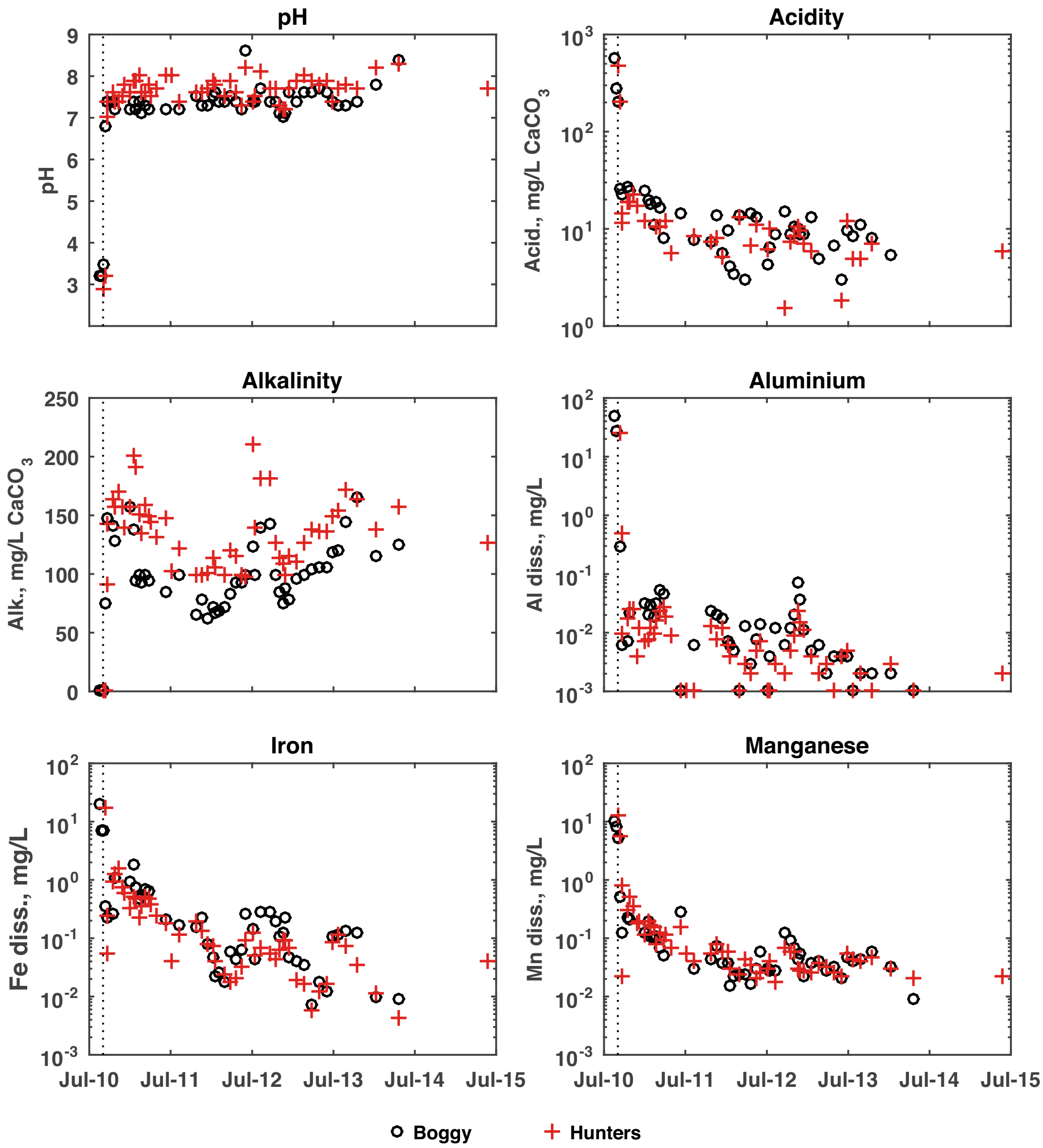


Figure 11 – pH, acidity, alkalinity, dissolved (<0.4 µm filtered) metals (aluminium, iron, and manganese) in Boggy and Hunters creeks between 2010 and 2015. The vertical dotted line represents the return of surface water levels to pre-drought averages in September 2010. Note: a log scale is used for the acidity and dissolved metal plots to better highlight the changes in concentration over time.

Findings

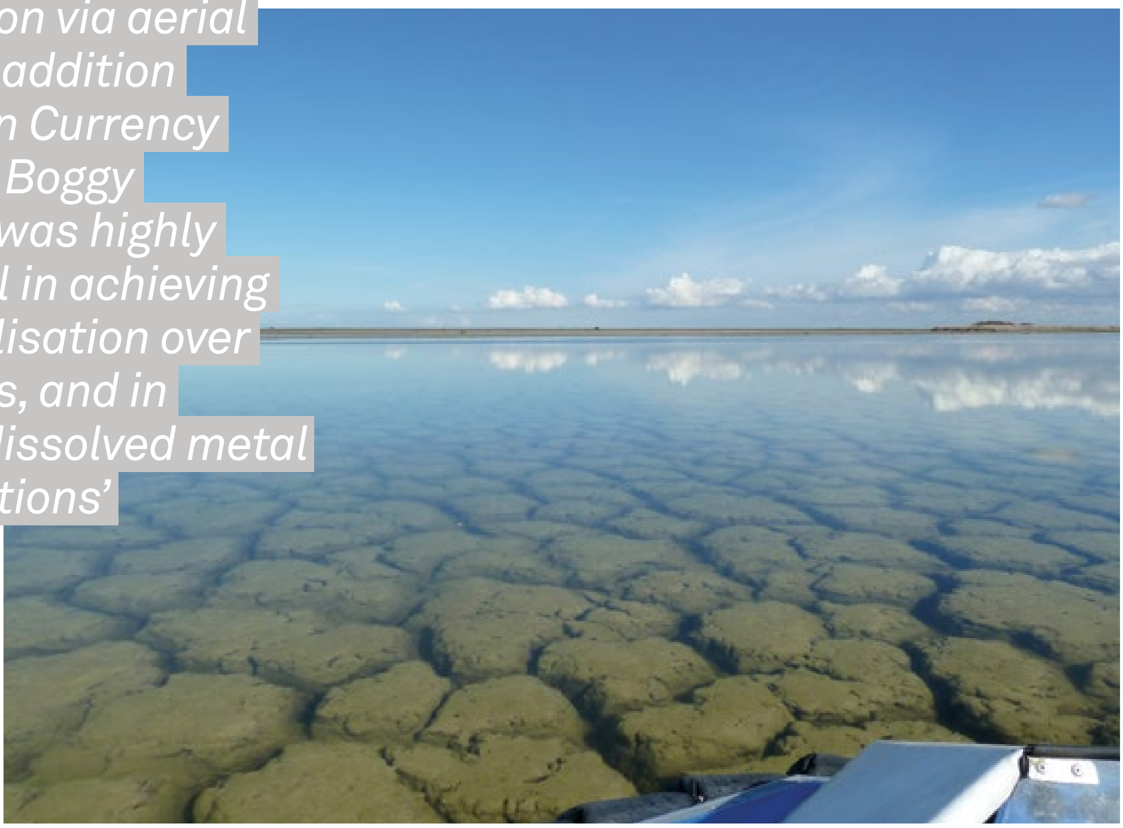
- Several surface water acidification events (pH 2.2—6.5) occurred during the 2008–10 drought period. These areas were on the shallow lake margins, often in embayments which have limited connection with the main lake water body. The total acidified area was estimated to be 2,173 ha, which represented about 3% of the Lower Lakes surface water area (Mosley *et al* 2014a). Different severities and durations of acidification (pH<6.5, ANZECC 2000) were observed, ranging from weeks to months and is ongoing in some areas. Dissolved metal concentrations were very high in the acidified waters, in exceedance of guidelines for protection of aquatic ecosystems. Neutralisation of acidification was accomplished naturally in several areas by dilution and alkalinity input following a rapid rise in lake levels following Murray–Darling Basin floodwater inflows during 2010.

- Treatment of acidification via aerial limestone addition occurred in Currency Creek and Boggy Lake, and was highly successful in achieving pH neutralisation over large areas, and in reducing dissolved metal concentrations. For example, Figure 10 shows how water pH was increased away from its acidic state following two additions of limestone via aerial dosing (Natt *et al* 2010). Mosley *et al* (2014b) found limestone addition was also successful for managing the acidification in Boggy Lake, although the efficiency of limestone dissolution was only about 25% (due to surface armouring by dissolved metals). Additional limestone barriers were placed in the upstream acidified regions of the Finniss River and Currency Creek to help contain and neutralise the acidic water.

- Boggy and Hunter's creeks both acidified in 2011. Residual acidity and dissolved metals are still present in the water column, although concentrations have been declining over time (Figure 11). Hamilton *et al* (2014a) installed benthic flux chambers and found increases in concentrations of acidity, soluble and total metals (Al, As, Fe, Mn, Ni, Zn) occurred inside the chambers, indicating fluxes from the sediment to the surface water. Despite these fluxes, none of the chambers went acidic (pH<6.5, zero alkalinity) over the six-week experiment, although minor pH (<0.5 pH units) decreases were observed.

- Monitoring of the Narrung Narrows following removal of the bund (a drought emergency measure) in September 2010 showed that mixing and dilution of the more saline Lake Albert water with the fresher Lake Alexandrina water was limited and dependent on wind seiching events and managed water level cycling.

'Treatment of acidification via aerial limestone addition occurred in Currency Creek and Boggy Lake, and was highly successful in achieving pH neutralisation over large areas, and in reducing dissolved metal concentrations'



Acidic water in Boggy Lake following rewetting of cracked acid sulfate soils. Credit: EPA

2.3 Lower Lakes and Tributaries – groundwater monitoring

Aims

- To monitor the groundwater quality beneath lake margins that were exposed in the drought
- To provide data to assist in assessing risks of acidified groundwater flux to the main lake and creek water bodies.

Methods

Monitoring of groundwater under exposed sediments of the Lower Lakes and Tributaries started in 2009 due to concerns that acid groundwater transport from exposed acid sulfate soils could impact the remaining lake water body. Transects comprising 24 piezometers were located in Lake Alexandrina, Lake Albert, and Currency Creek (Figure 12). At each location except Currency Creek, the piezometers were positioned along a transect perpendicular to the shoreline. Each transect consisted of four sites, spaced at 75 m intervals at Point Sturt (transect length 225 m) and 50 m at the Campbell Park and Windmill locations (transect length 150 m). At Currency Creek, the whole tributary embayment was exposed and three piezometers were installed in a transect parallel to the shoreline. For further details on sampling methods, piezometer construction, installation and bore hole logs see Earth Systems (2010), Hamilton *et al* (2014b) and Leyden *et al* (2016).

Sampling was conducted on a monthly basis until April 2011 and at approximately quarterly intervals thereafter. Prior to sampling, piezometers were purged using a Solinst™ peristaltic pump connected through a flow cell at Lake Albert and Lake Alexandrina sites, and a 1-m bailer at Currency Creek. At least three well volumes were removed from each piezometer and sampling was conducted when EC, pH and temperature were stable, as per standard groundwater sampling techniques.

Post-purging, the groundwater was bottled for laboratory testing, and field analysis was also conducted using a calibrated YSI Pro Plus™ multi-meter. Data logging of groundwater levels and sediment moisture was also undertaken up until 2011. Due to the surface water (lake water) covering the well casings when river inflows dramatically increased the lake levels in late 2010, a modified groundwater sampling technique involving a piezometer extension above surface water levels was required from February 2011 (see Leyden *et al* 2016 for further details).

For the list of parameters analysed please see Appendix 1.

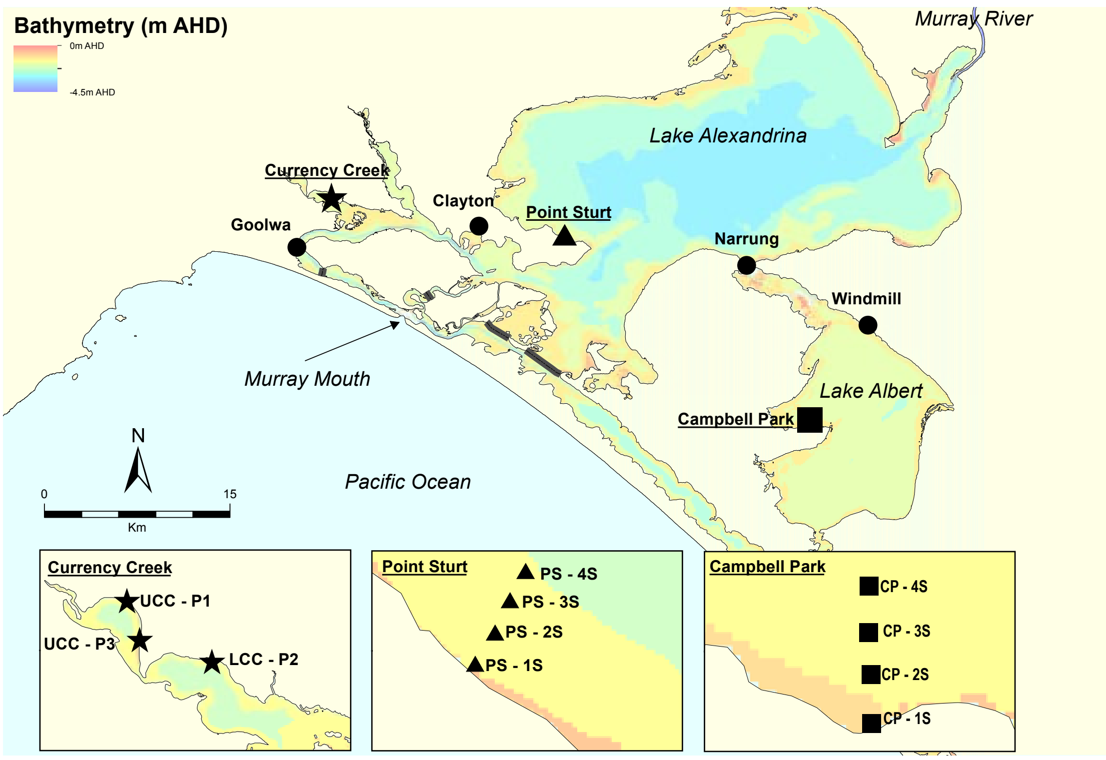
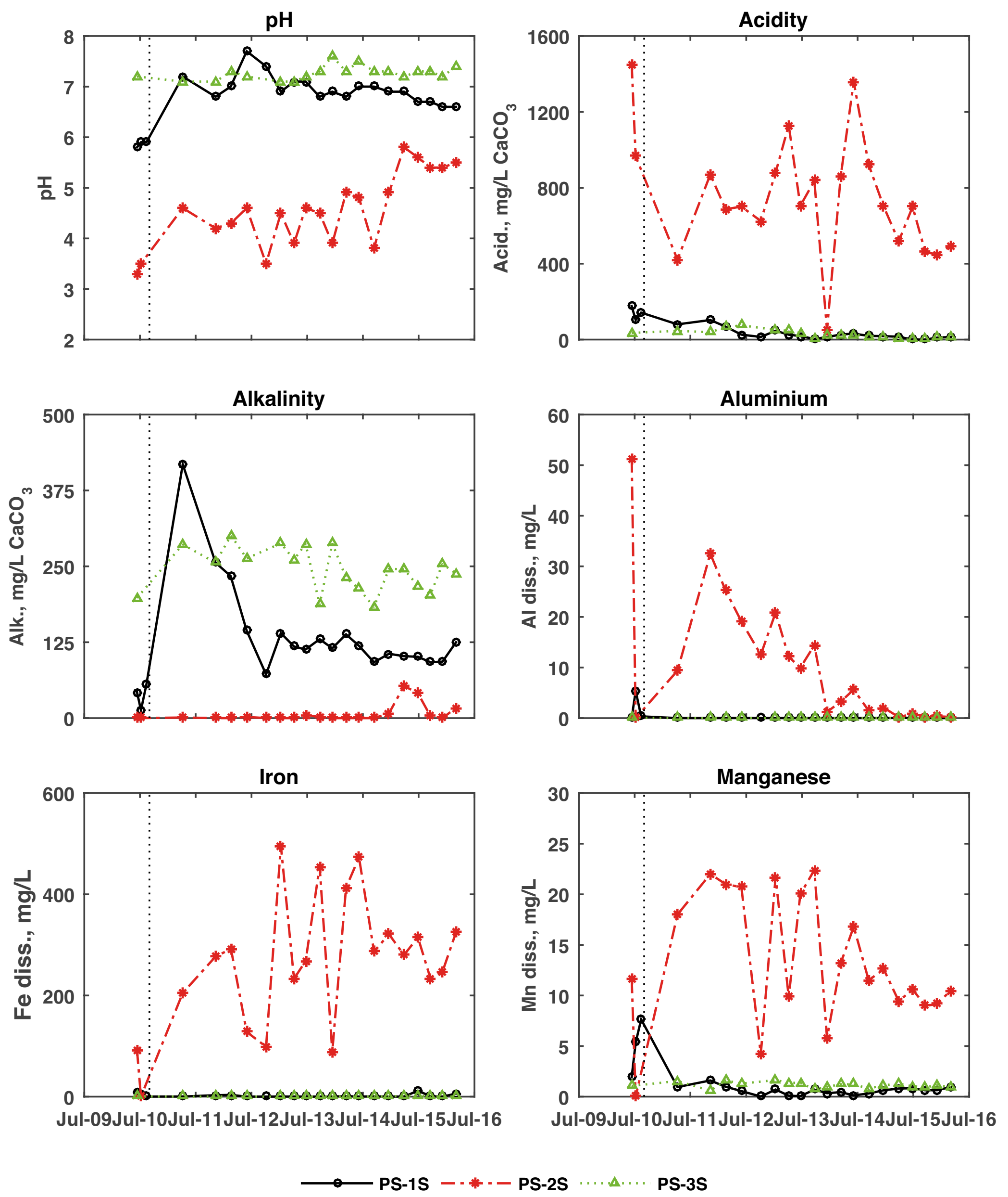


Figure 12 – Map of Lower Lakes groundwater monitoring sites, Currency Creek, Point Sturt and Campbell Park.

Findings

- Acidic groundwater (pH 3–5) was recorded at three of the four piezometer locations (Point Sturt, Campbell Park and Currency Creek) in 2009 (Figure 13). The acidic groundwater (0.5–2 m below lake bed) at these sites is likely to have originated from vertical transport of acid from the upper oxidised sediment layer formed during the drought.
- Acidic shallow groundwater with high dissolved metal levels has persisted at many sites for over four years following re-inundation post-drought (see Figure 13 for Point Sturt site and Leyden *et al* 2016).
- Groundwater hydraulic head gradients were low, indicating there was limited potential for groundwater flux to the lake although gradients temporarily increased during high rainfall events (Leyden *et al* 2016). The hydraulic gradients at all locations were dynamic with complex relationships and transport processes along the nearshore environment (Cook *et al* 2011; Cook and Mosley 2012).
- Detailed groundwater quality and transport processes monitored by the EPA in the CLLMM region is covered by Leyden *et al* (2016), expanding further on these findings.

Figure 13 – pH, acidity, alkalinity, dissolved metals (aluminium, iron, manganese) in groundwater at Point Sturt (Lake Alexandrina) between 2009 and 2016. The vertical dotted line represents the return of surface water levels to pre-drought averages in September 2010.



2.4 Coorong and Murray Mouth – ambient monitoring

Aims

- To assess Coorong-wide ambient water quality.
- To provide water quality data to support the *Ruppia* translocation project.

Methods

Quarterly water quality monitoring was undertaken by boat, sampling at eight sites in the North and South lagoons of the Coorong from July 2014 until January 2016 (Figure 14). Due to the distance involved and the shallow water level in the South Lagoon, sampling was undertaken by two boats on the same day, commencing at opposite ends on the Coorong. Samples were taken for laboratory assessment, and field tests were conducted at all sites. Continuous water quality measurements were made along the Coorong from which salinity transect maps were created which clearly display the large differences in salinity along the length of the Coorong.

The method of water testing for transect maps mentioned in section 2.1 was varied for use on an inflatable dinghy used in the shallow waters of the southern lagoon. An in-line pump powered by an external battery was connected to a water take off tube to allow constant flow to the water quality meter, even when travelling at slow speeds. Later, a filter system was installed to prevent algal blockage.

For the list of parameters analysed please see Appendix 1.

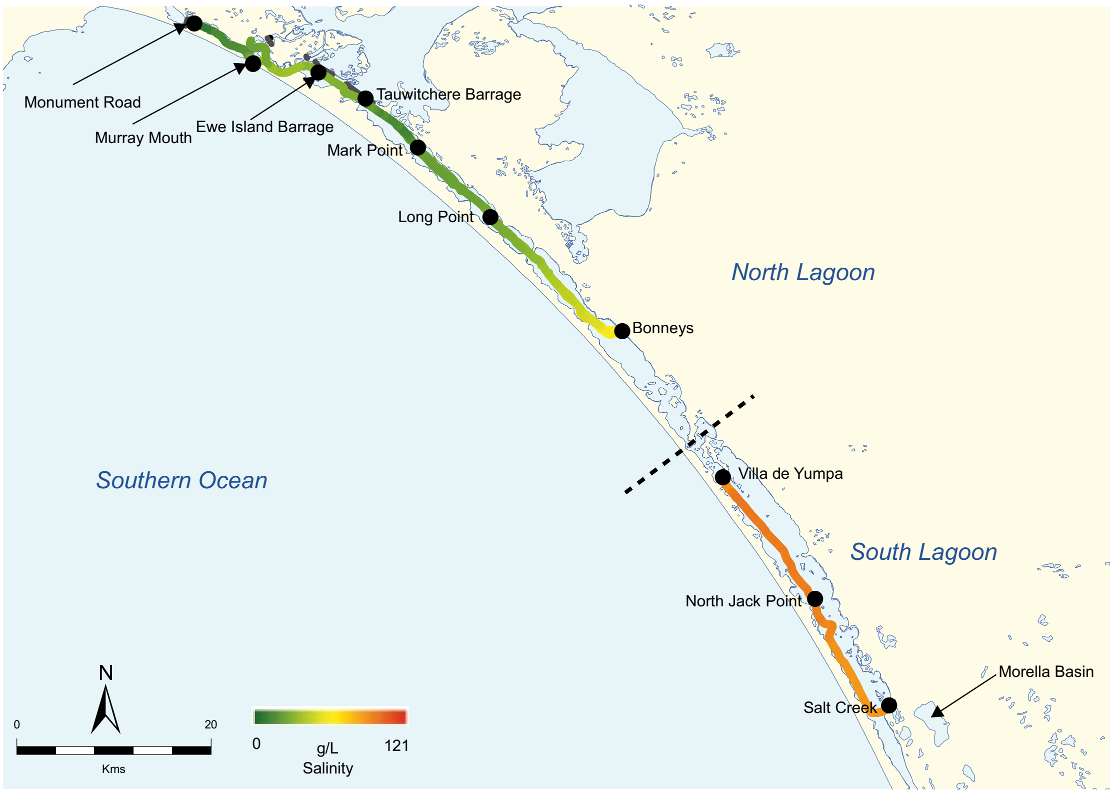
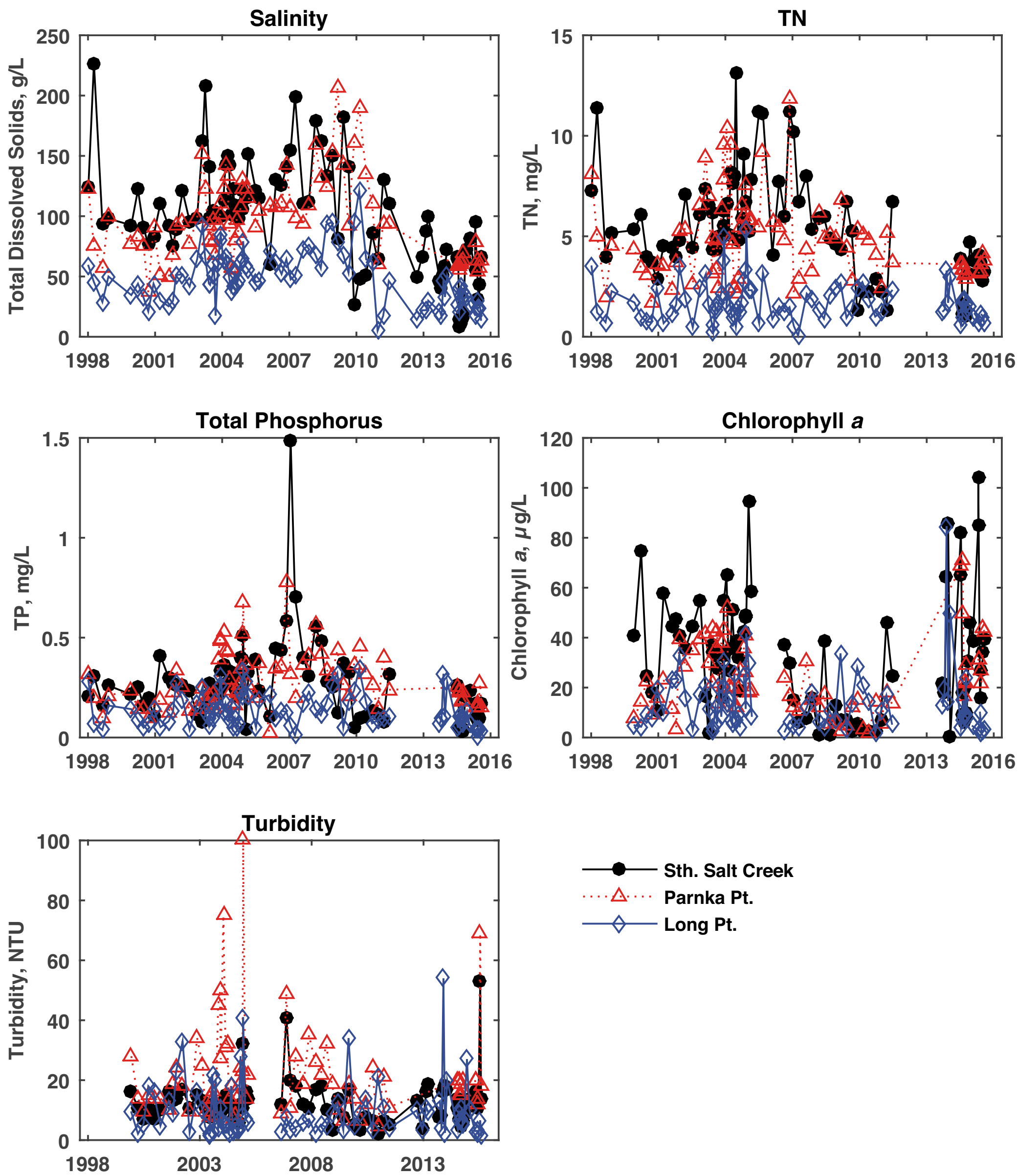


Figure 14
Map of Coorong ambient monitoring sites, with salinity transect from January 2015.

Findings

- The water quality data from the Coorong provided vital links with a number of other recovery program initiatives. Salinity conditions (including their rate of change) and nutrient concentrations influence the relative growth of seagrass and filamentous algae in the Coorong. Assessment of the overlying water quality enabled an understanding of whether conditions were suitable for *Ruppia* health. The data was incorporated into a number of management tools for the ongoing stewardship of the wetland.
- Data from the region was synthesised to inform long-term water quality changes. Salinity, TN and TP increased significantly from 2004 to 2010, during the Millennium Drought period (Figure 15). Chlorophyll *a* and turbidity were lower during the extreme drought period from 2007 to 2010 which is likely due to lack of nutrient supply for algal production and high salinities resulting in particle aggregation. The return of higher River Murray flows and releases through the barrages in late 2010 resulted in decreasing salinity, TN and TP, while chlorophyll *a* and turbidity increased. For further details see publications by Mosley (2015) and Oliver *et al* (2013, 2014, 2015).

Figure 15 – Electrical conductivity, TN, TP, turbidity, chlorophyll *a* and pH in the Coorong from 1998 to 2016.

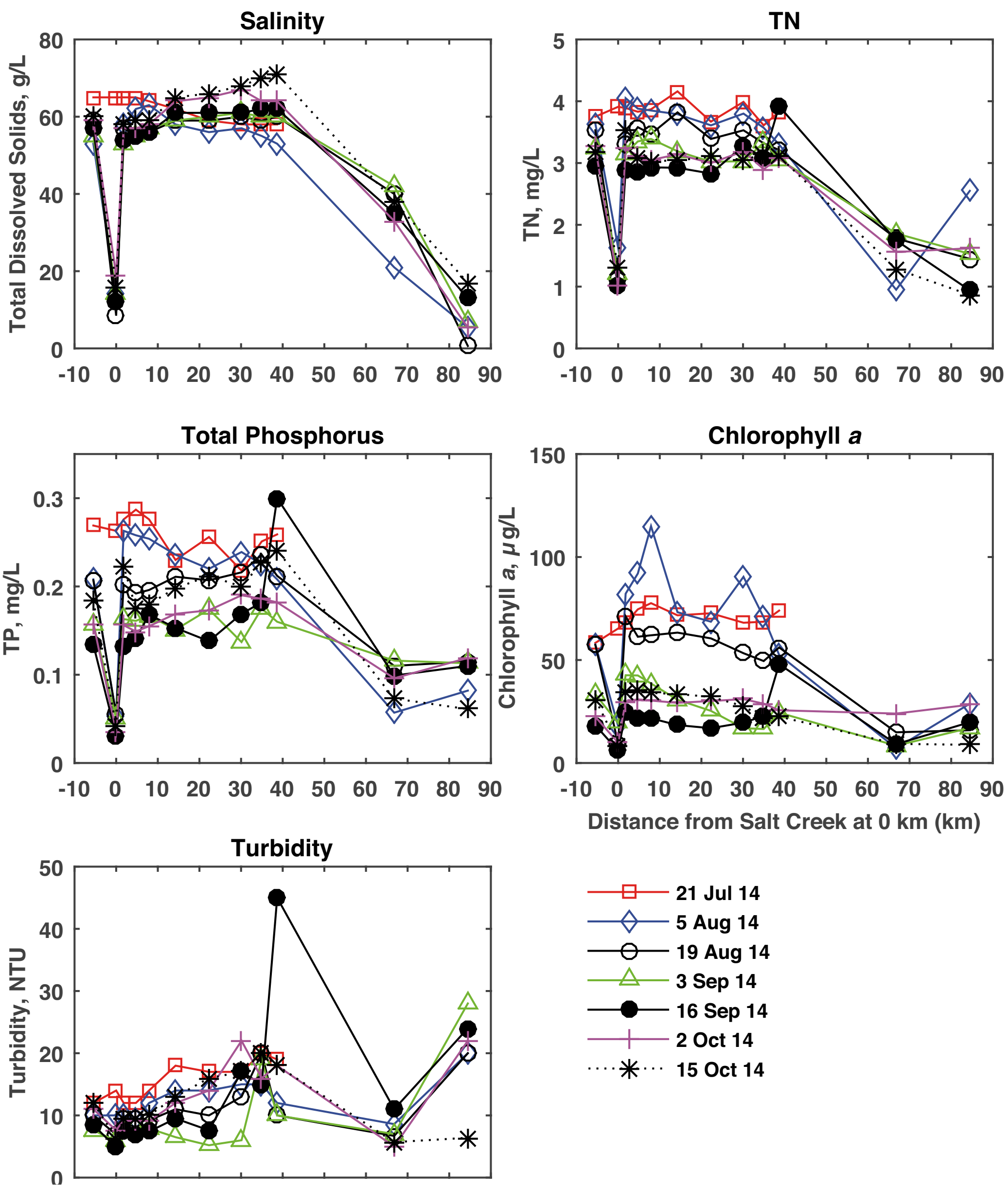


2.5 Coorong and Murray Mouth – event based monitoring

Aims

- To improve understanding of the load of nutrients (nitrogen and phosphorus species) entering the Coorong South Lagoon via Morella Basin water releases from Salt Creek.
- To improve understanding of the fate of nutrients inflowing at Salt Creek within the Coorong.
- To improve understanding of the spatial and temporal effect of Salt Creek inflows on salinity within the Coorong.
- To monitor the effects of barrage releases on Murray Mouth and Coorong salinity.
- To provide samples of phytoplankton and zooplankton for allied studies, and associated metadata on water quality.

Figure 16
–
Salinity, total nitrogen (TN) and phosphorus (TP), chlorophyll *a*, and turbidity in the Coorong during the 2014 Morella Basin release. Distance from the Morella Basin discharge into the Coorong via Salt Creek is shown on the x axis. See Appendix 1 for site names in regard to distance from Salt Creek.



Methods

Morella release events – a study area map showing the sample sites is shown in Figure 16. Sites extended from near Tauwitchere barrage in the north, then south to the vicinity of Salt Creek. Samples were also collected in Salt Creek at the flow gauge, composite sampler or the Morella Basin outlet regulator when there was water available. Samples in the Coorong were collected by boat and salinity transect maps were created, except when water levels were unnavigable and were then collected by driving to sites and wading into the water. Sampling was undertaken fortnightly during winter release events in 2013, 2014 and 2015, and monthly in 2016 from January to June.

Murray Mouth events – salinity sampling was conducted to determine the effect of higher volume (82 GL over approximately one week) barrage releases on Coorong and Murray Mouth water quality. Transects and depth profiles were taken by boat. The aim of the trial was to inform development of optimal barrage release strategies for potential operations in the future.

Zooplankton collection – This was conducted by the EPA across the CLLMM region from 2012 to 2014 on behalf of the University of Adelaide, with water quality samples taken simultaneously at all sites. Sites in the Lower Lakes and Coorong were sampled by boat, while the tributaries were sampled from shore. Two samples were collected at each site using two different methods. One was a 30-µm mesh tow net pulled over 5 metres just below the water surface, and the other was a 10-litre box trap sampled approximately 0.5 metres below the surface, which was then filtered through a 30-µm net. Excess water was drained from the sample jars and the nets were washed down with ethanol to wash the zooplankton into the jar and preserve the sample. These samples were processed and data assessed by the University of Adelaide (see Shiel *et al* 2013a, b for more details).

For the list of parameters analysed please see Appendix 1.

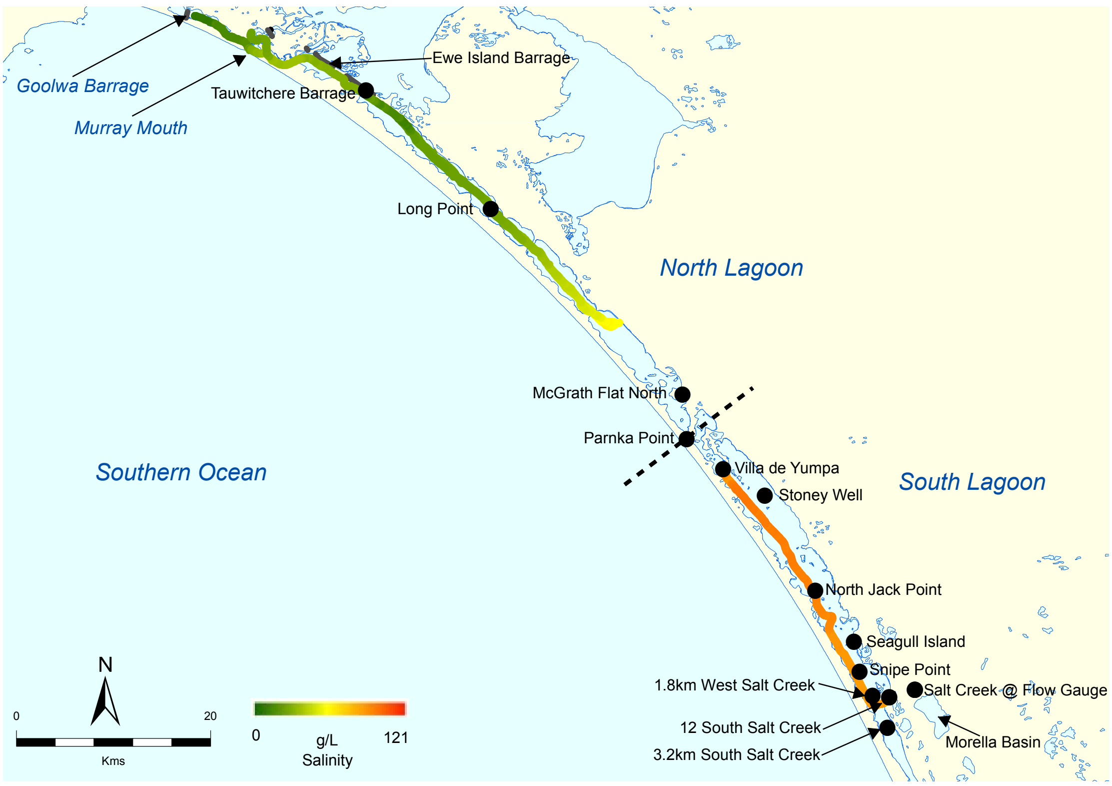
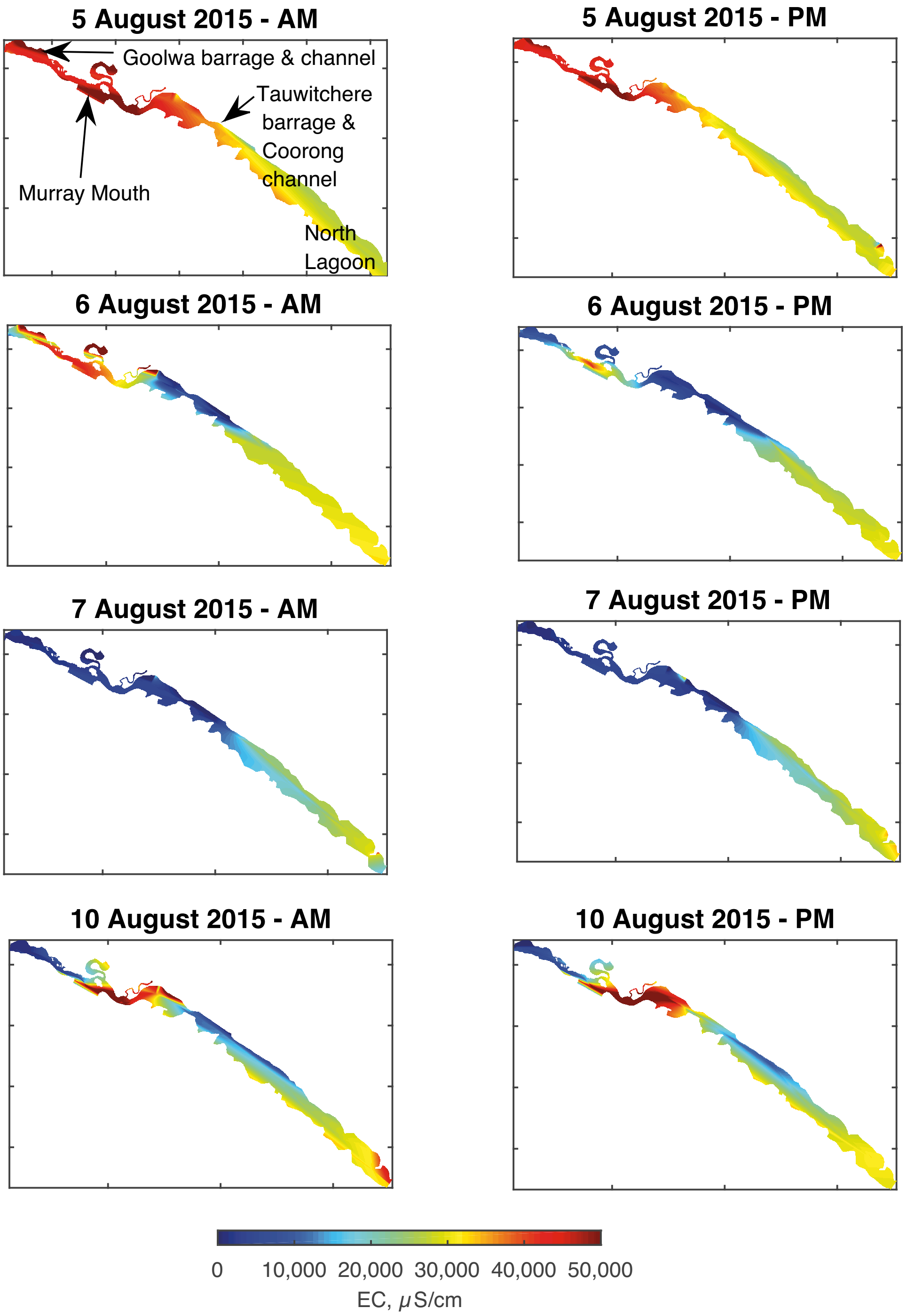


Figure 17 – Salinity plotted using continuous salinity transect data collected in January 2015. Coorong Morella release event sample sites labelled with black circles.

Figure 18 – Salinity measured continuously along a transect from Goolwa Barrage to the North Lagoon of the Coorong (at Long Point) during a barrage water release event.



Azolla sp. and *Baumea articulata* from the Finniss region.
Credit: Goolwa to Wellington Local Action Planning Association

‘Barrage releases and storm events significantly altered the salinity pattern. Salt water is displaced from Goolwa, Mundoo and Coorong channels following barrage releases’

Findings

- The release of water from Morella Basin to the Coorong did not appear to have any negative water quality effects (e.g. increased algal or nutrient levels). In contrast, the most comprehensive dataset in 2014 indicated significant improvements in water quality for nutrients, chlorophyll and salinity along the South Lagoon (Figure 16). This effect appears to relate to the inflow of Morella Basin water driving export of South Lagoon water to the North Lagoon (Mosley 2015).

- Increase in dissolved/bio-available nutrients only occurred in the immediate mixing zone, which extended for less than 2 km from where Salt Creek enters the Coorong.

- Continuous profiling of salinity was useful for determining the longitudinal salinity patterns along the whole Coorong (Figure 17). Barrage releases and storm events significantly altered the salinity pattern. Salt water is displaced from Goolwa, Mundoo and Coorong channels following barrage releases. Storm events typically push water from the Murray Mouth into the Coorong. If barrage releases are occurring this can produce salinity improvements in the Murray Mouth region through to the North and South Lagoons. This effect is particularly apparent during southerly storm events when water levels are elevated at the Murray Mouth and fresher water released from the barrages is pushed towards the South Lagoon (Mosley 2016). For example, the longitudinal patterns in surface salinity before, during and after a barrage release event in August 2015 are shown in Figure 18. The marked decrease in salinity in the Goolwa, Mundoo and Coorong channels during the release can be clearly seen on 6–7 August plots. The reduction in salinity in the entire Goolwa and Coorong channels during the release is approximately 20,000 to 45,000 µS/cm (Figure 18). The zone of fresher salinities arising from the barrage discharges also spreads in a south easterly direction along the North Lagoon. On 10 August when the release was stopped, seawater is observed flowing in from the Murray Mouth and spreading up the Goolwa and Coorong channels. This also appears to push fresher water along the North Lagoon with the largest reduction in salinity occurring after the continuous monitoring transects were completed (see Mosley 2016 for more details).

3 Summary of management learnings

3.1 Value of the water quality monitoring program

The CLLMM water quality monitoring program was successful and delivered critical information for management of the region. The data has been used for the following purposes:

- Provision of data for DEWNR and other organisations to underpin and validate research throughout the region (including Lake Albert scoping study, flow scenario calculations).
- Validation of water quality modelling of salinity and acidification risks that led to installation of critical infrastructure such as bunds, pipelines and regulators to prevent risk to industries, community and the environment.
- Interpreting and dissemination of information throughout the CLLMM and wider community for multiple interest groups (scientific, commercial and community).
- Assessment of impacts of regulator construction and operation.
- Identification and management of acidification events across the Lower Lakes region.
- Assessment against alkalinity triggers in real-time management strategy to prevent acidification.
- Determining the effects of the Millennium Drought on system-wide water quality and recovery timescales.
- Determining impacts on freshwater aquatic ecosystems in the Lower Lakes from salinity increases during the Millennium Drought.
- Water quality risk assessment for the Coorong: South East Flows Restoration Project.
- Informing assessment of risks to public health via monitoring of toxic algal levels.
- Assessment of risks to river drinking water sources via seiching of lake water upstream.
- Monitoring of salt transport between Lake Alexandrina and Lake Albert.
- Calculation of salt loads delivered over the barrages.
- Assessing suitability of irrigation for various crops and livestock.
- Assessing suitability of use for domestic water supplies.
- Determining effect of Morella Basin and barrage releases on Coorong water quality.
- Continuous transect data provided to DEWNR and community to understand spatial variations in salinity and water mixing processes.
- Assessment of dredging impacts at the Narrung Narrows.
- Assessment of water quality during regulator construction and removal at Narrung, Clayton and Currency Creek.
- Informing *Ruppia* and vegetation translocation projects of local water quality.
- Provision of data to aquatic ecological (*Ruppia*, bird, frog, fish, etc.) monitoring projects undertaken by DEWNR, other organisations and the community.
- Assessment of long-term trends in water quality which highlighted deterioration over time (Oliver *et al* 2015).
- Informing assessment of acidic fluxes from previously acidified sediments in Boggy and Hunter's creeks.
- Contribute to the basin-wide assessment of a low dissolved oxygen 'blackwater' event (Whitworth *et al* 2013).
- Encouraging inter-governmental relationships to accomplish best monitoring practice during events of environmental significance.
- Publishing research in numerous literature formats to improve future understanding of anthropogenic impacts on a terminal wetland under drought conditions and recovery timescales.

3.2 Water quality impacts on environmental and socio-economic values during the Millennium Drought

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Salinity increases during the Millennium Drought were very large, (up to 10,000–30,000 µS/cm, see Figure 7 and Figure 8), particularly in Lake Albert and the southern regions of Lake Alexandrina, furthest from the river inflow and closest to the barrages which leaked seawater into the lakes (due to sea levels being higher than the lakes for much of the drought period).

As a consequence of these salinity increases, major losses of freshwater species occurred (Nielsen *et al* 2003; EPA 2010), with a shift from freshwater dominated assemblages to marine and hypersaline assemblages. Large-scale death of freshwater mussels along the Lower Lakes shoreline were a highly visible indicator of salinity rises and water level recession, leaving them stranded. The salinity increases also enabled the marine tubeworm, *Ficopomatus enigmaticus* to colonise the Lower Lakes, and resulted in mortality of turtles by the smothering of their shells (Dittman *et al* 2009).

With the salinity increases, the lake water also became unsuitable for irrigation [e.g. limits of >1,000–5,000 µS/cm for many crops and soil types including pasture, lucerne and vines (ANZECC 2000)]. Coupled with the water recession stranding irrigation channels and pipes, this had catastrophic impacts with many irrigators ceasing operations, some of which have not recommenced post-drought. New pipelines were installed for stock and domestic water around Lake Albert (sourcing water from the River Murray at Tailem Bend) and an irrigation pipeline was installed from Jervois on the River Murray to Langhorne Creek. These multi-million dollar projects were required as a direct result of saline water, and to increase water security.

The acidification events in the Lower Lakes region imposed significant management challenges and costs. The direct acidification management interventions (limestone dosing, construction of bunds or temporary regulators and associated pumping) were estimated to cost more than $50 million (Mosley *et al* 2014). The acidification also impacted ecology with shells of mussels dissolving in acidic water and some toxic effects evident after reflooding of exposed sediment (Corbin *et al* 2014, 2015).

3.3 Prolonged recovery of water quality from the Millennium Drought

The water quality in the CLLMM region has still not completely recovered from the Millennium Drought.

The monitoring program results show that despite hydrological recovery with return of flows and water levels to 'normal', the surface and groundwater quality in large parts of the region has not recovered, and in some areas remains of poor quality. For example, groundwater under parts of Lakes Alexandrina and Albert is still acidic in several locations due to acid sulfate soil exposure during the extreme drought period. Some recovery is occurring although pH is still below the ANZECC guideline of 6.5 at many sites (see above section and Leyden *et al* 2016). Community monitoring by the Lakes Hub of acid sulfate soils has shown similar findings of persistent acidity in some locations that were exposed during the drought (Thomas *et al* 2016).

Water quality and phytoplankton community structures in Lake Albert have not recovered to pre-drought conditions, with elevated salinity, nutrient and cyanobacteria levels (Oliver *et al* 2013, 2014, 2015). This is predominately due to the terminal nature of the lake limiting water exchange. The implications of these results are that acid sulfate soils, water quality, ecological and infrastructure impacts may not recover during inter-drought periods.

Campbell Park, Lake Albert. Credit: EPA

3.4 Water quality management triggers

Triggers for early warning of acidification are listed in the Drought Emergency Framework for lakes Alexandrina and Albert (Table 1, MDBA 2014) and were originally developed by Mosley (2008).

Various actions are recommended in this framework depended on water levels and quality. Increased water quality monitoring frequency and number of sites to appropriately track key triggers is critical. During the Millennium Drought acidification risk period of 2008—10 monitoring occurred daily to weekly at key locations. Field-based monitoring of pH, alkalinity, acidity, salinity and dissolved oxygen was useful for informing management actions as data was immediately available to use. Comparison with laboratory data showed high consistency for most parameters (Mosley *et al* 2013, r^2>0.97 for pH, EC, alkalinity and r^2=0.54 for acidity).

Acidification is present in the water body when the pH is less than 6.5 (ie below ANZECC guidelines of 6.5—9.0). Early warning and prediction are important because the acidification impacts can be immediate and severe, and difficult to recover from. It is also important to note that acid sulfate soil materials exposed on the lake margins are a hazard to aquatic fauna, infrastructure and vegetation. When these materials rewet (e.g. following rainfall or lake refill) metals and acidity can diffuse or be leached into the surrounding water.

Table 1 – Commencement triggers for aerial limestone dosing (over a minimum of two locations for two consecutive days; pH < 7.5) [from MDBA 2014].

Trigger value	Proposed action
Alkalinity >100 mg/L but >20% fall in alkalinity compared to lake concentrations	Increase monitoring rate of alkalinity change (ambient and event-based monitoring)
Alkalinity <100 mg/L and >20% fall in alkalinity compared to lake concentrations	• Monitor alkalinity weekly • Get dosing equipment ready
Alkalinity <25 mg/L and acidity present in the waterbody	• Commence aerial limestone dosing • Monitor application rate • Monitor upstream and downstream water quality daily
Acidity >100 mg/L	• Continue larger scale aerial limestone dosing to counter acidity • Monitor application rate • Monitor upstream and downstream water quality daily
Acidity >1,000 mg/L	• Increase rate of limestone application • Monitor application rate • Monitor upstream and downstream water quality daily • Commence additional application of limestone at effected areas

Groundwater monitoring under Lake Albert post-drought. Credit: EPA

'The relationship of ecological impacts to these water quality values also requires further assessment in regard to target setting'

The water level management targets to prevent whole of lake acidification are greater than −1.75m AHD for Lake Alexandrina and greater than -0.75m AHD for Lake Albert (Hipsey *et al* 2014; MDBA 2014). The risk profile substantially increases past these water levels and also with prolonged time that the water level is near these levels. The Basin Plan (MDBA 2010) water level targets are greater than zero metres AHD 100% of the time and greater than +0.4 m AHD 95% of the time which should protect against exposing as large an area of acid sulphate soils in future. Sediment acidification is also an important issue as it will impact the ability of benthic ecosystems to recover (Corbin *et al* 2014, 2015).

Characteristic water quality values (median, 1st, 5th, 95th, 99th percentiles) for the CLLMM region are shown in Table 2 (adapted from Oliver *et al* 2015). These provide a guide to the range of concentrations of water quality parameters over the past 30 to 40 years (excluding the extreme drought period). These values can be used to assess water quality monitoring data to determine if water quality is in 'normal' or 'abnormal' ranges. For example, the water quality in the Millennium Drought exceeded the concentrations in the entire previous data set. Exceeding the 99th percentile values in Table 2, and/or 1st percentile for parameters such as pH and dissolved oxygen, can be considered an extreme water quality event. The values can also be used as a management trigger, e.g. exceedance of the 95th percentile for salinity would indicate a potential problem is developing while exceedance of the 99th percentile for salinity would indicate a major issue has developed.

Water quality has been noted to be deteriorating over time for many parameters in the CLLMM region e.g. increasing EC, TN, and chlorophyll *a* in the Lower Lakes over the last 20–40 years (Oliver *et al* 2015). The Lower Lakes and Coorong are currently highly eutrophic (nutrient and algal rich) which is likely a consequence of agricultural and other pollution inputs from the whole Murray–Darling Basin, and a marked reduction in flows which aid flushing. Setting of formal water quality targets requires consideration of this issue, as it may be justified to set targets which improve water quality, rather than just maintain it in the ranges shown in Table 2. The relationship of ecological impacts to these water quality values also requires further assessment in regard to target setting. Management, monitoring and reporting in regard to the ecological character of the Ramsar site by DEWNR will address this relationship.

Aerial limestone dosing of acidified water in Currency Creek. Credit: EPA

Table 2 – Characteristic descriptors of water quality parameters in the CLLMM; values of the Median (50th percentile) and 1st, 5th, 95th and 99th percentiles. Blanks indicate a lack of suitable data. Data excludes the learnings from, and implications of, management actions relating to water quality.

	Flow over Lock 1 (ML/d)	Level (mAHD)	EC (µS/cm)	Turbidity (NTU)	TP (µg/L)	TN (µg/L)	DO (mg/L)	Chlorophyll *a* (µg/L)
Lake Alexandrina								
Median	8,062	0.77	660	60.5	144.2	1,150	9.2	22.6
1st %	397	0.55	284	17.4	32.9	513	6.2	13.3
5th %	1,301	0.61	350	20.9	56	720	7.6	14.2
95th %	72,400	0.87	1,200	207.8	322.4	2,000	10.9	41.2
99th %	119,432	0.9	1,486	290.7	419.9	2,526	11.8	46
Lake Albert								
Median		0.75	1,383	48.4	91.3	1,458	9.5	36.8
1st %		0.49	1,075	8.3	42.8	865	7	17.8
5th %		0.56	1,150	13	58.9	1,049	7.2	20.2
95th %		0.89	1,786	158	288	2,580	11.9	70.6
99th %		0.97	1,987	250.3	431.5	3,364	13.3	101.7
Coorong North								
Median		0.29	37.5	9.6	158.6	2,295		28.8
1st %		–0.12	7.9	3.6	58.8	803		9.9
5th %		–0.03	13	4.3	72	1,064		13.3
95th %		0.8	62.8	31.9	314	4,604		56.5
99th %		0.97	72.7	37.4	362.1	5,975		71
Coorong South								
Median		0.28	74.8	16.3	288	5,399		56.7
1st %		–0.35	28.1	6.2	132	2,282		9.2
5th %		–0.24	36.3	7.8	151	3,095		12.4
95th %		0.82	110.9	28.5	510	8,837		86
99th %		0.99	128.1	37.1	718	10,561		108.2

3.5 Management actions relating to water quality

Localised and lake-wide prevention of acidification events via water level management was achieved. The Lake Albert pumping and the Goolwa Channel Water Level Management Project prevented acidification in localised areas.

Unless fresh water is available, these types of management actions are not possible. Modelling suggests the whole of Lake Albert would have acidified without the management actions that maintained water levels via pumping (Hipsey *et al* 2014). Localised management of acidification using aerial dosing of limestone was successful in Currency Creek and Boggy Lake. These management actions did not prevent other water quality impacts such as salinity increases.

Acid sulfate soil impacts have also been persistent since the drought; groundwater is still acidic under the Lower Lakes five years after water levels returned to normal (Figure 13, Leyden *et al* 2016). Soil is also still acidic in many regions (Thomas *et al* 2016). Dissolved metal acidity impacts are persistent (still ongoing at low levels) in Boggy and Hunter's creeks after the drought has ended (Figure 11).

High river flows in 2010 and 2011 were able to recover Lake Alexandrina water quality quite quickly. However, Lake Albert water quality was not able to recover as fast. The slow recovery is influenced by the terminal nature of the lake which limits water exchanges, leaving it reliant on seiching and diffusion to and from Lake Alexandrina. Hence prevention of water quality impacts in Lake Albert is important. Lake level cycling is beneficial but is a long-term strategy and dependent on availability of environmental flows.

'Modelling suggests the whole of Lake Albert would have acidified without the management actions that maintained water levels via pumping (Hipsey et al 2014)'

3.6 Practical considerations for future monitoring of droughts

Practical learnings for future consideration were:

- Sample sites had to be moved when lake levels receded and then returned to normal.
- The number of sample sites had to be increased from the pre-drought number due to a larger spatial variation in water quality than expected (Aldridge *et al* 2009).
- Changes to sampling method were necessary when the water returned to some areas e.g. groundwater piezometer sampling, change from boat sampling to wading.
- Sampling was very difficult and specialist equipment such as kayaks, quad bikes, and hovercrafts were required to access shallow water and soft mud areas.
- Data was entered into spreadsheets within a day of sampling, and unusual water quality events such as acidification, water discolouration, and fish die-off were reported immediately for management action consideration.
- Risk maps and modelling were useful to predict areas most at risk of water quality impacts (Hipsey *et al* 2014).
- Field based monitoring of pH, acidity and alkalinity was very useful in relation to acidification management and compared well to laboratory data for many parameters (Mosley *et al* 2013).
- Depth profiling gave important information in some locations where stratification due to salinity or temperature dynamics was present.

Monitoring of water quality and acid sulfate soils in the drought using a hovercraft
Credit: EPA

3.7 Importance of maintaining environmental flows and Basin Plan implementation

Water quality in the CLLMM region is highly dependent on flows from the Murray–Darling Basin.

The extreme water quality impacts seen during the Millennium Drought were driven by the lowest flows and water levels on record (Mosley *et al* 2012, 2014). This had devastating impacts on ecology and socio-economic values in the region. A range of anthropogenic impacts such as over-extraction, flow regulation and diversion, as well as biological impacts such as land clearing have reduced the resilience of the Murray—Darling Basin to deal with drought conditions.

Under the Basin Plan implementation, water is being recovered from irrigators for environmental purposes. The modelling for the Basin Plan suggests that the flows and water levels in the Millennium Drought will not re-occur in the CLLMM (i.e. zero m AHD is the lowest level predicted, Basin Plan 2012 Schedule 5 target). The availability of this environmental water is critical, as it should prevent both extreme water quality impacts as seen in the Millennium Drought and further long term deterioration in water quality observed due to a lack of flushing. However, median river flows in the southern Murray–Darling Basin are predicted to decline further over the next 20 years (13% decrease by 2030) due to climate change (CSIRO 2008). It remains to be seen whether the Basin Plan can protect the CLLMM region over the long term climate changes predicted.

Divisible by three, Coorong Credit: Patrick Boylan

‘Median river flows in the southern Murray–Darling Basin are predicted to decline further over the next 20 years (13% decrease by 2030) due to climate change (CSIRO 2008)’

Goolwa Barrage.
Credit:
Beth Nixon

4 Recommendations

Recommendations

The Department of Environment, Water and Natural Resources and other key stakeholders should consider the following recommendations:

- Ambient water quality monitoring should be continued at historical sites and increased in frequency, parameters (e.g. add metals and acidity) and site number during low flow or lake drawdown events.
- At-risk areas identified in this report should be first priority for monitoring in future low flow or lake drawdown events.
- Annual assessment of previously and currently acidified sites for sediment, surface and ground water quality (e.g. Boggy and Hunters Creek, Currency Creek, Point Sturt, Campbell Park) should be undertaken.
- Existing CLLMM water quality triggers should be revised and included in the Basin Plan and state guidelines. These need to consider the deterioration in water quality that has been observed over time and the ecological impacts

4.1 Summary

In summary, the water quality monitoring program has been highly successful in addressing essential information needs to underpin management of the CLLMM region. The Millennium Drought had major negative effects on water quality with increased salinity, nutrients and acidification. Recovery from the drought has been prolonged and is ongoing for water quality in many parts of the region, in particular Lake Albert and acidified groundwater sites.

The water quality monitoring program was critical for informing management interventions and helped keep local communities aware of the water quality in their region. The program provided greater certainty for future management of the water quality in the region. The program has also filled critical knowledge gaps relating to water quality interactions and processes in the region. Continuing water quality monitoring is highly valuable and important in order to protect and manage the CLLMM region.

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5 Acknowledgements

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Loveday Bay
Credit: EPA

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Appendix 1

Program components and list of parameters analysed by laboratory

Lower Lakes and Tributaries — ambient

Samples were collected for laboratory analysis of: salinity, pH, alkalinity, conductivity and total dissolved solids (TDS), turbidity, nutrients, total nitrogen, TN; ammonia, NH4; TKN as N, oxidised nitrogen, NOx; total phosphorus, TP; soluble/filtered reactive phosphorus, FRP), chloride, silica, chlorophyll *a* & *b*, algal speciation (at selected sites), dissolved oxygen, colour, dissolved organic carbon, and total and soluble (<0.4 µm) metals (aluminium, iron). Additional field parameters were also measured including conductivity/TDS, pH, dissolved oxygen, oxidation—reduction potential (ORP), acidity and alkalinity

Lower Lakes and Tributaries – event based

Samples were collected for laboratory analysis of: aluminium (total, soluble and acid soluble), arsenic (total and soluble), calcium, iron (total and soluble), magnesium, manganese (total and soluble), potassium, sodium, sulfate, hardness (as CaCO3), chloride, fluoride, silica reactive, alkalinity, conductivity, total dissolved solids (TDS), pH, turbidity, and acidity. Additional field parameters were also measured including conductivity/TDS, pH, dissolved oxygen, oxidation-reduction potential (ORP), acidity and alkalinity.

Lower Lakes and Tributaries – groundwater

Samples were collected for laboratory analysis of: salinity, pH, alkalinity, acidity, total and soluble (<0.4 µm) metals (aluminium, iron, manganese), major ions (sulfate, chloride, calcium, potassium, and sodium). Additional field parameters were also measured including conductivity/TDS, pH, dissolved oxygen, oxidation-reduction potential (ORP), acidity and alkalinity.

Coorong — ambient

Samples were collected for laboratory analysis of: salinity/total dissolved solids (TDS), temperature, pH, turbidity, nutrients (total nitrogen, TN; oxidised nitrogen, NOx; total phosphorus, TP; filterable reactive phosphorus, FRP) and chlorophyll *a*. Additional field parameters were also measured including conductivity/TDS, pH, dissolved oxygen, oxidation—reduction potential (ORP), acidity and alkalinity.

Coorong — event based

Samples were collected for laboratory analysis of: conductivity/total dissolved solids (TDS),TKN, total phosphorus, filterable reactive phosphorus (FRP), reactive silica, chloride, ammonia as N, nitrate and nitrite as N, and chlorophyll *a* and *b*. In 2015/16 TOC and DOC were added. During zooplankton collection a dominant suite of algal taxa (blue green, diatoms, and green) were also included laboratory analysis. Additional field parameters were also measured including: temperature, conductivity/TDS, pH, dissolved oxygen, oxidation-reduction potential (ORP), acidity and alkalinity.

Lake Albert,
Credit: DEWNR

List of sample sites, their location and distance northwards from Salt Creek (point of Morella Basin discharge to the Coorong via Salt Creek)

Site name	Region	Easting	Northing	Approximate distance north along Coorong from Salt Creek (km)
Morella Basin at outlet regulator	Coorong	380179	6001380	Not applicable
Morella Creek at gauge	Coorong	378811	6001360	Not applicable
3.2 km south Salt Creek	Coorong	377570	5997290	-5.48
12 Sth Salt Creek	Coorong	377597	6000430	0
1.8 km west Salt Creek	Coorong	375882	6000470	1.80
Snipe Point	Coorong	374406	6002900	4.73
Seagull Island (Policeman's Point)	Coorong	372453	6005680	7.90
10 Nth Jack Point	Coorong	369342	6010970	14.26
Stoney Well	Coorong	365104	6017790	22.29
Villa de Yumpa	Coorong	359175	6022890	30.11
Parnka Point boat ramp	Coorong	355237	6025730	34.96
McGrath Flat north	Coorong	354600	6029390	38.67
3 Long Point	Coorong	333756	6048260	66.78
1 Tauwitchere	Coorong	320219	6059690	84.47

List of sample sites and their location

Site Name	Region	Easting	Northing
Goolwa Barrage	Goolwa Channel	300692	6067199
Dunns Lagoon	Goolwa Channel	313310	6070356
Currency Creek 2	Tributaries	301808	6071433
Finniss River 2	Tributaries	308112	6073435
Hunters Creek 1	Hindmarsh Island	308875	6066444
Boggy Creek 6	Hindmarsh Island	311612	6066862
Milang	Lake Alexandrina	321246	6076714
Point McLeay	Lake Alexandrina	323335	6067399
Middle	Lake Alexandrina	333095	6077956
Poltalloch	Lake Alexandrina	340328	6073420
Jockwar Road	Lake Alexandrina	351450	6083372
Wellington	Lake Alexandrina	353268	6089029
Dog Lake	Lake Alexandrina	332668	6086815
Boggy Lake	Lake Alexandrina	335414	6089677
Loveday Bay	Lake Alexandrina	326364	6061874
PS – 1S (Groundwater)	Lake Alexandrina	321167	6070263
PS – 2S (Groundwater)	Lake Alexandrina	321202	6070330
PS – 3S (Groundwater)	Lake Alexandrina	321228	6070408
UCC – P1 (Groundwater)	Currency Creek	299270	6074127
UCC – P3 (Groundwater)	Currency Creek	299586	6073013
LCC – P2 (Groundwater)	Currency Creek	301321	6072963
CP – 1S (Groundwater)	Lake Albert	341213	6056472
CP – 2S (Groundwater)	Lake Albert	341212	6056516
CP – 3S (Groundwater)	Lake Albert	341176	6056538
CP – 4S (Groundwater)	Lake Albert	341201	6056616
Lake Albert Opening	Lake Albert	344300	6062650
Water Level Recorder	Lake Albert	349301	6058806
Meningie	Lake Albert	348605	6052257
Narrung Narrows	Lake Albert	335447	6068555
Bascombe Bay	Lake Albert	343911	6045207
Monument Road	Coorong	302097	6066373
Murray Mouth	Coorong	308015	6063155
Ewe Island Barrage	Coorong	315213	6062103
Mark Point	Coorong	325762	6054914
Bonneys	Coorong	347969	6037304