Lead in Victorian wetlands study
Preliminary investigation

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Contents

List of figures and tables

Glossary of terms

Alkalinity: the chemical ability of water to neutralise acid.

Bioavailability: the degree to which a substance can be absorbed into a living system or the body of a living thing.

Inductively coupled plasma mass spectrometry: a type of laboratory chemical analysis that is used to measure metals in water and sediment.

In-situ: meaning ‘in the original place’. In-situ environmental measurements are measured in the field, at the place in which they are found in the environment (samples are not taken away to a laboratory).

Guideline value: a measurable quantity (for example, concentration) of a specific chemical, which, if met, represents a level of risk of unacceptable effects occurring to a relevant environmental value or use.

Parameters (water quality): physical, chemical or biological properties of water.

pH: a measure of the acidity or alkalinity of a solution.

Lead: a metal, used in roofing, plumbing, batteries and formerly to make lead shot.

Shot: firearm ammunition; metal pellets contained in shotgun cartridges.

Wastewater: any water that has been adversely affected in quality by anthropogenic (human) influence.

Water quality: refers to the chemical, physical, biological, and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more species and/or to any human need or purpose.

Waterfowl: ducks, geese, or other large aquatic birds, especially when regarded as game.

Wetland: land consisting of marshes or swamps; saturated land, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem.

Waterbody: a collection of water forming a physiographical feature, for example a wetland, lake or reservoir.

Executive summary

Lead-based firearm shot was once used by hunters targeting waterfowl in Victorian wetlands, until it was banned in 1994. Although lead-based shot is no longer used to hunt waterfowl, legacy lead shot remains in wetlands where hunting took place.

In response to community concerns about the presence of lead, Environment Protection Authority Victoria (EPA) sampled water and sediment at several Victorian recreational water bodies during winter 2017.

The purpose of the study was to provide preliminary information about the potential for environmental and health risks from lead remaining in these water bodies, and serve as the basis of further investigation should this be required.

The study objectives were to:

1. identify and sample water bodies that are and were used for waterfowl hunting activities
2. compare results from water and sediment sampling against the relevant standards
3. compare current lead concentrations in water and sediment with results previously reported by EPA in 1989
4. identify whether potential environmental and human health risks exist from the lead in the waterbodies.

Eleven water and sediment samples were collected from nine waterbodies in the Kerang and District Lakes, Western District Lakes and at Cairn Curran Reservoir (map provided in Figure 2). This choice of sampling sites allowed results to be compared with the results reported in 1989.

The lead concentrations found in sediment samples from all nine wetlands were below relevant sediment quality guideline values and therefore would not pose an environmental risk. These guidelines are concentrations designed to protect the functioning of healthy aquatic ecosystems.

Lead concentrations in the waters of all nine waterbodies were below the livestock drinking water quality guideline value and the recreational water quality guideline value. This indicates that the concentrations of lead pose a very small health risk to people swimming in the water, or to livestock drinking the water.

Two waterbodies (Lake Colongulac and Lake Boort) slightly exceeded the lead guideline for drinking water. In the unlikely scenario that this untreated water was used for regular drinking water, the concentrations of lead would pose a very small risk to human health.

The ecosystem protection guideline value for 95 per cent species protection was exceeded at four waterbodies (Lake Colongulac, Lake Colac, Lake Boort and Cairn Curran Reservoir). This indicates that in these waterbodies, slightly less than 95 per cent of species in the ecosystem would be protected by the water quality, based on lead alone.

In summary, low concentrations of lead were found in water and sediments in wetlands from the Western District Lakes, Kerang and District Lakes, and in Cairn Curran Reservoir. In the unlikely circumstance that the water is regularly consumed as untreated drinking water, these lead levels could pose a very low risk to ecosystem and human health.

Based on these findings, EPA considers that lead shot from past hunting does not pose significant human or environmental health risk in the wetlands sampled.

EPA will consider further investigation to identify sources of the metals detected in this study and to address any changes in the wetlands that may change the concentrations reported.

Figure 1: Lake Cullen. Foreground: three waterfowl (Grey teal, Anas gracilis), which are a commonly-hunted species in the wetlands.

Project background

In 2017, community members residing near a Victorian water storage reservoir used for waterfowl hunting expressed concerns to EPA about the potential environmental and health risks from legacy lead shot deposited during past recreational waterfowl hunting.

The use of lead shot for waterfowl hunting was banned in 1994 in Victorian waterbodies and has been replaced with non-toxic shot including steel and other iron alloys, and tungsten alloys (Game Management Authority, 2017).

Lead is a cumulative metal that is acutely and chronically toxic to humans, aquatic biota, including waterfowl and other animals and plants (EPA, 1989 and references therein). There are three potential exposure routes by which lead in wetlands could pose environmental and human health risks:

1. Through the breakdown of lead pellets in sediments, with subsequent remobilisation into the water column or up the aquatic food chain.
2. Through direct ingestion of lead shot in sediments by waterfowl and bottom-feeding fish.
3. Ingestion by birds of prey feeding on the flesh of waterfowl containing embedded lead pellets (EPA, 1989 and references therein).

In late 1987 and 1988, EPA assessed the extent of lead pollution in waters and sediments of waterbodies in the Western District Lakes, and Kerang and District Lakes regions. Results are reported in an EPA report published in 1989 (EPA, 1989). This investigation indicated that the use of lead shot to hunt waterfowl had not resulted in elevated concentrations of lead in water or sediments of the Western District Lakes, or Kerang and District Lakes. Since most of the lakes sampled during the study had reasonably firm sediment layers, the study concluded that any deposited shot would remain in the top few centimetres of sediment for some time. Although using lead shot for waterfowl hunting has since been banned, deposited lead shot from legacy hunting remains in wetland sediments.

Objectives

The objectives of this study were to:

1. identify and sample water and sediments in waterbodies that are and were used for recreational waterfowl hunting activities
2. compare water and sediment sampling results against national water and sediment quality standards
3. compare current water and sediment lead results with those reported in the 1989 EPA study
4. assess the potential for environmental and human health risks from lead in the waterbodies tested.

Testing of aquatic animals such as waterfowl, fish (including eels) and crustacea were not included in this preliminary investigation.

Methods

Sampling sites

To enable comparisons over time, the current study returned to the same sites previously sampled in 1989 (Figure 2) based on maps provided in the report. Sampling sites used in the 1989 study (EPA, 1989) were mapped using ArcGIS version 10.1 software (Environmental Systems Research Institute, 2014). While no coordinates were included in the 1989 report, sample sites in 2017 were chosen to be as close as possible to those in 1989.

Sediment and water samples, and in-situ water quality parameters were collected at eleven sites within nine waterbodies during May 2017 (Figure 2).

Two lakes in the Kerang region that were sampled in the 1989 report (Top Marsh and Second Marsh) were not sampled in 2017 due to a lack of water. Lake Cullen only had a southern sampling site in 2017 as flooding restricted access to the previously-sampled northern site. Two new sampling sites – both at Cairn Curran Reservoir – were included in the 2017 study, as community concerns about legacy lead (reported to EPA in late 2016) were specifically related to this waterbody.

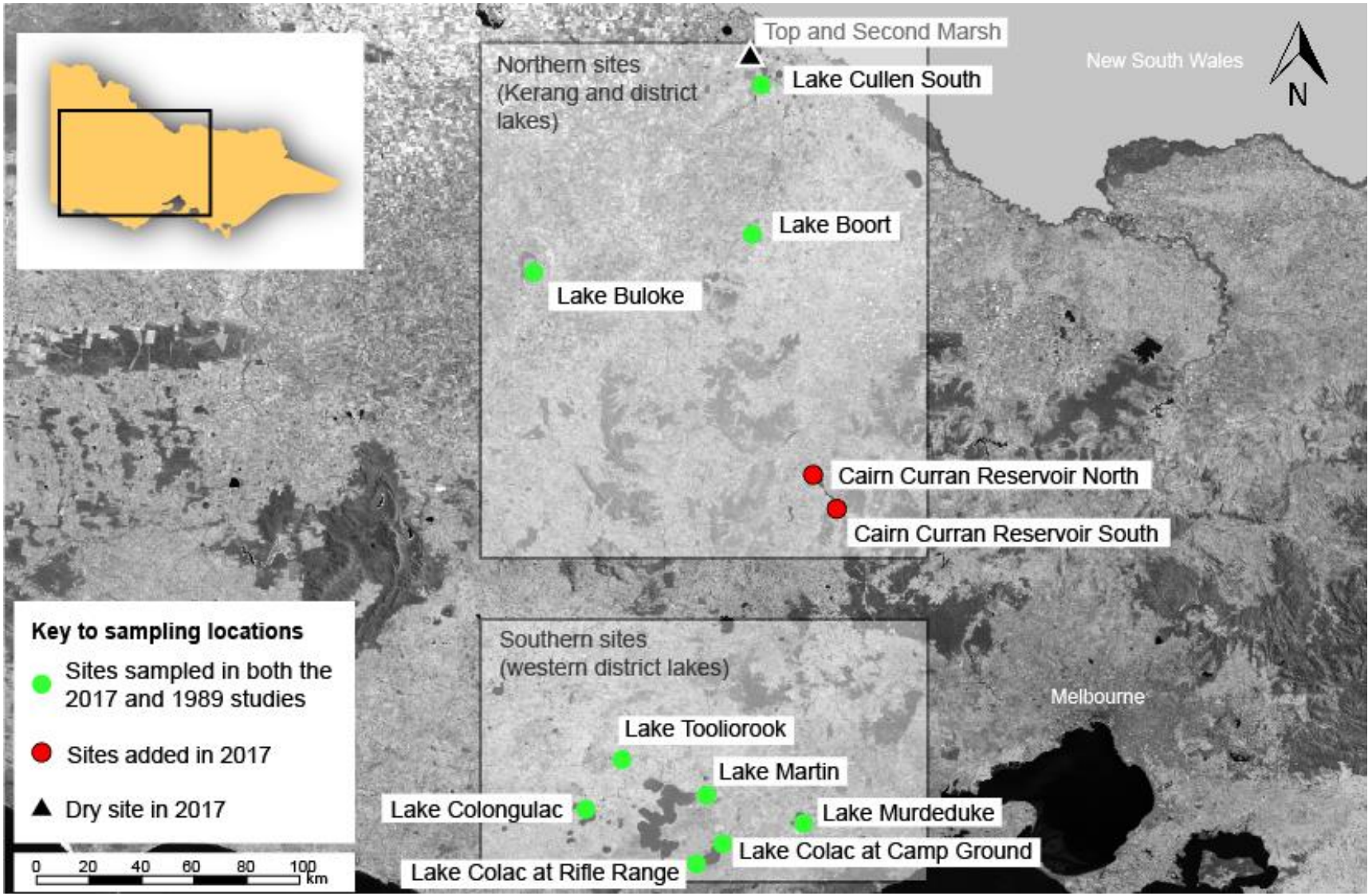

Figure 2: Map of the 11 sites from nine wetlands/waterbodies sampled during 2017. Sites resampled from the 1989 study are marked with green circles. As the Top Marsh and Second Marsh sites were dry during the 2017 study, they were not resampled (black triangle). Cairn Curran was sampled at two additional sites (red circles). See Appendix 1, Figure 7, Figure 8 and Figure 9 for higher resolution maps.

All sampling sites had evidence of waterfowl hunting, including areas of concentrated feathers (Figure 3), signage indicating that shooting occurred at the waterbody and/or spent shot gun shells on the shores of the waterbody. The 1989 study had identified Lake Tooliorook as a site of minimal hunting activity, and for that reason it was previously treated the site as a control site. In May 2017, Lake Tooliorook had a sign indicating active hunting, so it was not treated as a control in 2017.

Figure 3: Cairn Curran Reservoir with waterfowl feathers on the shore of the reservoir indicating hunting activity.

The water bodies sampled in 2017 (Figure 4) are also used for recreational boating (powered and unpowered), camping, fishing, occasionally swimming, and past waste water disposal (Lake Colongulac only). Cairn Curran reservoir supplies water for irrigation, stock and domestic use along the Loddon River.

Figure 4: Varying habitat types within the water bodies sampled in 2017, including inundated eucalypts, grazing land, open shallow wetlands and a water supply reservoir.

Water and sediment sample collection

Sampling methods were based on current best practice, as described in:

- *EPA Publication IWRG701: Industrial Waste Resource Guidelines: Sampling and Analysis of Waters, Wastewaters, Soils and Wastes.* (EPA, 2009)
- *Handbook for Sediment Quality Assessment* (Simpson *et al*., 2005).

Sampling density and locations reflected those in EPA's 1989 report so that results could be directly compared.

In accordance with *EPA Publication IWRG701*, water samples were collected in acid-washed polytetrafluoroethylene (PTFE) bottles for the analysis of metals. Water samples were collected from a depth of around 50 cm below the surface and within 50 to 100 m from the shore.

Sediment was collected using a shovel to scrape the top 2 to 4 cm of sediment bed material, which was then transferred into a 20 L polypropylene pail (Figure 5). Three sediment samples were collected at each site and then homogenised (mixed uniformly) into a single pail. A selection of the homogenised sample was retained and transferred into both a 500 ml glass jar with a Teflon-lined lid, and a 500 ml PTFE jar.

Chemical analysis

In-situ water quality parameters were recorded for: pH, electrical conductivity, temperature and dissolved oxygen, using a YSI Pro Plus Multi-probe; alkalinity, using a Hach Field Alkalinity Kit; and turbidity using a Hach 2100Q Turbidity Kit. These were measured at the same location where water and sediment samples were collected.

Water samples were stored in a refrigerator at less than 1º C before being delivered to ALS Environmental (Scoresby, Melbourne) for laboratory analysis of metals by inductively coupled plasma mass spectrometry (ICP-MS).

Sediment jars were stored in a refrigerator at less than 1º C before being delivered to ALS Environmental (Scoresby, Melbourne) for laboratory analysis of metals by ICP-MS.

Chemical analysis methods have improved over time allowing for more-efficient metal extraction from current samples compared with earlier methods. The 1989 study used a Chemtronics Portable Digital Voltammeter 2000, with in-field measurement of the lead content in the water and sediment samples. This method claimed to be able to determine low concentrations of metals, with a lowest detection limit of 0.002 mg/L for lead.

Figure 5: EPA staff collecting sediment samples.

Comparing results against guidelines

Water and sediment sample results were compared against guideline values to identify any potential environmental and/or human health risks (EPA, 2004). Guideline values, if exceeded, indicate there may be a potential environmental problem, and may trigger a management response or further investigation (ANZECC and ARMCANZ, 2000). If they are not exceeded, this indicates that there will be no significant impact on human or environmental values.

Water guidelines

Water results were compared against the following Australian guidelines:

- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ, 2000) including:
  - toxicants in water at the 95 per cent level of ecosystem protection
  - recreational water quality guidelines
  - livestock drinking water guidelines *
- *Australian Drinking Water Guidelines 6, 2011* (NHMRC,2011) **
- *EPA Publication 1302: Environmental Quality Guidelines for Victorian Lakes* (EPA, 2010).

*Cattle were observed grazing the shoreline of many of the wetlands sampled and therefore the livestock drinking water guidelines are considered relevant to this study.

**Although the water at most sampling sites is not used for human drinking, EPA did not want to eliminate the chances that this water *could* be extracted from Cairn Curran Reservoir for domestic purposes such as drinking and washing-water. Consequently, this study compared water quality results with the drinking water guidelines.

Sediment guidelines

Concentrations of lead in sediment samples were compared against the *Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines* (Simpson *et al*., 2013).

The sediment quality guideline values (SQGV) specify sediment contaminant concentrations that are likely to impair water quality and pose a risk to aquatic ecosystems. The SQGVs set low and high trigger values which, if exceeded, indicate that there is a possible (low-trigger value) or probable (high-trigger value) ecological risk from metals in sediment. If the contaminant concentrations exceed one or more of the SQGVs, further investigation should determine whether environmental risks are associated with the exceedance. If the SQGV for a particular contaminant is not exceeded, it is unlikely that it will result in any biological impact for organisms inhabiting that sediment.

Results and discussion

Water and sediment quality compared to guideline values

Table 1 summarises the results of in-situ water quality parameters and lead concentrations in both water and sediments measured at 11 sites at nine waterbodies in May 2017. Other metals besides lead (24 in total) were analysed at the same time. Because the focus on this report was lead, only lead is included in the table below. All metals concentrations are presented in Appendix 1.

Table 1: Summary of in-situ water quality parameters, and lead concentrations in water and sediment samples from the 11 sites sampled May 2017. Grey, bold or italicised numbers show where results exceeded that guideline value.

Site name	In-situ water quality parameters							Lead	
	Dissolved Oxygen (%)	Dissolved oxygen (mg/L)	pH	Temp (°C)	Electrical Conductivity (µS /cm at 25°C)	Alkalinity (mg/L)	Turbidity (NTU)*	Lead in water (mg/L)	Lead in sediment (mg/kg)
Southern sites (Western District Lakes)									
Lake Murdeduke	**155.1**	14.7	**8.8**	17.5	64787	740	**47.9**	0.001	9
Lake Colongulac	90.7	6.2	**9.0**	15.0	29743	1040	**94.1**	**0.013**	10
Lake Martin	118.4	11.7	**9.7**	15.1	6896	280	**28.2**	<0.001	11
Lake Colac at Rifle Range	94.4	9.8	**8.7**	12.9	5675	320	**78.6**	0.002	8
Lake Colac at Camp Ground	84.7	9.1	**8.6**	11.3	5751	380	**129**	0.004	10
Lake Tooliorook	101.4	10.1	**8.8**	14.8	6226	420	**31.7**	<0.001	<5
Northern sites (Kerang and District Lakes)									
Lake Buloke	**140.9**	14.1	**9.9**	14.8	4857	260	**50.3**	0.001	19
Lake Boort	108.4	10.9	**8.7**	15.2	935	300	**88.7**	**0.013**	9
Lake Cullen South	23.5	2.4	7.1	14.6	1667	160	**25.4**	<0.001	11
Cairn Curran Reservoir North	85.9	9.0	7.8	13.7	311	80	**27.3**	0.003	<5
Cairn Curran Reservoir South	91.1	9.5	7.7	13.3	339	80	**42.3**	0.005	8
Guideline values									
Livestock drinking water								**0.1**	
Recreational water quality (ANZECC)								*0.05*	
Drinking water								**0.01**	
ANZECC 95%								0.0034	
SQGV - Low									**50**
SQGV - High									220
Environmental quality guidelines for Victorian Lakes	**80-120**		**6.5-8.5**				**15**		

Table Notes:

*NTU: Nephelometric Turbidity Unit

In-situ water quality

The pH levels of the lakes were generally above the range provided in EPA's *Environmental Quality Guidelines for Victorian Lakes* (EPA, 2010) of 6.5 – 8.5, meaning the lakes are generally more alkaline than guidelines values. Only Lake Cullen South, Cairn Curran Reservoir North and South were within the environmental quality guidelines values for water quality indicator values of 6.5 – 8.5 (Table 1). Alkaline pH values in most waterbodies indicate less likelihood for lead shot to dissolve into the water from the sediments.

Dissolved oxygen values in the waterbodies were generally within the range of 80 – 120 per cent as provided in EPA's lakes guidelines (EPA, 2010). Exceptions were Lake Cullen South, which had a very low dissolved oxygen concentration of 23.5 per cent, while Lakes Murdeduke and Buloke were substantially higher than the guideline values being 155.1 per cent and 140.9 per cent respectively (Table 1). Low dissolved oxygen at Lake Cullen South could increase the risk of lead shot dissolving into the water and sediments.

Electrical conductivity (a measure of salinity) in the lakes mainly ranged from 311 – 6,896 microsiemens per centimetre (µS/cm), but was much higher at Lake Murdeduke (64,787 µS/cm) and Lake Colongulac (29,743 µS/cm). With increasing levels of salinity, water becomes more undrinkable and biodiversity decreases.

Alkalinity in the lakes generally ranged from 80 – 420 mg/L, but Lake Murdeduke was higher at 740 mg/L and notably higher at Lake Colongulac (1,040 mg/L). A higher alkalinity can help protect against increases in water acidity and modify the effects of some metals.

Turbidity in the lakes ranged from 25.4 – 88.7 NTU, but Lake Colongulac was higher at 94.1 NTU and was 129 NTU at Lake Colac at Camp Ground (Table 1). All turbidity levels were elevated compared with Victorian lakes guidelines (EPA, 2010). Sediment particles (from increased turbidity) bind with metals such as lead, and reduce the metal's availability for uptake by organisms.

Lead in water

Lead concentrations in the surface waters of all nine waterbodies were below the Livestock Drinking Water Quality Guideline value (0.1 mg/L) and the Recreational Water Quality Guideline value (0.05 mg/L).

Two waterbodies – Lake Colongulac and Lake Boort – slightly exceeded the Drinking Water Guideline value (0.01 mg/L). Both recorded a lead concentration of 0.013 mg/L. However, these two waterbodies are not used for drinking water purposes. Lead concentrations at Lake Martin, Lake Tooliorook and Lake Cullen South were all below the level detectable by laboratory analytical methods (<0.001 mg/L) (Table 1).

The guideline for 95 per cent ecosystem protection (ANZECC and ARMCANZ 2000) was exceeded at five sampling locations:

- Lake Colongulac
- Lake Colac at Camp Ground
- Lake Boort
- Cairn Curran Reservoir North
- Cairn Curran Reservoir South.

The source of the lead in these areas could possibly be attributed to lead from legacy hunting although other sources cannot be ruled out. Results from EPA's 1989 study indicated that lead levels were below detectable levels (which was below the 95 per cent ecosystem protection guideline value) in all the above-mentioned waterbodies when lead shot was still used.

Cairn Curran Reservoir is used primarily for recreation, stock and irrigation supply. The lead concentrations from the two samples collected at the reservoir were below the guideline values for drinking water (0.01 mg/L) in raw water supplies, i.e. before any water treatment has occurred, and guideline for recreational water quality (0.05 mg/L). These results indicate that the water is suitable for these purposes.

As noted above, the chemical behaviour and bioavailability of contaminants such as lead is controlled by the pH and dissolved oxygen levels in the water (Simpson *et al*., 2013). Low concentrations of dissolved oxygen and low pH can increase the concentrations of lead leaching into the water from the lead shot and this does not appear to be a factor in these water bodies.

Lead in sediment

Sediments are a potential source of contamination to the water above and between the sediment particles. Lead concentrations in sediment samples from all sampling sites were considerably lower than both the low and high sediment quality guideline values (50 and 220 mg/L respectively) (Table 1). These results indicate that the current concentrations of lead in sediment are unlikely to have an impact on human health or the environmental values of the lakes.

A range of other metals were also tested in sediment samples. Result are provided against guidelines (where available) in Appendix 1, Table 5 and Table 6.

Water and sediment quality compared with historical data

Table 2 compares in-situ water quality measurements and lead concentrations from water and sediment reported in both 2017 and 1989.

Table 2: Comparative in-situ water quality data and lead concentrations in surface water and sediments reported in 2017 and 1989.

	Conductivity (µS/cm)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Mean lead concentrations Surface water (mg/L)	Mean lead concentrations. Stirred bottom water (mg/L) *	Mean lead concentrations. Sediments (mg/kg)
Lake Murdeduke							
Dec '87	24,000	24	14.4	9.1	<0.002	0.004	6
March '88	32,000	24	12.9	9.1	<0.002	0.002	2
June '88	18,000	13	14.2	9.0	<0.002	0.004	3
Oct '88	17,000	14	12.4	8.9	<0.002	0.003	2
Dec '88	19,800	20	12.6	9.2	<0.002	<0.002	2
May '17	64,787	17.5	14.7	8.8	0.001	-	9
Lake Colac west side (rifle range)							
March '88	3,600	17.5	9.1	8.9	<0.002	0.004	4
June '88	2,400	10.5	9.7	8.4	<0.002	0.003	6
Oct '88	2,100	12	9.6	8.7	<0.002	0.007	3
Dec '88	2,600	20	8.1	8.6	<0.002	0.004	4
May '17	5,675	12.9	9.8	8.7	0.002	-	8
Lake Martin							
Dec '87	9,000	23	8.8	8.5	<0.002	0.001	5
March '88	17,000	24	9.2	8.8	<0.002	0.008	5
June '88	10,000	13	12.8	8.7	<0.002	0.008	9
Oct '88	10,000	14	9.2	8.7	<0.002	0.001	4,6,12
Dec '88	12,800	19	9.5	8.8	<0.002	0.002	10
May '17	6,896	15.1	11.7	9.7	<0.001	-	11
Lake Colongulac							
Dec '87	16,000	23	13.2	9.2	<0.002	0.005	7
March '88	19,000	17	5.1	9.3	<0.002	0.001	2
June '88	10,300	9.5	11.4	9.7	<0.002	<0.002	5
Oct '88	12,000	12	10.9	9.6	<0.002	<0.002	6
Dec '88	12,500	17	8.7	10.3	<0.002	<0.002	6,5,4
May '17	29,743	15	6.2	9.0	0.013	-	10
Lake Tooliorook							
March '88	3,100	19.0	10.6	8.8	<0.002	0.008	1
June '88	1,900	12	12.1	8.9	<0.002	<0.002	7
Oct '88	2,150	15	11.4	8.9	<0.002	<0.002	4
Dec '88	2,400	19	10.5	8.9	<0.002	0.002	4
May '17	6,226	14.8	10.1	8.8	<0.001	-	<5
Lake Cullen							
Jan '89 (NW)	4,250	17.5	7.9	10.1	<0.002	0.002	8
Jan '89	5,300	20	9.1	9.8	<0.002	0.002	14,10
May '17	1,667	14.6	2.4	7.1	<0.001	-	11
Lake Boort							
Jan '89	1,680	22	12.8	10.0	<0.002	0.002	7
May '17	935	10.9	10.9	8.7	0.013	-	9

	Conductivity (µS/cm)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Mean lead concentrations Surface water (mg/L)	Mean lead concentrations. Stirred bottom water (mg/L) *	Mean lead concentrations. Sediments (mg/kg)
Lake Buloke							
Jan '89	1,000	21	10.2	8.6	<0.002	0.003	3,5,7
May '17	4,857	14.8	14.1	9.9	0.001	-	19

Table notes:

- *Also included in the table are the lead concentrations from the stirred-up bottom water from the 1989 study. This was not sampled in 2017 (represented by a dash) as this is no longer best practice (EPA, 2009).
- The 1989 study reports on samples collected and analysed between 1987 and 1989.
- Note that Cairn Curran Reservoir is not included in the table as this was not sampled in the 1980s, and as such, could not be compared to past results.

In general, results for dissolved oxygen and pH recorded in 2017 were similar to those found previously. Temperature was lower during 2017 due to the timing of the sampling (spring and summer sampling for the 1989 study, and autumn sampling for 2017).

The most notable difference in in-situ water quality results was the salinity (as measured by electrical conductivity) at Lake Murdeduke, which ranged from 17,000 – 32,000 µS/cm) in the 1989 study, but was notably higher (64,787 µS/cm) in 2017. Similarly, Lake Colongulac conductivity ranged between 10,300 and 19,000 µS/cm during the 1989 study and was higher (29,743 µS/cm) in 2017.

Lead concentrations in water appeared to be higher in 2017 compared with those reported in 1989, noting the differences in detection limit. Four lakes that previously had lead levels below detection levels (<0.002 mg/L) in the 1989 study, recorded detectable lead concentrations in 2017 – these were Lake Colongulac (0.013 mg / L), Lake Boort (0.013 mg/L), Lake Buloke (0.001 mg/L) and Lake Murdeduke (0.001 mg/L), the latter two were both at current limit of detection (Table 2).

While efforts were made to replicate the 1980's sampling approach, to be able to compare lead concentrations between the 1980s and 2017, the analytical method for lead used in 1980s was a field-based method, making comparisons challenging. It is likely that the field-based method was poorer at extracting the metals from the water than the laboratory method, potentially leading to underestimates of the lead concentrations in the 1989 report.

The increased concentrations at Lakes Boort and Colongulac may be affected by other sources of lead, including: stormwater from urban and road run-off; waste water discharges. Urban sources of lead may be more likely sources than legacy recreational hunting, as other metals such as arsenic, boron, chromium, copper, manganese, nickel, zinc and antimony were also elevated, exceeding guideline values in some waterbodies (Appendix 1, Table 3 and Table 4).

The presence of these other metals in the waterbodies indicate that sources other than waterfowl hunting could be contributing to the elevated lead levels detected in 2017. It is possible that the wet conditions of April 2017, where these regions received rainfall that was well above average (Bureau of Meteorology monthly decile data) just prior to sampling, resulted in influxes of organic material, sediment and other stormwater contaminants into the lakes. This may have created relatively anoxic (low dissolved oxygen) conditions in the bottom waters, with resulting releases of metals.

The detection of elevated concentrations of metals, including lead, requires further assessment and monitoring to ensure that the health of these lakes is maintained to support aquatic life and to maintain their beneficial uses.

Lead in sediment samples

Lead concentrations in sediment samples were all higher in 2017 compared with those reported in 1989, except for Lake Tooliorook, which recorded similar concentrations between time periods (Table 2). Again, this could be due to improved analytical techniques. Results for additional metals in sediments are provided in Appendix 1, Table 5 and Table 6.

Field observations

At all eleven sampling sites, significant amounts of shot gun shell waste, as well as general domestic waste such as food and drink containers, were consistently observed. At some sites, an estimate of 40 to 50 used shot gun shells were observed with a 200 m stretch of shoreline, despite anti-litter signage at some of the water bodies (Figure 6). Although shot density was not measured as part of the 2017 study, spent shot gun shells found at the sampling sites were all checked to see whether they were steel shot (as read from the labels on the spent shells). Opportunistic observations during sampling did not find any spent lead pellets at any of the wetlands sampled.

Figure 6: Sign at Lake Colongulac indicating contaminated water in the wetland due to blue-green algae. Also note the 'take your rubbish home' signage.

Conclusion

The results of this preliminary investigation indicate that impacts from the historical use of lead shot to hunt waterfowl has not significantly affected water or sediment quality. Results do not exceed the recommended recreational, livestock water quality or sediment quality guidelines for lead.

Drinking water guidelines for lead were exceeded in two lakes but these are not used for drinking water. The ecosystem guideline values for lead in water was exceeded in some lakes in the Western District Lakes, Kerang and District Lakes and Cairn Curran Reservoir.

Overall, water quality at these lakes could be improved to maintain the ecosystem values and beneficial uses of the lakes and further monitoring will be required to ensure that changes in parameters, such as pH, do not alter the metals profiles.

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Appendix 1 – Additional tables and figures

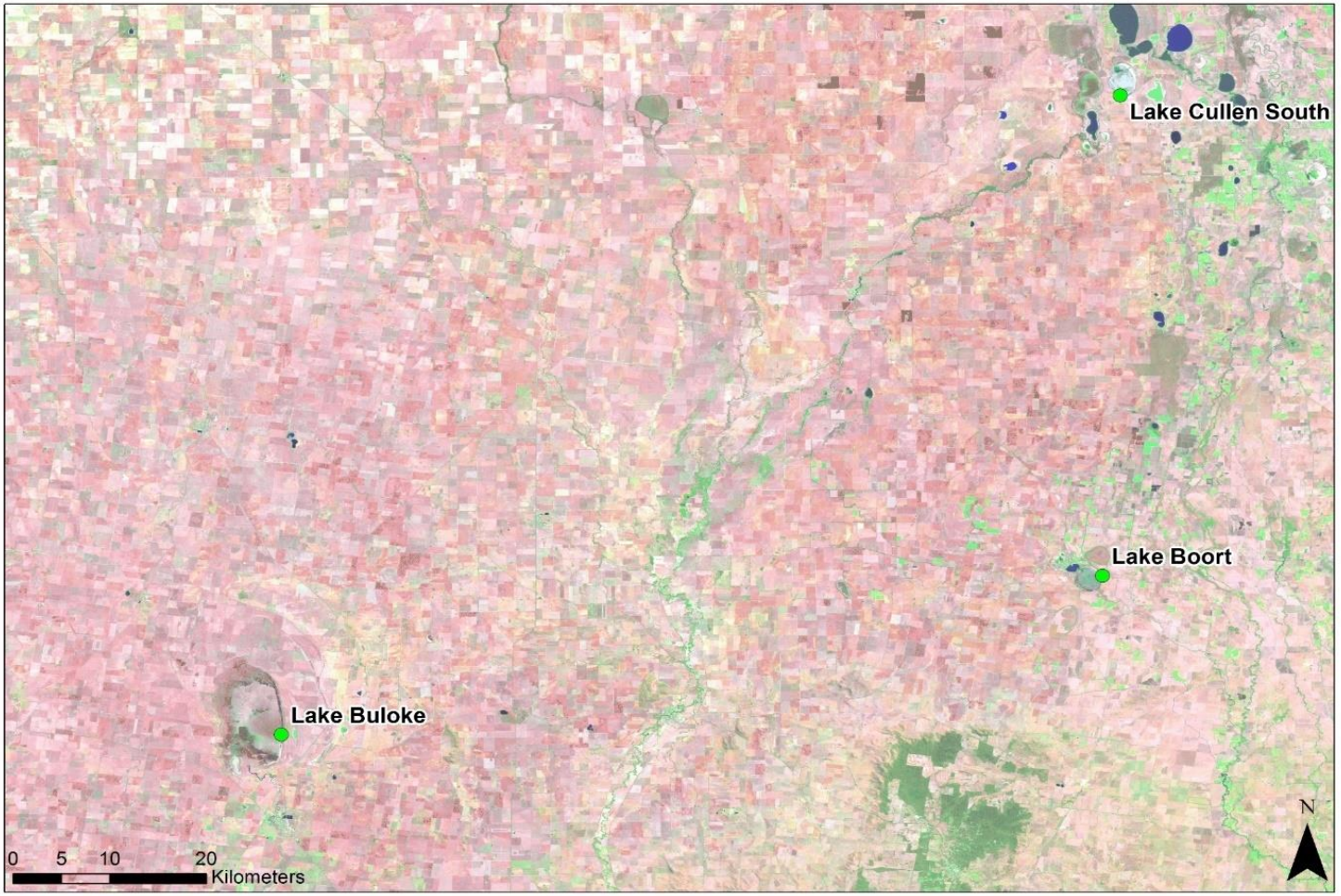

Figure 7: Kerang and District Lakes and sampling locations.

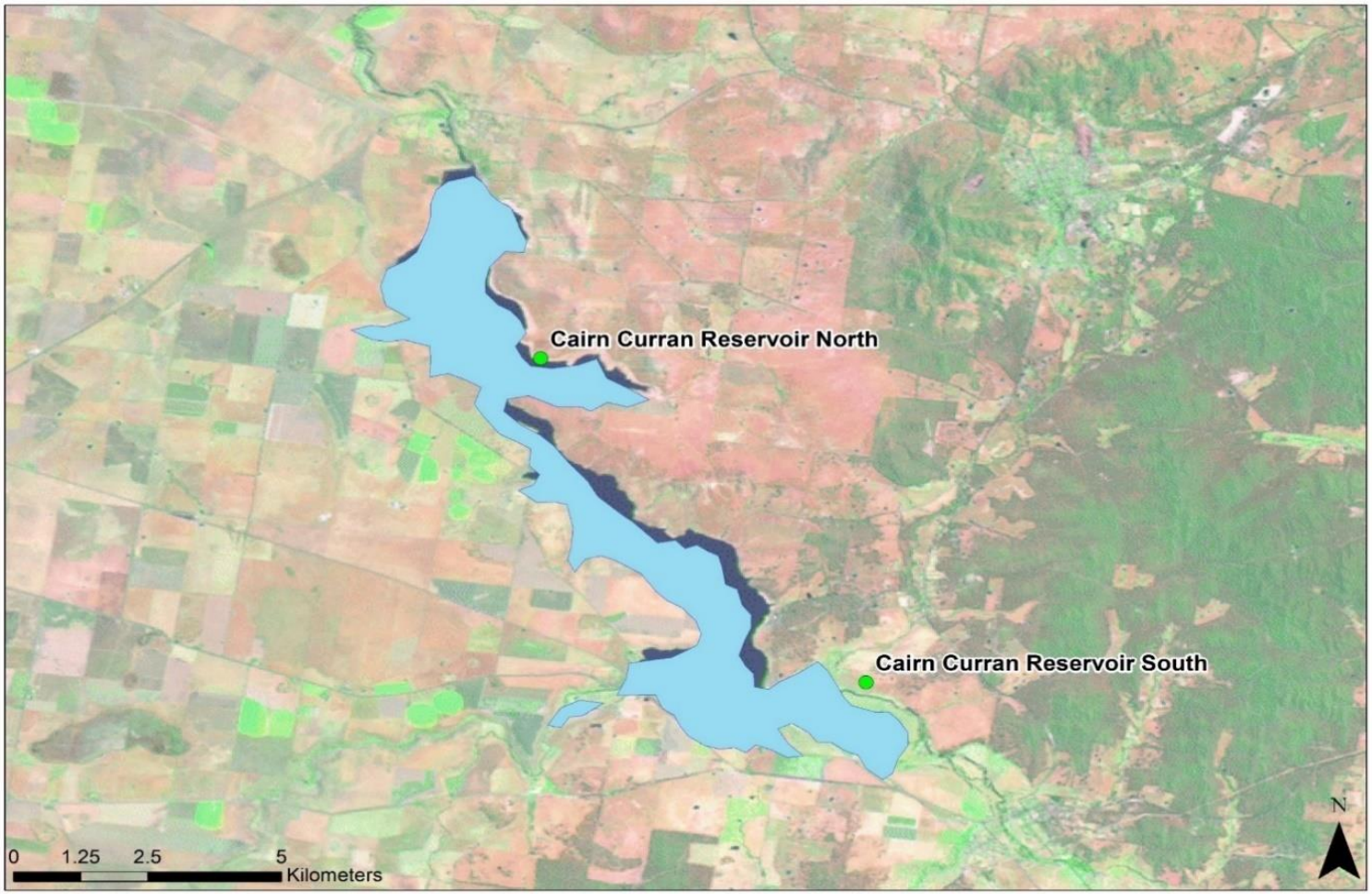

Figure 8: Cairn Curran Reservoir and sampling locations.

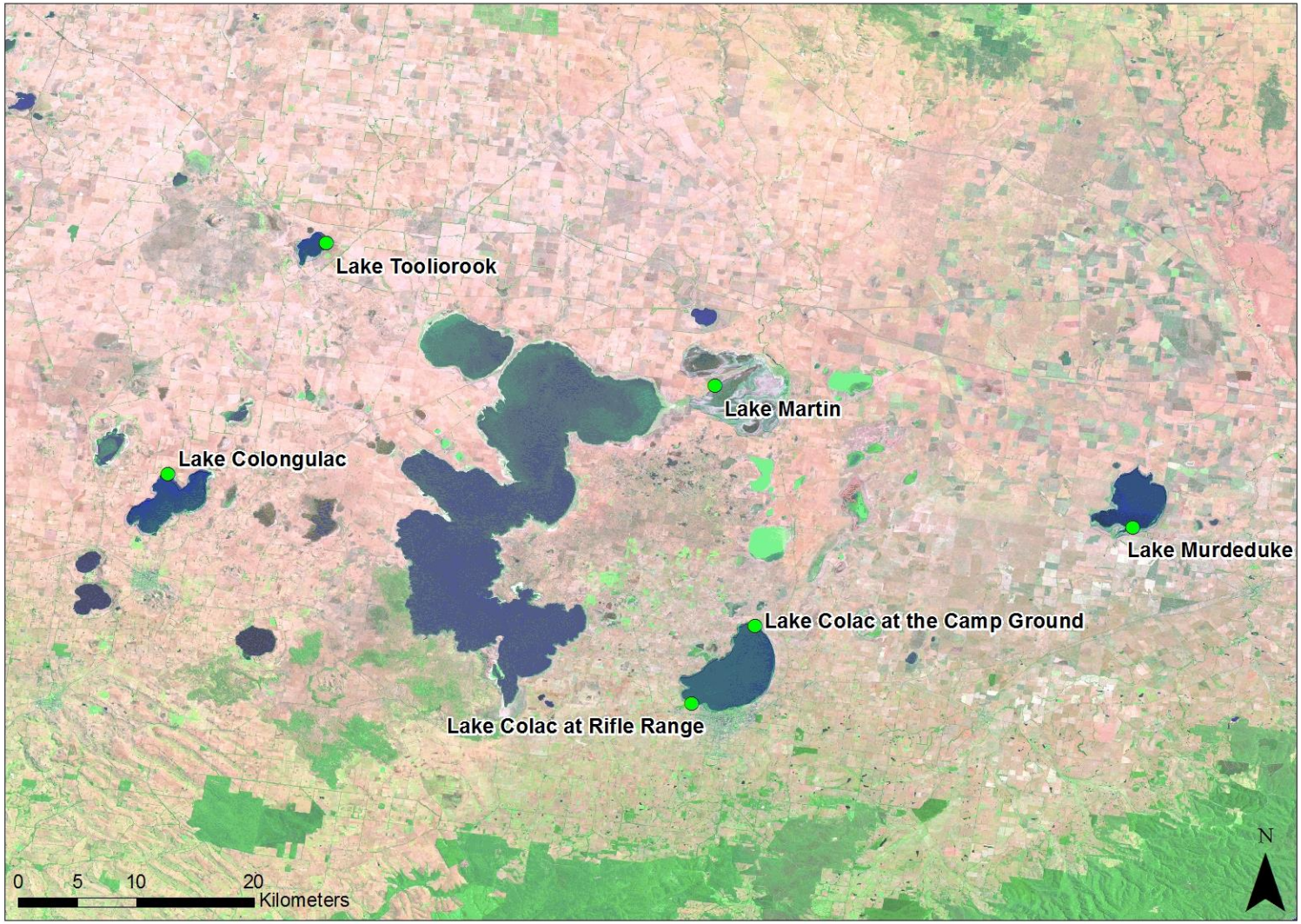

Figure 9: Western District Lakes sampling locations.

Table 3: Results for total organic carbon (TOC) and metals in water samples taken from the 11 sites sampled in May 2017. Also included are the national guideline values (ANZECC and ARMCANZ 2000) for ecosystems and recreational water quality and NHMRC for drinking water. All values are expressed as mg/L. Grey, bold or italicised text are those that exceeded a guideline value.

Site Name	TOC and metals in water*													
	TOC^	Al	As	B	Cd	Cr (CrV)	Cu	Pb	Mn	Hg (inorganic)	Ni	Se	Ag	Zn
Lake Murdeduke	84	*0.58*	**0.03**	*3.9*	<0.002	0.001	0.001	0.001	0.015	<0.0001	0.009	0.002	<0.001	0.004
Lake Colongulac	34	*34*	**0.12**	*2.6*	<0.002	***0.068***	0.024	**0.013**	*0.33*	<0.0001	**0.067**	0.005	<0.001	0.06
Lake Martin	29	*0.45*	0.008	0.62	<0.002	<0.001	0.002	<0.001	0.008	<0.0001	0.003	<0.001	<0.001	0.004
Lake Colac at Rifle Range	23	*5.7*	**0.012**	0.38	<0.002	0.007	0.005	0.002	0.064	<0.0001	0.013	0.002	<0.001	0.021
Lake Colac at Camp Ground	23	*11*	**0.013**	0.4	<0.002	0.015	0.006	0.004	*0.12*	<0.0001	0.019	0.002	<0.001	0.025
Lake Tooliorook	28	*0.49*	0.01	0.46	<0.002	<0.001	<0.001	<0.001	0.024	<0.0001	0.003	<0.001	<0.001	0.015
Lake Buloke	110	*2.7*	**0.019**	0.89	<0.002	0.003	0.005	0.001	0.026	<0.0001	0.01	0.001	<0.001	0.014
Lake Boort	46	*3.3*	**0.024**	0.23	<0.002	0.004	0.004	**0.013**	*0.85*	<0.0001	0.009	<0.001	<0.001	0.01
Lake Cullen South	14	*0.72*	0.005	0.49	<0.002	<0.001	<0.001	<0.001	*0.19*	<0.0001	0.002	<0.001	<0.001	0.005
Cairn Curran Reservoir North	12	*4.2*	0.006	0.04	<0.002	0.005	0.004	0.003	0.04	<0.0001	0.005	<0.001	<0.001	0.016
Cairn Curran Reservoir South	12	*4.5*	0.008	0.03	<0.002	0.005	0.004	0.005	*0.12*	<0.0001	0.006	<0.001	<0.001	0.016
Guideline Values														
Recreational water quality (ANZECC)		*0.2*	*0.05*	*1.0*	*0.005*	*0.05*	*1.0*	*0.05*	*0.1*	*0.001*	*0.10*	*0.01*	*0.05*	*5.0*
Drinking water (NHMRC)			**0.01**		**0.002**	**0.05**	**2**	**0.01**		**0.001**	**0.02**	**0.01**	**0.1**	
ANZECC 99% species protection		0.027	(As III) 0.001	0.09	0.00006	0.00001	0.001	0.001	1.2	0.06	0.008	0.005	0.00002	0.0024
			(AsV) 0.008											
ANZECC 95% species protection		0.055	(As III) 0.024 (AsV) 0.013	0.013	0.0002	0.001	0.0014	0.0034	1.9	0.6	0.011	0.011	0.00005	0.008

Table notes:

*__Al__: Aluminium; **As**: Arsenic; **B**: Boron; **Cd**: Cadmium; **Cr**: Chromium (CrVI); **Cu**: Copper; **Pb**: Lead; **Mn**: Manganese; **Hg**: Mercury (inorganic); **Ni**: Nickel; **Se**: Selenium (Total); **Ag:** Silver; **Zn**: Zinc.

^ **TOC**: Total organic carbon.

Table 4: Summary of metals in water samples collected from the 11 wetlands sampled May 2017. Metals other than antimony and barium do not have associated Australian water quality guidelines. All units are expressed as mg/L.

Site Name	Metals in water samples continued										
	Antimony	Barium	Beryllium	Cobalt	Iron	Molybdenum	Strontium	Thallium	Tin	Titanium	Vanadium
Lake Murdeduke	0.001	0.29	<0.001	0.001	0.52	0.006	5	<0.001	<0.001	0.02	0.021
Lakes Colongulac	<0.001	0.28	0.001	0.018	39	0.049	2.4	<0.001	0.002	1.3	0.13
Lake Martin	<0.001	0.081	<0.001	<0.001	0.37	0.004	1.1	<0.001	<0.001	0.016	0.015
Lake Colac at Rifle Range	<0.001	0.12	<0.001	0.002	4	0.005	1.3	<0.001	<0.001	0.38	0.033
Lake Colac at Camp Ground	<0.001	0.14	<0.001	0.003	7.7	0.006	1.4	<0.001	<0.001	0.73	0.043
Lake Tolliorook	<0.001	0.076	<0.001	<0.001	0.52	0.001	1.1	<0.001	<0.001	0.012	0.01
Lake Buloke	<0.001	0.11	<0.001	0.002	1.7	0.002	0.62	<0.001	<0.001	0.063	0.029
Lake Boort	<0.001	0.16	<0.001	0.003	4.2	0.004	0.46	<0.001	<0.001	0.05	0.019
Lake Cullen South	<0.001	0.071	<0.001	<0.001	0.68	0.003	1.3	<0.001	<0.001	0.013	0.006
Cairn Curran Reservoir North	<0.001	0.048	<0.001	<0.001	4.7	<0.001	0.1	<0.001	<0.001	0.14	0.008
Cairn Curran Reservoir South	<0.001	0.057	<0.001	0.001	6.1	<0.001	0.11	<0.001	<0.001	0.15	0.009
Guidelines											
Drinking water	**0.003**	**0.7**									

Table 5: Summary of metals in sediment samples collected from the 11 sites sampled May 2017. These metals do not have relevant sediment quality guideline values.

Site Name	Metals in sediment samples (mg/kg) *															
	Al	Be	Ba	B	Co	Fe	Mn	Mo	Se	Sr	Sn	Ti	Tl	Th	U	V
Lake Murdeduke	25000	<5	66	93	11	31000	230	<5	5	580	<5	95	<5	<5	<5	52
Lakes Colongulac	28000	<5	130	100	18	45000	300	<5	8	700	<5	540	<5	5	<5	87
Lake Martin	23000	<5	100	42	10	32000	270	<5	7	520	<5	180	<5	7	<5	74
Lake Colac at Rifle Range	15000	<5	65	15	7	16000	270	<5	5	97	<5	110	<5	<5	<5	36
Lake Colac at Camp Ground	16000	<5	110	18	8	18000	290	<5	11	330	<5	180	<5	<5	<5	39
Lake Tolliorook	2400	<5	15	<10	<5	11000	56	<5	<3	78	<5	67	<5	<5	<5	39
Lake Buloke	28000	<5	130	24	10	29000	270	<5	9	79	<5	37	<5	9	<5	49
Lake Boort	6700	<5	37	<10	<5	6800	95	<5	3	13	<5	22	<5	<5	<5	13
Lake Cullen South	16000	<5	100	23	8	18000	330	<5	7	260	<5	59	<5	5	<5	26
Cairn Curran Reservoir North	3100	<5	16	<10	<5	3700	70	<5	5	<5	<5	120	<5	8	<5	9
Cairn Curran Reservoir South	6700	<5	49	<10	<5	11000	140	<5	6	12	<5	120	<5	<5	<5	13

Table notes:

* **Al:** Aluminium; **Be**: Beryllium; **Ba**: Barium; **B**: Boron; **Co**: Cobalt; **Fe**: Iron; **Mn**: Manganese; **Mo**: Molybdenum; **Se**: Selenium; **Sr**: Strontium; **Sn**: Tin; **Ti**: Titanium; **Tl**: Thallium; **Th**: Thorium; **U**: Uranium; **V**: Vanadium.

All values are expressed as mg/kg.

Table 6: Results for TOC and metals in sediment samples collected from the 11 sites sampled May 2017 and compared with the ANZECC/ARMCANZ sediment quality guidelines (Simpson et al. 2013).

Site Name	TOC and metals in sediment										
	TOC*	Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
Lake Murdeduke	24000	<5	8	<0.2	57	13	9	<0.05	36	<5	34
Lake Colongulac	29000	<5	33	<0.2	76	17	10	0.07	68	<5	65
Lake Martin	11000	<5	26	<0.2	46	10	11	<0.05	30	<5	33
Lake Colac at Rifle Range	19000	<5	7	<0.2	27	8	8	<0.05	25	<5	49
Lake Colac at Camp Ground	21000	<5	9	<0.2	28	9	10	<0.05	29	<5	50
Lake Tooliorook	1300	<5	16	<0.2	13	<5	<5	<0.05	7	<5	<5
Lake Buloke	21000	<5	10	<0.2	46	15	19	<0.05	23	<5	38
Lake Boort	15000	<5	7	<0.2	10	6	9	0.07	6	<5	13
Lake Cullen South	16000	<5	7	<0.2	22	9	11	<0.05	14	<5	30
Cairn Curran Reservoir North	2900	<5	<5	<0.2	7	<5	<5	<0.05	<5	<5	6
Cairn Curran Reservoir South	20000	<5	10	<0.2	13	8	8	0.09	9	<5	37
Guidelines											
Sediment quality trigger value		2	20	1.5	80	65	50	0.15	21	1	200
SQC - High		25	70	10	370	270	220	1	52	4	410

Table notes:

*TOC: Total organic carbon.

All values expressed as mg/kg.

Grey shaded boxes are those that exceeded a guideline trigger value.