Water and sediment quality in the Bull Creek catchment and City of Melville lakes 2021

Prepared by the South East Regional Centre for Urban Landcare

for the City of Melville

Rock riffle at Brentwood Living Stream

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South East Regional Centre for Urban Landcare

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Introduction and recommendations in brief

This assessment of surface water and sediment quality within the Melville Bull Creek catchment has been part of an ongoing partnership program between the City of Melville (the City), South East Regional Centre for Urban Landcare (SERCUL) and Department of Biodiversity, Conservation and Attractions (DBCA). The purpose of this program has been to monitor the water and sediment quality in the western side of the Bull Creek catchment (closest to the City) in order to guide management responses within the catchment. The assessment in 2021 was similar to those of most previous years and included four surface water sampling events and one sediment sampling event. This report discussed the data in two ways. First by comparing the 2021 data with data from the previous 14 years of monitoring (2007 - 2020), and second by investigating if there have been changes to the wetlands (in terms of parameters measure and site specific activities by others) since sampling began in 2007 up to and including 2021.

The following recommendations for future work are based on the results of these findings and aim to respond to issues that are of elevated risk to the health of the wetlands.

Reduce inflow of pollutants into wetlands.

Focus rehabilitation activities at the sites that are closest to and influence sites that are functioning well.

Review the issues facing Booragoon Lake and Blue Gum Lake. These lakes are in poor condition and may need alternative or additional approaches or works.

Identify pollutant sources entering John Creaney Park as this upstream site is likely to contribute significant amounts of pollutants into the drain it is part of. Water enters John Creaney Park to the west and leaves the park to the east. This water then flows into Bull Creek Main Drain close to Bateman Park, where it continues into the Canning River near Bateman Park.

Maintain monitoring of sites. This may include adding sites to the program as well as reducing the number of parameters monitored at sites that are functioning best. Additional sites include those most upriver of the Bull Creek Main Drain itself.

Link the extensive data gathered with information on rehabilitation activities to identify key associations.

A continuing recommendation is to analyse the existing data in more depth to gain a better understanding of trends with time as well as relationships between parameters. Because of the value in historical data sets, the monitoring program needs to continue and further sites included. While there are indications that remediation may have beneficial effects, the monitoring programs should only cease once this can be confirmed (National Health and Medical Research Council (NHMRC, 2008, page 2). In addition to continuing the water quality monitoring program, recommendations have been made to implement existing City of Melville management plans, restoration projects and to adopt the recently published City of Melville Stormwater Management Guidelines (SERCUL 2019).

Overall summary

There were several differences between sites in terms of physicochemical, nutrient, metal and sediment parameters. Some general separation of the sites could be made based on these characteristics that aided explaining some of the findings, a more detailed understanding of these parameters, however, is needed that considers seasonal, perennial and site-specific variations and characteristics. This has been partly done in this report with the most notable finding being that perennial variations in the data, particularly since 2013, 2014 or 2015, suggest that at some of the sites, rehabilitation of sites has stabilised physical or chemical parameters of the wetlands. Additionally, site specific factors, such as the location along a drain, flow, urban development, extent of rehabilitation as well as site specific characteristics, such as sediment type, may influence physical and chemical characteristics at sites along a drain line. These insights need further investigation.

The following section includes a map (Figure 1) with summary codes of the overall results from sampling at the three drainage lines. This is followed by overall summary texts referring to each of the three drainage lines. The map contains the Compliance Grading Scores (coloured letters) and summaries of parameters that tended to differ between sites with time (black letters). The latter was created by examining nutrients (total nitrogen and phosphorus), some metals that are known to be toxic and often common in urban landscapes (copper and lead) as well as the pH of the water. This allows for additional insights to how the water quality at the sites have varied since sampling began in 2007.

Overall findings based on assessments against standards are as follows;

1. Bull Creek Main Drain indicates that while the water quality is poor upstream, this improves downstream. This drain consists of the inlet and outlet of John Creaney Park (sites 15 and 5), Elizabeth Manion Park (site 16), Brockman Park (site 2) and Bull Creek Main Drain near Leach Highway (site 1).
2. The Brentwood Drain branch has better water quality than the Bull Creek Main Drain. This drain includes the Brentwood Drain, RAAF Drain and Bateman Park (sites 13, 14, and 6).
3. Of the Melville lakes, Marmion Reserve and Fredrick Baldwin (sites 11 and 10) were of good quality, Quenda Lake and Blue Gum Lake (sites 9 and 12) intermediate and Piney Lakes and Booragoon Lake (sites 8 and 7) in the poorest condition.

The **physicochemical variable that could** separate the sites was **pH:** in particular, the low pH at Booragoon Lake and Piney Lakes (sites 7 and 8), while Marmion Reserve followed by Fredrick Baldwin (sites 11 and 10) have the highest pH.

In terms of **Nutrients:** Booragoon Lake and Brockman Park (sites 7 and 2) have the highest levels of nutrients, while Fredrick Baldwin and Marmion Lake (sites 10 and 11) have the lowest levels of nutrients.

In terms of **Metals:** The water flowing into John Creaney Park (inlet sampled), Elizabeth Manion Park, Booragoon Lake and Blue Gum Lake (sites 15, 16, 7, and 12) have on average the highest levels of total and soluble metals, in particular total zinc and copper and soluble lead and copper. The lowest metal content was observed in Marmion Reserve. In terms of metals in the sediments, concentrations of aluminium and iron were highest at the Bull Creek Drain near Leach Highway, John Creaney Park outlet, Brentwood Drain and Booragoon Lake (sites 1, 5, 13 and 7) and lowest at Quenda Lake, RAAF Drain and Bateman Park (sites 9, 14, and 6) (note; sediment samples were not taken at all sites). In contrast, all other metals were on average highest in sediments at Booragoon Lake (site 7) and intermediate at John Creaney Park outlet, Brentwood Drain and Fredrick Baldwin (sites

5, 13, and 10) and lowest at Quenda Lake, RAAF Drain and Bateman Park (sites 9, 14, and 6) (note; sediment samples were not taken at all sites).

Summaries of data related to the three drains

Bull Creek Main Drain Branch (2007 to 2021)

This branch includes John Creaney Park outlet, John Creaney Park inlet, downstream at Elizabeth Manion Park and Brockman Park (sites 15, 5, 16 and 2, respectively) and Bull Creek Main Drain (site MELDR-01, previously called PSDTBCMD). See also Discussion of results that follows t results section of this report.

Physical parameters; pH at these sites ranged between 6 and 7 and temperature between 16 and 22°C on most sampling occasions, and both of these parameters tended to trend downwards with time interannually. While total suspended solids was higher at sites such as Elizabeth Manion Park and the inlet at John Creaney Park (sites 16 and 15) compared to the other sites, this was likely to be due to turbulence at the sampling locations. Oxygen saturation and dissolved oxygen concentration however, remained low and below ANZECC guidelines in most sites.

Nutrients: Total nitrogen and nitrogen as ammonia/ammonium was highest at Brockman Park (site 2), followed by Bull Creek Main Drain near Leach Highway (site 1). At the latter site, filterable phosphorus was also highest. The inlet and outlet at John Creaney Park as well as Elizabeth Manion Park (sites 15, 5 and 16) had lower levels of nutrients. The elevated nutrient concentrations at site 2 represents a confluence of a southern and western branch of the drain, the higher levels of these nutrients is a summation of that of water flowing along these branches as well as added nutrients from nearby urbanisation. By the time the water reaches the upstream site (site 1), some of the nutrients, in particular the nitrogen, may have been used by living organisms along the drain.

Metals: Total and soluble zinc, lead and copper were highest in water at upstream sites (John Creaney Park and Elizabeth Manion Park) than at downstream sites. Total and soluble chromium, however, did not follow this trend and most sites were quite comparable. In regard to the sediment, the aluminium and iron at the John Creaney Park outlet and Bull Creek Main Drain near Leach Highway was much higher than that at Brockman Park (site 2) confluence. Water hardness was also higher downstream than upstream, which at site 1, the site closest to Canning River, may partly be a tidal influence from the Canning River (needs confirmation). There are also some upwards trends in the metals in the water at some sites since around 2014, in particular in the John Creaney inlet and outlet (sites 15 and 5). The overall downwards trend with time of all metals in the sediment at the most downstream site (site 1) was interesting and should be further examined. It may be a function of both streamflow as well as decreasing metal input into the drain itself.

Brentwood Drain Branch (2007 to 2021)

This branch includes Brentwood Main Drain, RAAF Drain and Bateman Park (sites 13, 14 and 6, respectively).

Physical parameters; pH at these sites was between 6.5 and 7.5 and temperature between 16 and 22°C on most sampling occasions, with pH tending to trend upwards with time at these three sites. Total suspended solids tended to trend down with time (years) at Bateman Park (site 6), remained quite variable at Brentwood Drain (site 13) and has remained low at RAAF Drain (site 14). Differences were possible due to turbulence at the sampling locations. The water remained well oxygenated at most sampling times and while conductivity peaked in July 2012 at site 6, it has remained within ANZECC acceptable levels for wetlands, but above that for lowland rivers. Additionally, water hardness seem to have been stabilising in this drain since 2015.

Nutrients; Overall, the highest concentrations of nutrients were found in the RAAF Drain (site 14, in particular several forms of nitrogen) and least in Brentwood Drain (site 13). At Bateman Park (site 6), total and filterable phosphorus was highest. It is likely that, as site 6 is immediately downstream of the confluence of the other two sites (site 13 and 14), higher levels of nutrients at this site is a summation of that of water flowing from the other sites. In terms of conductivity, this was highest at site 6 which is closest to the Canning River and may therefore also be influenced by tides.

Metals: Total zinc, and chromium as well as soluble lead and copper were the most common forms of metals in all these three sites. Overall, metals were most concentrated in the Brentwood Drain (site 13), followed by Bateman Park (site 6) and then the RAAF Drain (site 6). Several metals, including iron and aluminium decreased at these sites, while copper is possibly increasing and chromium stabilising. Further work is needed to identify sources of metals. Water hardness was also higher downriver at site 6 than upriver, which is possibly because site 6 is closest to Canning River and may be influenced by tides. There are also some upwards trends in the metals in the water at some sites since around 2014, in particular in the John Creaney inlet and outlet (sites 15 and 5). Both aluminium and iron were highest at Brentwood Drain (site 13) than at the other two sites, and there are some indications that several metals are increasing slightly with time at the three sites. in the highest sediment metal concentrations were recorded at site 13 in October 2016, but not in the other two sites.

Melville Lakes

This includes Booragoon Lake, Piney Lakes, Quenda Lake, Frederick Baldwin, Marmion Reserve and Blue Gum Lake (sites 7, 8, 9, 10, 11 and 12, respectively). Because the lakes represent individual ecosystems that are not connected as well as a drainage line, the summaries of the findings will be presented by comparing the lakes rather than detailing parameters along drainage lines.

In summary, Booragoon Lake (site 7) had the most variable and frequently the highest levels of conductivity, total suspended solids, total zinc, copper and soluble lead and copper in the water and copper, chromium, arsenic, nickel, and aluminium in sediment, of all these lakes. In contrast, Quenda Lake, Marmion Reserve and Fredrick Baldwin had the lowest levels of metals and conductivity and higher pH of all lakes. There are some indications that water hardness, aluminium, iron, chromium, and lead are decreasing or stabilising in the lakes while copper and zinc are increasing, particularly since 2013 - 2015. But there does not seem to be an association between pH and metals in these trends.

In terms of oxygen, the lakes were at times well oxygenated and at other times hypoxic. The reasons for these variations are unclear. The concentrations of nutrients at Booragoon Lake (site 7) were much higher and showed more variation with time than the other lakes. Blue Gum Lake (site 12) had intermediate levels of nutrients, while Marmion Reserve and Fredrick Baldwin (sites 11 and 10) had the lowest levels of nutrients. Oxidised nitrogen was unusually high in all lakes in 2019. Rainfall during 2019 was lower than average, and the cause may be related to this, the cycling of nitrogen in wetlands and other activities or inflows of nutrients into these wetlands. Since sampling began, there have been some trends suggesting that nutrients in Booragoon Lake and Blue Gum Lake have increased, but trends at each lake have remained constant with time.

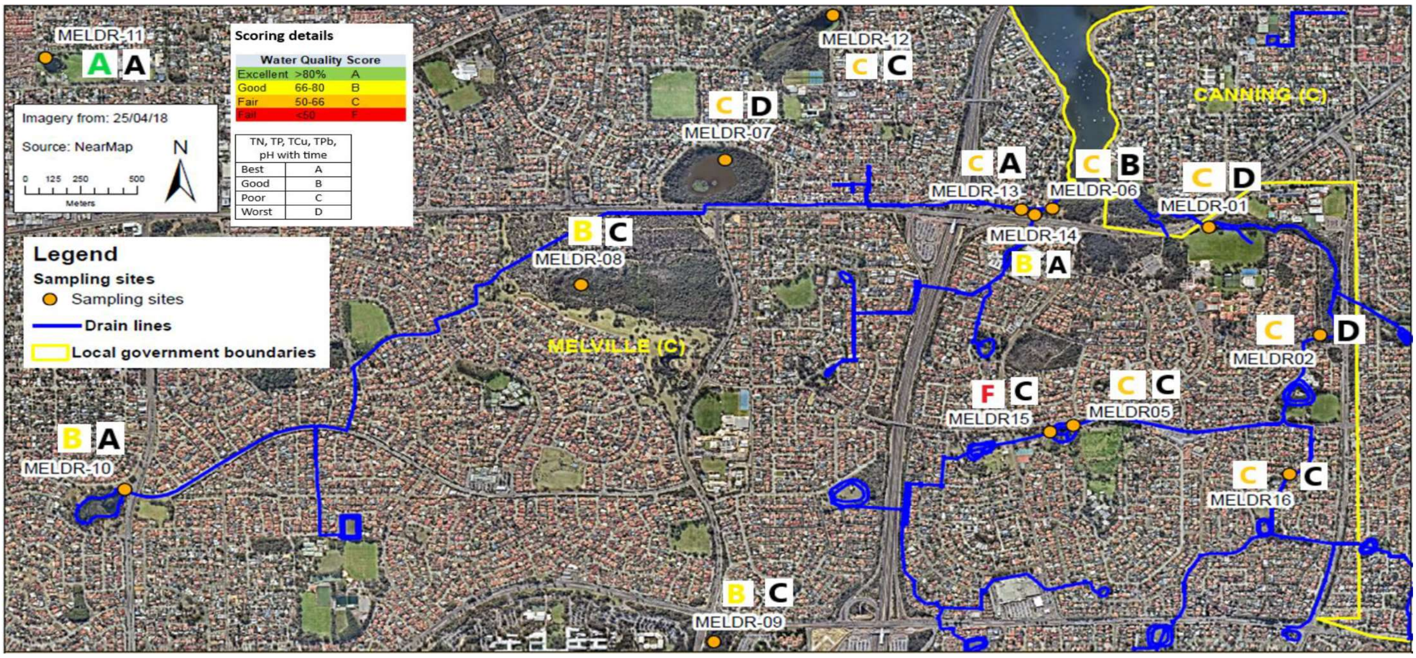


Figure 1. Map of drainage branches with two summary scores. The coloured letters are final compliance scores derived after comparing the 2021 samples to the medians of all previous years. The black letters summarise the results based on total nitrogen, total phosphorous, copper, lead as well as pH levels in the water over time to give an indication of how key parameters (nutrients, metals, and pH in particular) influence sites.

Introduction

City of Melville and the catchment monitoring program

The City of Melville (the City) is located eight kilometres (km) south-east of the central business district of Perth and has an area of approximately 53 km^2 with 18 km of foreshore (City of Melville, 2022). The City encompasses eighteen suburbs connected by over 1,300 km of local, arterial and major roads (City of Melville, 2022). The City is the third largest local government in the metropolitan region (Melville Talks, 2018) and in 2019 had an estimated population of 102,307 with an average of 19.29 persons per hectare (ha; .id, 2020). The City residents enjoy more than two hundred parks and reserves comprising 778 ha of public open space and 295 ha of bushland (City of Melville, 2021). In the City, there are approximately sixty-seven drainage sumps (City of Melville, 2010) and over 341 km of stormwater drainage pipes (City of Melville, 2016a).

Melville Bull Creek catchment

The Bull Creek Catchment contains the sub-catchments of Bull Creek itself and six other adjacent drainage catchments that have outfalls to the Canning River (Swan River Trust, 2012). The entire Bull Creek Catchment covers an area of approximately 43.5 km^2 (Swan River Trust, 2012). The catchment includes areas within the cities of Melville and Canning in Perth's southern and south-eastern suburbs Willagee, Kardinya, Winthrop, Murdoch, Leeming, Bull Creek, Rossmoyne, Willetton, Riverton, Shelley and Parkwood. Most of the Bull Creek Catchment has been cleared for urban residential development, with some recreational areas and a light industrial area in Willetton. To accommodate this development, the drainage network within the Bull Creek Catchment is highly modified and is largely piped, however some natural wetlands remain. There is over 10 km of foreshore within the Bull Creek catchment, some of which is in relatively natural condition (Swan River Trust, 2012).

This water quality assessment concerns the western part of the Bull Creek catchment within the City. The assessment includes the Bull Creek Main Drain and Brentwood drain, as well as the chain of lakes to the west of Bull Creek (Booragoon Lake, Blue Gum Lake, Piney Lakes, Quenda Wetland, Frederick Baldwin Lake and Marmion Reserve). Collectively, these will hereafter, be referred to as the "Melville Bull Creek catchment."

Bull Creek Main Drain meanders through a series of parks and urban landscape in the lower catchment, receiving stormwater from local drains, before discharging directly into Bull Creek and the Canning River (Swan River Trust, 2012). Bull Creek Main Drain has strong flow all throughout the year, even in summer, and is likely to receives some input through groundwater (Foulsham, et al, 2009).

The Brentwood drain also flows permanently due to groundwater interception and receives additional water when flood control pumps at Frederick Baldwin Lake and Kingston Place in Kardinya are in operation. Frederick Baldwin Lake and Kingston Place receive stormwater and groundwater from the suburbs of Kardinya and Murdoch (City of Melville, 2004). The Brentwood Main Drain also receives water from local drains and converges with the Mandala Crescent Branch Drain (also known as the RAAF drain) at the Brentwood Living Stream site before passing through Bateman Park and discharging into the Canning River.

The Brentwood Living Stream project, driven by a partnership of several agencies (including Department of Biodiversity, Conservation and Attractions [DBCA] Rivers and Estuaries Branch, the City, South East Regional Centre for Urban Landcare [SERCUL], Water Corporation and Main Roads) was launched in 2012 to mitigate some of the water quality issues identified in Brentwood drain at Bateman Park. The project involved the reconstruction of the water course where the Brentwood and Mandala Crescent drains converge (upstream of Bateman Park) using urban water sensitive nutrient/non-nutrient stripping designs.

Booragoon Lake, Blue Gum Lake outlet and Piney Lakes Reserve represent the northern extent of the Beeliar Wetland chain, a system consisting of inter-dunal depressions between the Spearwood and

Bassendean dune systems which include a series of lakes running parallel with the coast (City of Melville, 2019a, 2019b and 2016d). The chain of wetlands holds significance for the local aboriginal people (Whadjuk Noongar people) as they were important camping and ceremonial areas, as well as having provided an abundant source of food, offering fish, waterfowl, shellfish, vegetable roots and bulbs (City of Melville, n.d.). These wetlands are a surface expression of the underlying Jandakot Groundwater Mound aquifer (Natural Area Consulting, 2012a).

Booragoon Lake Reserve is located approximately 10.5 km south of Perth CBD in the suburb of Booragoon, bounded by Leach Highway, Aldridge Road and Lang Street, and occupies an area of approximately 13.5 ha. The reserve is comprised of wetland areas, upland remnant vegetation and parkland cleared spaces (Natural Area Consulting, 2012a). In the 1970s and 80s the Council drew water from a subterranean bore in the Alfred Cove area and pumped it into Blue Gum and Booragoon Lakes during summer to maintain the water level (City of Melville, 2004). However, this practice no longer occurs, and the Lake now has a water regime typical of Swan Coastal Plain wetlands, with water levels fluctuating in response to rainfall and groundwater level. Stormwater also enters the Lake from the surrounding urban catchment via six drains (including one drain collecting water from Leach Highway) and one drainage basin (City of Melville, 2019b).

Blue Gum Lake Reserve is a wetland reserve located approximately 9.5 km south of Perth Central Business District in the suburb of Mount Pleasant and occupies an area of approximately 11.1 ha. The Reserve is bounded by Canning Avenue, Moolyeen Road and Rountree Road and is comprised of wetland areas, upland remnant vegetation and parkland cleared spaces. The Reserve is comprised of four main areas: two wetland basins with an artificial island located between them, two areas of upland Banksia woodland community, a transitional zone characterised by *Melaleuca spp.* and *Eucalyptus rudis* woodlands, and parkland cleared areas with an over storey of predominantly non-native eucalyptus. In addition to being a surface expression of the groundwater, Blue Gum Lake also receives water from stormwater inflow from seven drains collecting water from the surrounding urban catchment, two of which have defective basins at their outlet (Natural Area Consulting, 2012b). Historically Blue Gum Lake would respond to fluctuations of the water table relating to seasonality and climatic variations; however following development in its surrounding area the lake has experienced significant changes to its natural water cycle (Natural Area Consulting, 2012b).

Piney Lakes Reserve is a dryland and wetland remnant area surrounded by urban development in the suburb of Winthrop. The Reserve is bound by Leach Highway to the north and Murdoch Drive to the east and encompasses approximately 67 ha (50 ha of bushland and wetland environments and approximately 17 ha of developed parklands to the south and west) (Natural Area Consulting, 2016). Piney Lakes includes two conservation category groundwater dependent wetlands, conservation category sumpland 6503 (eastern wetland) and conservation category sumpland 6504 (western sumpland) (DPaW, 2016). The western wetland is sampled for the purposes of this assessment. The western wetland historically contained water permanently, although since 2014 has shown no surface water expression (City of Melville, 2016c).

Quenda Wetland is a small unique reserve of a high conservation value located at the corner of Murdoch Drive and South Street in the suburb of Murdoch. The wetland is a conservation category sumpland with a man-made lake that collects stormwater runoff from surrounding development areas (City of Melville, 2016b). The wetland was originally seasonal, drying out in the summer months; however, it was artificially deepened to accommodate for the increased surrounding land uses (i.e., pine plantations). Since the recent increase in surrounding urban construction, increased stormwater flows enter the lake through various stormwater drains (including a large drain collecting water from Murdoch St John of God Hospital carparks), keeping the lake inundated throughout majority of the year (City of Melville, 2016b).

Marmion Reserve is located in the suburb of Myaree. In 2012 the lake was found to be infested with a pest eel-tailed catfish species (*Tandanus tandanus*) and the aquatic weed *Salvinia molesta* (City of Melville, 2016d). In an effort to control these species the lake was drained in 2014 and the species successfully eradicated (Clayton, 2015). Revegetation and removal of old vegetation has been occurring immediately surrounding the lake since this time (City of Melville, 2016d).

Background to the monitoring program

The City began water quality sampling of its lakes and the Bull Creek drainage biannually in 1996. In 2006, the Australian Government's Coastal Catchments Initiative identified the Swan Canning river system as a coastal 'hot spot' and funding was provided to the Swan River Trust (now DBCA Rivers and Estuaries Branch) to coordinate a Water Quality Improvement Plan (WQIP) for the region. The Swan River Trust developed the Local WQIP for the Bull Creek Catchment which was released in November 2012. The Bull Creek Catchment WQIP aims to reduce nutrient loads entering the Canning River through nutrient intervention and changed management practices. By using a treatment train approach, a combined set of management actions are applied along the nutrient pathways to meet water quality targets in the catchment (SRT 2012). The water quality monitoring partnership program between the City, SERCUL and DBCA forms part of the "Prevention" approach.

In 2007 a partnership between the City, SERCUL, the Department of Water (now Department of Water and Environmental Regulation [DWER]) and the Swan River Trust (now DBCA Rivers and Estuaries Science) was established in order to standardise all water quality monitoring data collection, management and storage methods. Since this time, the sites and parameters monitored have been modified in response to changes in budget and requirements (see Appendix B). The City has utilised data collected from this ongoing monitoring program to develop management plans for surface water assets within the city.

Purpose of the sampling

The purpose of this sampling program is to:

- assess current water and sediment quality in the Melville Bull Creek Catchment.
- identify patterns in water and sediment quality over time in the Catchment.
- identify any pollutant hotspots in the Catchment;
- monitor the success of management actions, including those under the Bull Creek WQIP, since 2007, and
- make recommendations for continuous improvement of water and sediment quality in the Catchment.

This water quality monitoring program also contributes valid data to the DWER Water Information (WIN) database, which is utilised in the management of the State's water resources.

Sampling Methodology

For more information regarding the methodology of this monitoring program see City of Melville Bull Creek Catchment and Melville Lakes Water and Sediment Quality Sampling and Analysis Plan 2021 (SERCUL, 2021).

Site locations

Fourteen sites from the Melville Bull Creek catchment were sampled to represent the water quality in different portions of Bull Creek catchment and the Melville lakes, whilst considering accessibility and historical sampling sites.

Table 1 provides a detailed location description and Easting and Northing of each of the sample sites. A map showing the location of the sites is provided in Figure 2.

Note that hereafter, sites will be referred to as their number only, without the prefix “MELDR-,” for the purposes of brevity. Also, site MELDR-01 historically was called PSDTBCMD although will be referred to as site 1 throughout the rest of this report.

Table 1. List and description of sampling sites (*waypoints; WGS84, 2010 to 2015***)**

Site No.	WIR site ref.	Drain section/component	Sampling point location	Easting	Northing
MELDR-01 (previously PSDTBCMD)	6162178	Bull Creek Park main drain	Culvert under Leach Hwy	392965.3	6453785.6
MELDR-02	6162370	Brockman Park	Where piped drain opens	393466.5	6453208.5
MELDR-05	6162373	John Creaney Park outlet	Compensation Basin Outlet	392359	6452734.7
MELDR-06	6161691	Bateman Park	Downstream of the confluence of the two drains	392269.8	6453880.2
MELDR-07	6162375	Booragoon Lake	In the lake at the end of the boardwalk jetty	390734.68	6454164.09
MELDR-08	6162376	Piney Lakes	At the lake outlet	390151.59	6453473.10
MELDR-09	6140831	Quenda Lake	At the lake outlet	390749.20	6451597.51
MELDR-10	6162377	Frederick Baldwin	At the lake outlet	387989.87	6452295.91
MELDR-11	6162378	Marmion Reserve	At the lake outlet	387774.89	6454629.75
MELDR-12	6162379	Blue Gum Lake	In front of car park inlet	391282.81	6454886.75

Table 1 continued.

Site No.	WIR site ref.	Drain section/component	Sampling point location	Easting	Northing
MELDR-13	6165324	Brentwood drain	Pulo Rd & Leach Highway, 10 m walking from Pulo Rd. Site moved at beginning of 2015-16 sampling due to construction works reshaping the drain.	392126.59	6453865.28
MELDR-14	6165325	RAAF drain	10 m down from pipe under Leach Highway	392195	6453841
MELDR-15	6165331	John Creaney Park inlet	Approx. 5 m upstream of the main inlet into John Creaney Park, access via Water Corp drain utility access hole (lid lifting and bucket and rope required)	392256.48	6452699.35
MELDR-16	6165332	Closed pipe Downstream Elizabeth Manion Park	On Nicholls Cres close to Hurley Way, in front of pathway, access via Water Corp utility access hole (lid lifting and bucket and rope required)	393327.76	6452478.47

Figure 2. Melville Bull Creek Catchment and Melville Lakes sampling sites for 2021

Sampling schedule and procedures

Samples were collected in accordance with the protocols outlined in the Catchment Specific Sampling and Analysis Plan authored by SERCUL (2021).

Initial sampling to establish base line data in 2007 was intended to capture seasonal variations, in particular the impact of rainfall (online data from Bureau of Meteorology). Therefore, most sites were first sampled in July and October (2007) and again in January, April, September, and November (2007 and 2008). These sampling events established baseline data and identified July, August, September, October, or November as the most valuable sampling months; unless environmental factors such as dry wetlands (which has occurred several times in January and April), prevented it.

July sampling allowed for interpretations of significant 'first flush' events. August and September samples reflected winter months, and October or November indicated what may occur in wetlands as rainfall is gradually reduced in spring. Most of the sampling dates were also in the third or fourth week of each month. Any changes to sampling schedules were considered in the interpretations of the results. Field observations were also made to add value in understanding the ecological processes and real or potential human impacts on the wetlands.

In 2021, sampling was conducted at the 14 Melville sites on four sampling occasions (22nd July, 19th August ,16th September, and 14th October 2021). All sites were sampled on all sampling occasions. Temperature and rainfall data for the duration of the sampling is detailed in Appendix C (BOM, 2021). Field observation forms were filled out for all water samples.

Analytical procedures

All water samples, together with a Chain of Custody (COC) form, were transported to and analysed by the ChemCentre laboratory in Bentley, Western Australia. Laboratory results were reported as per the limits of reporting (LOR; being the minimum detection level) for each parameter listed in Table 3.

ChemCentre is an accredited laboratory by the National Association of Testing Authorities (NATA). Sediment samples were submitted to Microanalysis Australia for particle characterisation.

Parameters measured

Water at each of the 14 sites was measured *in situ* with a YSIProDSS Multimeter (sonde) for physical properties (dissolved oxygen, pH, electrical conductivity, temperature and total suspended solids). It should be noted that electrical conductivity has been measured as specific conductance: that is, values have been corrected to 25°C to allow for comparisons to be made between samples taken at different temperatures (i.e., between different sites and different months). The Standard Operating Procedures (SAP) document supplied to the City of Melville contains details of operational activities.

Water samples at all Melville Bull Creek sites were sampled at four times and analysed for nutrients and metals according to the following schema;

Nutrients - total phosphorus (TP), total nitrogen (TN), total oxidised nitrogen (NOx-N), total organic nitrogen (TON), dissolved organic nitrogen (DON), filterable reactive phosphorus (FRP) and nitrogen as ammonia/ammonium (NH_3-N/NH_4^+-N) at all sites on all four sampling occasions.

Total metals - aluminium (Al), chromium (Cr), copper (Cu), iron (Fe), lead (Pb) and zinc (Zn) assessed at all sites on the first sampling occasion for surveillance.

Soluble metals aluminium (Al), chromium (Cr), copper (Cu), iron (Fe), lead (Pb) and zinc (Zn) assessed at all sites on all four sampling occasions for ongoing assessment.

Total suspended solids and total water hardness at all sites on all four sampling occasions.

Total and soluble mercury (Hg) assessed at 3 sites (13, 14 and 6) on all four sampling occasions as these sites have previously been identified as high in Hg.

Total metals: mercury (Hg), arsenic (As) and nickel (Ni) at site 7 on the first sampling occasion for surveillance.

Soluble metals: mercury (Hg), arsenic (As) and nickel (Ni) at site 7 on all sampling occasions for ongoing assessment.

Sediment was collected from 11 of the 12 scheduled sites (sites 1, 2, 5, 6, 7, 9, 10, 11, 12, 13 and 14) for the analysis of:

Total metals/metalloids (Al, As, Cr, Cu, Fe, Hg, Ni, Pb, Se (Selenium), and Zn);

Moisture and particle size analysis.

It is noted that sediment could not be sampled at site 8 for a second year in a row due to the amount of organic matter covering the sediment layer. Notation for sampling methods for sampling also differed, though the SAP required a composite of 3 samples (CL) to be collected using a 9.5 cm diameter polycarbonate corer (CR). It is likely that on some occasions the CL/CR approach was used but noted down differently on the Chain of Custody form.

Table 2. Summary codes used on Chain of Custody forms to describe sediment sampling methods and instruments.

Year	Collection method	Collection instrument
2013 to 2017	CC – composite	Not noted of Chain of Custody forms
2018	CL composite localised sample	CR corer
2019	OL (not a DWER code)	CR corer
2020	CL composite localised sample	CR corer
2021	CL composite localised sample	CR corer

Table 3. Analyte and lowest limits of reporting (LOR) of the concentration of parameters detected in water and sediment samples. LOR is based on the precision and accuracy of methods.

Measured parameter	LOR (mg/L)	Measured Parameter	LOR (mg/kg)
WATER		SEDIMENT	
Total phosphorus	0.005	Aluminium – total	10
Total nitrogen	0.025	Arsenic – total	0.2
Total organic nitrogen	0.025 m	Chromium - total	0.05
Filterable reactive	0.005	Copper - total	0.5
Total oxidised nitrogen	0.01	Iron - total	5
Nitrogen as ammonia	0.01	Lead - total	0.5
Dissolved organic nitrogen	0.025	Mercury	0.02
Total Suspended Solids	1	Nickel - total	0.1
Total water hardness	1 m	Selenium	0.05
Aluminium – total and	0.005 mg	Zinc - total	0.25 or 5
Arsenic – total and soluble	0.0001		
Chromium - total and	0.0001		
Copper - total and soluble	0.0001		
Iron – total and soluble	0.005		
Lead - total and soluble	0.0001		
Mercury – total and soluble	0.00005		
Nickel – total and soluble	0.0005		
Zinc - total	0.005		
Zinc - soluble	0.01		

Sediment samples were also analysed for particle size distribution by *Microanalysis* Australia. Particles were grouped into the following size classes (Table 4) according to the Wentworth scale (Wentworth 1922) using wet sieving followed by laser diffraction (Murdoch et al. 1997).

Table 4. Particle size classification

Class	Size
Clay	<4 µm
Silt	4-62 µm
Fine sand	62-250 µm
Medium sand	250-500 µm
Coarse sand	500-2,000 µm
Gravel	>2,000 µm

Overview of chemical parameters

Physicochemical

All physicochemical parameter data (pH, dissolved oxygen, electrical conductivity, total suspended solids, and temperature) collected in 2021 from Melville Bull Creek catchment sites are shown in Table D-4 to Table D-9 in Appendix D. The factors that influence changes in these physicochemical parameters and the impacts that changes to these parameters can have to aquatic ecosystems are shown in Table E-46 in Appendix E.

pH

pH is a measure of the acidity or alkalinity of a water body and is measured on a logarithmic scale (base 10). For example, a pH of 5 is ten times more acidic than a pH of 6.

Dissolved oxygen

Dissolved oxygen (DO), measured in %saturation or mg/L indicates the amount of oxygen in a waterbody that has dissolved from the atmosphere and aquatic plants (US EPA 2021. Both %saturation and mg/L oxygen will follow the same trend, though acceptable levels of %saturation or mg/L for life will vary according to the source, water flow, seasonal and diurnal availability of oxygen. The difference between %DO and mg/L DO is that %DO reflects the total oxygen pressure in the water while mg/L DO is calculated by considering the combined impacts of %DO, temperature and salinity on oxygen saturation. The latter, mg/L DO, is therefore a more valuable measure of the DO available for aquatic life.

Electrical conductivity

Electrical conductivity (EC) (mS/cm) is the ability of water or soil to conduct an electrical current. It is commonly used as a measure of salinity or total dissolved salts. Solutions with high salt concentrations will conduct electricity better than pure water. EC is increased when the total concentration of inorganic ions (particularly sodium, chlorides, carbonates, magnesium, calcium, potassium and sulphates) is increased.

Total suspended solids

Total suspended solids (TSS) in a waterbody is a measure of the concentration of suspended materials in the water that can be removed by filtration. TSS can include a wide variety of material, most often comprising soil particles and organic material (e.g., algae, microorganisms, decaying plant and animal matter). A multiprobe will derive TSS from measures of turbidity (the amount of light that passes through a sample).

Temperature

It should be noted that water temperature will often increase throughout the day, and hence sampling time can partially influence recorded water temperature. During the 2021 monitoring period, sampling was conducted at varying times between 08:00 and 14:30 hours.

Nutrients

Nitrogen

Nitrogen in waterways can exist in both inorganic forms, including oxidised nitrogen (encompassing nitrate (NO_3^-) and nitrite (NO_2^-)), ammonia nitrogen (including both ammonium (NH_4^+) and ammonia (NH_3)), and dissolved and particulate organic forms. Nitrogen is converted between these forms, as well as nitrogen gas (N_2), via physical and biological processes known collectively as the nitrogen cycle (Figure 8). When plants and animals die or when animals excrete their wastes, organic nitrogen in the water is converted by bacteria to ammonium/ammonia (mineralisation), then to nitrite and nitrate (nitrification) (see below). The conversion to nitrite or nitrate requires dissolved oxygen, and if the water is anoxic, this process slows down and ammonia/ammonium levels may build up to toxic levels. Ammonium can be converted to ammonia gas (volatilisation) in alkaline conditions and nitrate can be converted to nitrogen gas (denitrification) in anoxic conditions, with the release of these gases into the atmosphere resulting in a loss of nitrogen from the water (Northern Territory Government, 2003). Plants use both nitrates and ammonium for growth, but high ammonium forms of nitrogen can be toxic to aquatic life while high nitrogen can result in excessive growth of plants and algae and thus oxygen extremes, either too much or too little oxygen conditions.

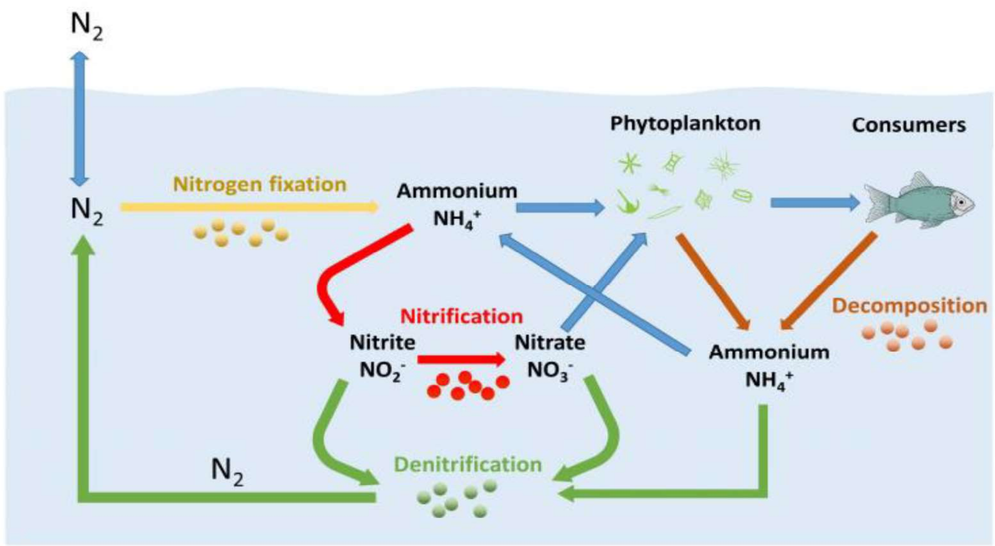


Diagram of the nitrogen cycle in a wetland. Note: the conversion of ammonium to nitrite and nitrates require dissolved oxygen. This highlights the importance of maintaining dissolved oxygen levels in wetlands. (image from Creative Commons, accessed 02092022)

Phosphorus

Phosphorus in water exists in both soluble and particulate forms. Soluble phosphorus is largely comprised of inorganic phosphate ions ($H2PO4^-$ and $HPO4^{2--}$, also known as orthophosphate) but small amounts of condensed phosphate (polyphosphates and metaphosphates) and dissolved organic forms of phosphorus may be present. Filterable reactive phosphorus (FRP) (sometimes also referred to as SRP, soluble reactive phosphorous) is a measure of the phosphates that pass through a 0.45 µm filter and respond to colorimetric tests without preliminary hydrolysis or oxidative digestions of the sample and is largely a measure of orthophosphate. Particulate phosphorus is comprised of organic material (decaying plant and animal matter); phosphorus adsorbed to particulate material and phosphorus minerals (e.g., apatite).

Plants and algae predominantly use orthophosphates to grow. Because of challenges in determination of phosphorus used by plants however, FRP (which tends to measure mainly orthophosphates) has been commonly used as a general indicator of bioavailability of phosphorus to plants. But its use in arriving at conclusions must be made with consideration of the difficulties associated with accurate determinations of phosphorus use by plants.

Metals in water and water hardness

Refer to tables in Appendix D show all metal and hardness concentration data collected in the Melville Bull Creek catchments for the 2021 water quality sampling program and tables in Appendix F outlines potential sources of metals and hardness and the impacts of these parameters on aquatic ecosystems. For all graphs (Appendix A), a value equal to half the LOR was substituted for those occasions where concentrations were recorded as 'below the laboratory limit of reporting' (<LOR) to allow these 'unknown' values to be represented graphically and to differentiate them from those samples that recorded concentrations equal to the LOR.

Total hardness, expressed as calcium carbonate ($CaCO_3$), is the combined concentration of earth-alkali metals, predominantly magnesium (Mg^{2+}) and calcium (Ca^{2+}), and some strontium (Sr^{2+}) in the water. Other metal ions (such as aluminium, iron, zinc and manganese) also contribute to water hardness. The source of this hardness is limestone dissolved by water that is rich in carbon dioxide. Increasing calcium and magnesium in water (hardness) is frequently associated with increases in alkalinity (as calcium and/or magnesium carbonate), and thus, pH (ANZECC and ARMCANZ 2000). Both hardness and pH influence metal and nutrient solubility and availability to plants.

Metals in sediment

A study of sediments in Bull Creek (Nice, 2009) identified sediment concentrations of zinc, mercury, lead and selenium exceeded ANZECC guidelines. Following this, an ecotoxicological investigation by Nice (2011) found that sediment collected in Bull Creek in the vicinity of the Bull Creek Main Drain and the Brentwood Main Drain was toxic to test organisms (mussels, *Mytilus edulis planulatus*), copepods (*Gladioferans imparipes)*, amphipods (*Grandidiella japonica)* and pink snapper (*Pagrus auratus)*. This investigation subsequently recommended further physical and chemical assessments of the sediments to assist the identification of potential causes of the above issues in the Bull Creek catchment. This water and sediment quality assessment will help determine the source of these metals in the catchment and how these move through or remain within the sediment

Refer to tables in Appendix D for all sediment total metal concentrations data collected in the Melville Bull Creek catchments in 2021. Potential sources of these metals are outlined in Appendix F.

For all graphs, a value equal to half the LOR was substituted for those occasions where concentrations were recorded as <LOR which is a standard technique (Helsel, 1990) to allow these 'unknown' values to be represented graphically and to differentiate them from concentrations equal to the LOR. Sites that underwent sediment sampling and analysis are outlined in section 1.3.

No guideline currently exists for aluminium and iron concentrations in sediment; therefore, it is difficult to gauge the severity of any potential impacts arising from the concentrations recorded in the sediment of the Bull Creek catchment.

Reporting

Data presentation

Graphs and descriptive statistics summarising the results from the analyses are described in the following sections and raw data is available in Appendices.

Findings were triangulated to established standards (see below) and summarised for each site with descriptive statistics used where it was considered to add value and depth to the findings. The sequence by which site data is reported is as follows;

1. **Bull Creek Main Drain**, composed of John Creaney Park and Bull Creek Main Drain wetlands – sites 15, 5, 16, 2 and 1
2. **Brentwood Drain** wetlands– sites 13, 14 and 6
3. **Melville Lakes**, Lakes of the Bull Creek Catchment – sites 7, 8, 9, 10, 11 and 12.

Guidelines and how these were used to analyse results

As noted previously, to provide a frame of reference for water and sediment quality data collected from the Melville Bull Creek catchment, multiprobe and laboratory results were compared to trigger levels from the ANZECC and ARMCANZ (2000, (ANZG, 2018)Australian and New Zealand Guideline for Fresh and Marine Water Quality (hereafter referred to as the “ANZECC guidelines”) and in most cases also the NHMRC (National Health and Medical Research Council) guidelines.

Exceedance of a trigger value from the ANZECC guidelines indicates that there is the potential for an impact to occur and should therefore prompt a management response. The rationale for the trigger values used in the ANZECC guidelines is provided in volume 2, chapter 8 of the guidelines. The ANZECC trigger values used to compare the results of the analysed parameters are shown in Appendix A.

The ANZECC guidelines specify trigger values that should not be exceeded for physical and chemical stressors of different ecosystem types. The results of some sites (1, 2, 5, 6, 13, 14, 15 and 16) were compared to the ‘lowland rivers’ trigger values and others (7, 8, 9, 10, 11 and 12) to the ‘wetlands’ ecosystem trigger values. These are considered to be most applicable for drain and lake sites, respectively. The ANZECC guidelines do not provide a trigger value for total suspended solids; however there has been an experimentally derived guideline value (6 mg/L) developed for CSIRO and Waters and Rivers Commission (by Hosking Chemical Services; pers. comms. Dominic Head, DWER), which was used for comparison purposes in this assessment.

To graph the site results and allow for comparisons with their referenced trigger values, sites have been grouped into lowland rivers and wetlands and displayed as such on the graphs. The ‘lowland rivers’ sites have been separated into the two main drainage lines (Bull Creek Main Drain and Brentwood Main Drain) and arranged from the top of the catchment to the bottom (entrance to the Canning River) creating a more visual display of the individual segments allowing for better interpretation of flow and spatial patterns and understanding the aquatic conditions upstream and downstream.

Total nitrogen and total phosphorus concentrations will also be compared to the long-term and short-term nutrient concentration targets in catchment tributaries of the Swan Canning river system in the Healthy Rivers Action Plan (SRT 2008).

The ANZECC (ANZG, 2018) guidelines also specify “high reliability” trigger values for toxicants (including metals and ammonia) in fresh waters where sufficient “No Observed Effect Concentration” data is available and is published in chapter 3 of the ANZECC guidelines. Several trigger values (99%, 95%, 90% or 80%) have been derived for each toxicant depending on the proportion of species for which protection is sought. Urban and industrial catchments tend to be highly modified and are often artificial ecosystems, where the risk of toxicant contamination is high and current environmental value is low. On that basis, the ANZECC trigger values for 80% protection of freshwater biota would be applicable to the waterbodies/tributaries within the City. However, the Bull Creek and Brentwood drains discharge into the estuary environment of the Canning River where environmental values are high and in the absence of established Australian or confirmed locally available trigger values for estuarine or brackish waters, interpretations were made based on site specific information and data with comparisons made to fresh and marine ANZECC trigger values for 95% protection (ANZG, 2018).

For the metals, cobalt and molybdenum, “high reliability” values are not available and therefore the ANZECC guidelines recommend the use of “low reliability” trigger values calculated by different means. For chromium (III), the “high reliability” trigger value is considered too high and therefore the use of an interim value for freshwater protection is recommended. For iron, the ANZECC guidelines suggest the use of an interim value based upon the current Canadian guideline level (CCREM 1991). The ANZECC guideline trigger values for protection of biota for chromium (III), copper, lead and zinc are hardness dependent, and as such specific trigger values for each sample have been calculated and adjusted based on corresponding site hardness levels (see relevant tables in Appendix D for the details and calculations).

The system being monitored is largely a piped system that ultimately discharges into the Canning River. Much of the monitoring captures data from water running directly off roads and residential areas with no treatment prior to entering the lakes and drains. From a human-use perspective, Bull Creek is not a source of drinking water but may be accessed by the public at several points, on public and privately owned land. Therefore, it is reasonable to compare the toxicant results to the National Health and Medical Research Council’s (NHMRC) Guidelines for Managing Risks in Recreational Water (2008) (hereafter referred to as the “NHMRC recreational guidelines”). Trigger values for pH and dissolved oxygen are specified in NHRMC recreational guidelines. For toxicant parameters (i.e., metals and ammonia), the NHRMC guidelines recommend that recreational trigger values be calculated by multiplying the relevant trigger values in the NHMRC (2016) Australian Drinking Water Guidelines 6: 2011 (ADWG) by ten. An exceedance of the referenced trigger level does not indicate that ‘standards’ are not being met but is an indication that further consideration should be given to the situation.

The revision to the ANZECC guidelines (ANZG, 2018) for sediment (Simpson, et al., 2013) provides both low and high trigger values for metals in sediment. Background concentrations should be investigated where concentrations are between the low and high trigger values. If the results exceed the high trigger value guidelines or are above the background concentrations a further assessment for the bioavailability of the metal is required.

Analytical methodology

Understanding the charts and compliance cards

Boxplots

In order to compare data collected in 2021 with that collected in all previous years boxplots were created (also known as box and whisker plot). These can be used to summarise descriptive statistics: median, lower quartile (Quartile 1 (Q1) = 25% of the samples/population), upper quartile (Quartile 3(Q3) = 75% of the samples/population), and gives an insight to more extreme upper and lower values (Flowingdata, 2008). The graph below (Figure 3) was obtained from Google Commons (accessed; 02092022).

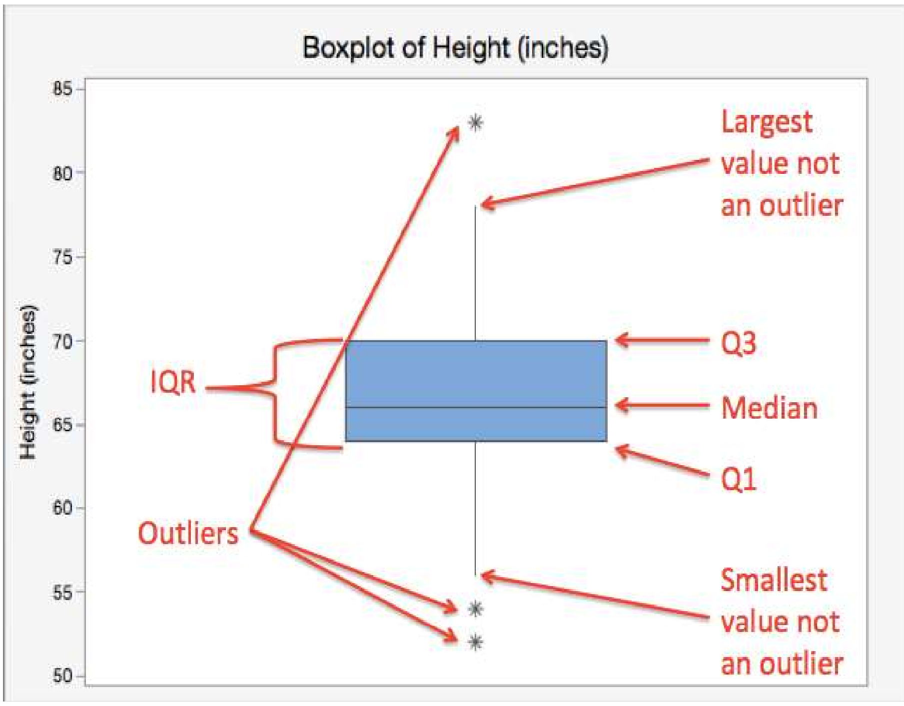


Figure 3. Boxplot or box-whisker plot with descriptors showing the purpose of the component parts of the plot. The data is fictional and used for display only.

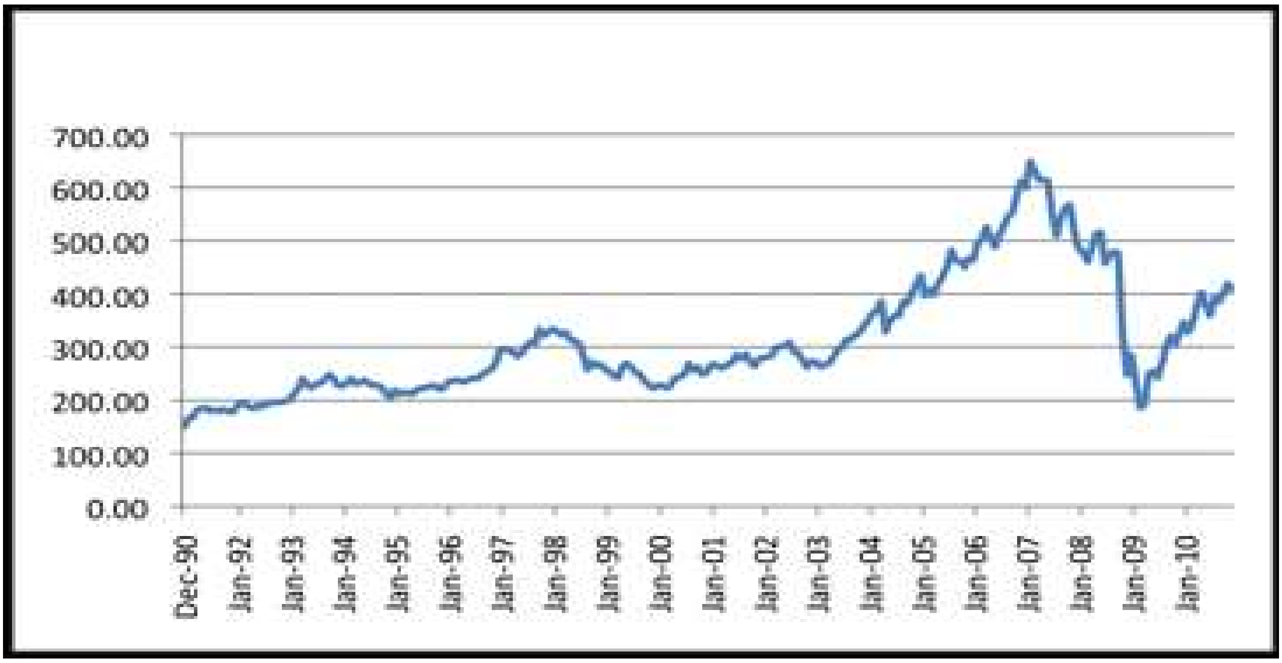
The box plots in this report include;

- median of data collected prior to 2021
- outliers of data collected prior to 2021

as well as the median for 2021 data.

Time series plots

To examine the influence that time (sampling times along the x-axis) has had on the data, time series plots were also produced. The data points were connected in order to view if overall trends with time (seasonal, annual or years) occurred at locations and to more easily and visually compare sites. These were done for each site or site group and parameter for water and per metal for sediments. Where data was highly variable and different, separate plots were done. All plots were explored for general trends and groupings. Linear trends were explored, but not added to the displayed plots as these would clutter the plots. In addition to this, descriptive statistics including mean, standard deviation and sample sizes of historical data is provided to explore differences between sites and within data. Although measures of central tendencies such as median and mode are common in highly variable data, in particular data influenced by outliers, the mean and standard deviations provide additional valuable insights. As normality in data was not assessed, no further analyses were done. Together with box plots, this comprehensive approach allows for in-depth analysis of the data.

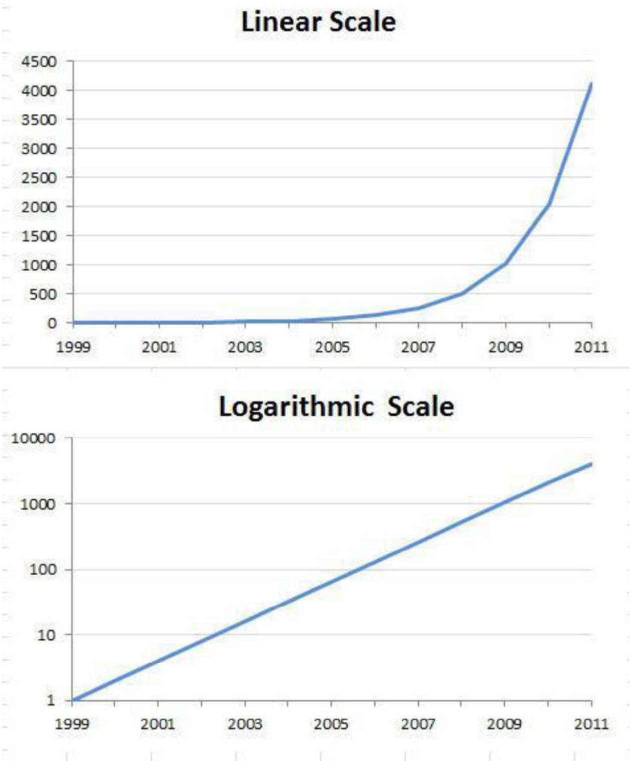


Google Commons; Accessed November 2022.

Figure 4. Time series plots where time is represented on the x axis can be used to view seasonal and interannual changes to parameters.

Data transformation and scales

Most data and plots of data is represented untransformed, i.e., in its raw form. But when there are large differences in the magnitude of y-axis parameter values, it can be difficult to visualise these without changing the scale of the y- axis. Therefore, in several cases the data on the y-axis is transformed by replacing each value (y) with the logarithm (log y) of that value. While most of these transformations are done using log to base 10, in some cases, log to base 2 allowed for better visualisation of the data. Note that these transformations were only done to improve the interpretability of the plots, not in preparation for statistical analyses.



Google Commons; Accessed November 2022

Figure 5. Logarithmic transformation can be used to allow better visualisation of small as well as large differences on one plot. It visually brings high values "down" and low values "up".

Compliance Cards

Wetland report cards were developed to communicate, often complex and substantial amounts of information about the condition of the aquatic environment at each site were created. These provide quick, visual, and historical information about the health of each site and can be used to guide their management and restoration. The analyses made about specific parameters of these cards (see cards for details) are based on how well they comply with published trigger values or guidelines (Appendix A), such as those published by ANZECC/ARMACANZ (Australia and New Zealand Environmental and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand) and NHMRC (National Health and Medical Research Council). As these report cards are therefore based on how well results comply to requirements they are referred to as Compliance Cards in this document.

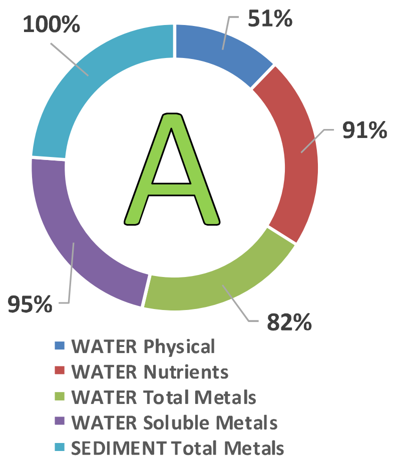
There are four main components to these score cards, a Circular graph, a Water Quality Score grade, and a summary data table (Figure 6).

1. A donut graph, allows information to be visualised in a proportional (percentage) manner. The arcs of the circle are proportional to what percentage of the samples of sets of parameters were compliant to trigger or guidance values. This included samples from the start of sampling up to 2020.
2. The Water Quality score is produced by taking the average number of times overall data for each group of analyses complied with trigger values or guidelines since sampling began and up to 2020, in the donut graph. The groups were; physicochemical (physical);

nutrients; total metals; soluble metals and total metals in the sediment. This was then ranked from Excellent to Poor (Figure 6).

3. The summary table is a horizontal bar chart where the percentage of compliances in the periods from start of sampling are compared to compliances in samples taken in 2021.
4. Information about the site location and reference codes.

Following the Compliance Cards are notes and, in most instances, images of the sites, as well as recommendations for management.



Doughnut graph

This is an example of the graphical representation of the health of the wetland based on all data. The percentages refer to the percentage of the specific sample type that are compliant with standards.

For example, 51% of samples examined for physical water parameters were compliant. In comparison, 100% of sediments samples examined for metals were compliant.

Water Quality Score grade

Water Quality Score		
Excellent	>80%	A
Good	66-80	B
Fair	50-66	C
Fail	<50	F

This coloured grade with a score index was used to present a quick visual indication of the overall health of the water in the wetland.

The symbol, A, B, C or D and its associated colour displayed in the Circular graph is derived from the data on compliances and background information and knowledge about the stie.

A quick calculation of the average water quality compliance was done and compared to a score index (Water Quality Score). For example, the average of the compliances to the left is 84 ((51+91+82+95+100)/4 =84). This falls within the Excellent quality category of above 80%. Hence, a green A reflects the overall health of this wetland.

Figure 6. The doughnut graph is abbreviated to ring with the final overall score added into the centre. This score was derived from the Water Quality Score table and based on the average of the proportions of compliances since sampling began and up to 2020.

In addition to the Doughnut Graph and Score Index (Figure 6) an overall table and plot of all the water quality data is presented (Figure 7). This table and plot contains information of historical compliances (mostly 2007 to 2020) alongside the most recent compliances (2021) with trigger values of guidelines for most parameters. Information of the number of samples, Water Quality Score water quality grade and average ranges (red and green lines) are also provided.

Alongside each parameter, are symbols, =, + and – that indicate if the compliance scores in 2021 were similar, better, (Wedlock, Burgess, & Ford, 2011) or worse respectively, to that of the historical compliances.

Note 1 – Water Quality Score was derived from research at a wetland in Queensland (Wedlock, Burgess, & Ford, 2011)

Note 2 – Sediment data is not presented in the table and was not collected from several sites until 2013. When data of sediment was available it was included in the Doughnut graph and used to generate a Water Quality Score grade score.

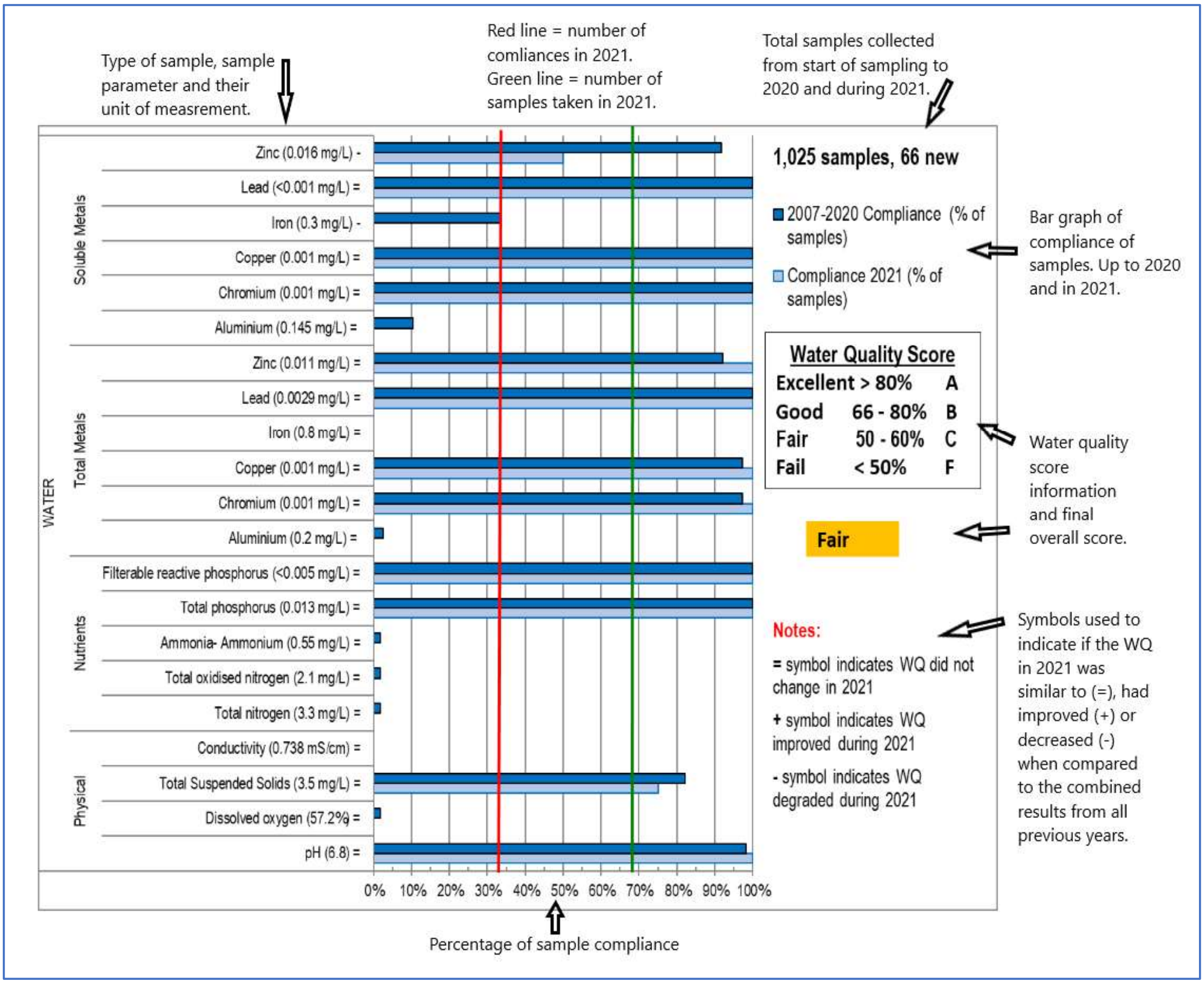


Figure 7. Graphical report card illustrating the data from when the site was first sampled (usually 2007) to 2020 and how it compares (based on compliance scores) to samples collected in 2021.

Results and detailed interpretations

The following section contains the field observations made in the 2021 sampling season at each site, the data plots where results and trends are examined, and finally key insights were highlighted.

Field observations

Table 5 shows the observations recorded during field work at Melville Bull Creek catchment sites on at least one sampling occasion in the 2021 sampling period.

Data plots

This section contains two types of plots and their interpretations. First, box whisker plots that compare overall medians from previous years of sampling (up to and including 2020) with that of the median from samples in the 2021 sampling period. The summary of these are directly before or after the plots.

Second, there are time series plots for most parameters to identify changes of the parameters since sampling began. Occasionally, plots use log10 or log2 on the y-axis to allow for visual comparisons. This is particularly valuable when there are large variations in values (highs and lows). The discussions about these follow that of the discussion about the box whisker plots (and are not always referenced to a figure). Additionally, in many cases summary descriptive statistics are also available (mean, Standard Deviation (SD) and sample size (n)). These allow for further comparisons of variation between sites.

Such in-depth analyses and interpretations of the data, allows for accurate comparisons to be made with previous data to the latest set of data, as well as examination of trends that will direct future management actions.

References to Figures and Tables in the results section

Please note, that as the Figures and Tables are arranged logically, the need to include intext direct references to them in the text was not considered necessary. Associate the box plots with test directly referring to these, time series plots to test referring directly to these. Tables of descriptive statistics are included in many cases to summarise data and explore variation within and between sites. These are referred to during discussions.

Notes for Table 5 on the next page.

**could be indicative of anoxic conditions*
Flow codes; N = No flow, Sl = Slow flow, M = Moderate flow, H = High flow, F = recorded as flowing but no observations made about velocity
Numeric codes;
1 few observations were made at sites 15 and 16
2 variations in water visibility are subject to weather conditions and events leading up to the sampling event. As such, sites can experience either very turbid or clear waters on any given day dependent on time of sampling.
3 sandy sediment- build up before rock riffle near bridge
4 suspected depositions from previous high flow event
5 considering the recent rainfall
6 sediment removal since last year (2020)

Table 5. Field observations made during the 2021 sampling occasions. The number of times the symbol 'x' is represented in the table indicates the number of sampling events this observation was noted when sampling in 2021. Note; when the drain was dry, sampling could not be done.

Sites	1	2	5	6	7	8	9	10	11	12	13	14	15[1]	16[1]
Flow at each sampling event Visual observation	M, Sl, M, M	Sl, F, M, Sl	Sl, F, M, Sl	M, F, M, M	N, N, N, N	N, N, N, N	N, N, N, N	N, F, N, N	N, F, N, Sl	N, N, N	M, F, M, M	M, Sl, M, M	N, Sl, M, M	Sl, F, H, Sl
Emergent macrophytes					x	xx	xx				x			
Clarity	xxx	xx	x		x	x		xx	xxx		x	xx	xx	xx
Tannins	x	xx		x	xx	xxx x	xxx x	x		xxx x	x	xx	x	
High water level		x			x	xx	xx	x	x	xx				
Low water level			x								x	x		x
Iron flocculation or possible iron reducing bacteria		x	x											
Suspended solids									x					x
Algae present (green)					x	x			xxx					
Surface water 'scum' and/or biofilm			xx					x		x			x	
Oil slick			x											
Unpleasant odour*				x								x		
Sediment deposition	x			x								x[3]		
Litter (anthropomorphic)			xx					x						
Organic debris			xx		x			xxx[4]		x		xxx		
Fallen grate												x		
Small fish		x												
Water birds		x			xx			x	xx					
Scum build-up similar to detergent bubbles		x												
Frogs heard					x	x	x							
Sediment removal	x[6]													
Neighbouring ground works													x	
Floating aquatic weeds/duck weed					x					x				

John Creaney Park and Bull Creek Main Drain Branch

This section discusses the parameters measured for sites John Creaney Park inlet (15) and John Creaney Park outlet (5), and the parameters measured for the Bull Creek Park drainage closed pipe downstream Elizabeth Manion Park (16), Brockman Park (2) and Bull Creek (Park) Main Drain (1).

Physicochemical Properties

pH

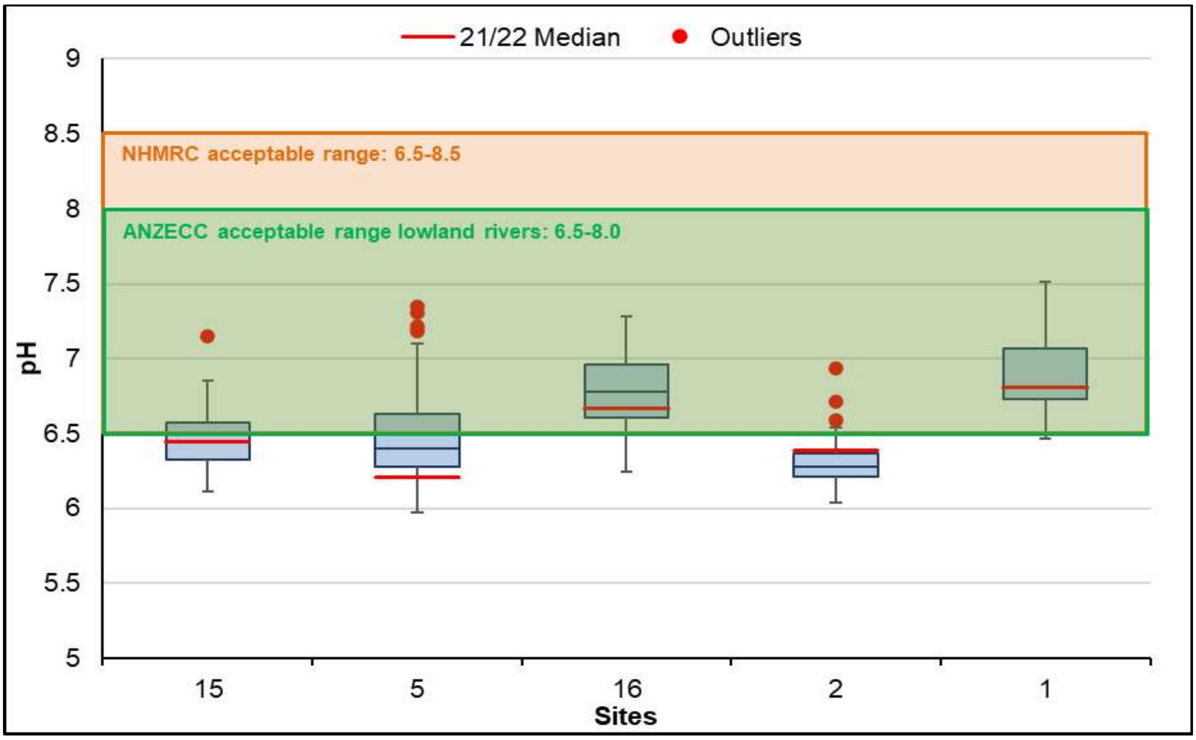


Figure 8. Box plot of pH 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box Whisker

When compared to data pre-2021, the data from these sites in 2021 typically recorded pH values below the acceptable range, except for site 16 and site 1 which recorded more acceptable levels than unacceptable (Figure 8 and Table D-4 in Appendix D). Sites 16 and 1 recorded pH medians within the ANZECC and NHMRC acceptable range (6.78 and 6.8, respectively). Sites 15, 5 and 2 recorded pH medians below the ANZECC and NHMRC acceptable range (6.49, 6.4 and 6.28, respectively). pH across the sites have long term medians ranging from 6.4-6.8 and 2021 medians ranging from 6.21-6.8.

Time series

There is a trend however, suggesting pH at the John Creaney Park outlet (site 5) has been decreasing since sampling began in 2007, but this seems to have settled at around pH 6.6 since 2014 (Figure 9).The variation at the outlet seems to have been higher than that at the inlet. There is also a trend suggesting pH at Bull Creek Main Drain near Leach Highway (site 1) had a higher pH when sampling began at this site in 2007 compared to that since 2014 sampling events. The pH at Brockman Park (site 2) has remained quite stable and that at

Elizabeth Manion Park (site 16) is trending upwards since sampling at these sites began in 2014. While Brockman Park may be the most acidic of these sites, that at Bull Creek Main Drain was least acidic. The differences observed at these 5 sites, is likely due to the fact that water most downstream at Bull Creek Main Drain is influenced by tides at the nearby estuary as well as possible contamination downstream.

Table 6. Descriptive statistics of of all pH samples taken up to and including 2021 at John Creaney Park and Bull Creek Main Drain sites.

Site	Mean	SD	n
15	6.48	0.22	31.00
5	6.50	0.32	55.00
16	6.78	0.28	29.00
2	6.30	0.16	59.00
1	6.90	0.28	59.00

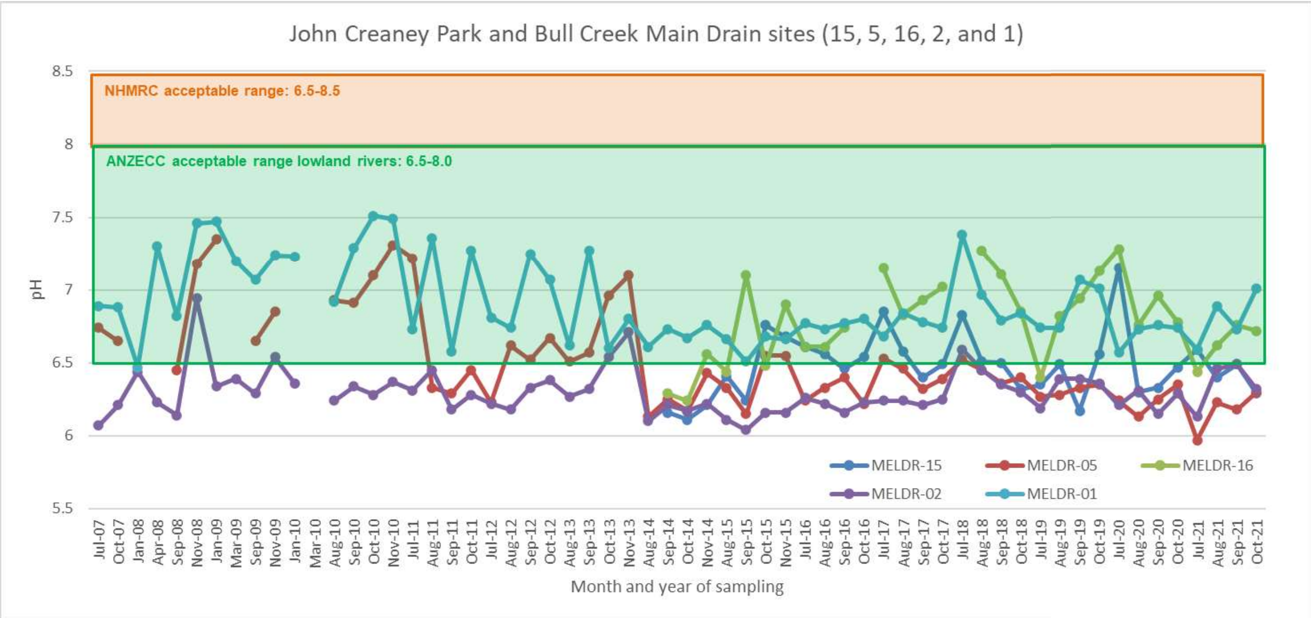


Figure 9. pH recorded at John Creaney Park (sites 15 and 5) and Bull Creek Main Drain (site 2) since 2007 and Bull Creek Main Drain (sites 1 and 16) since 2014.

Oxygen saturation (%) and concentration (mg/L)

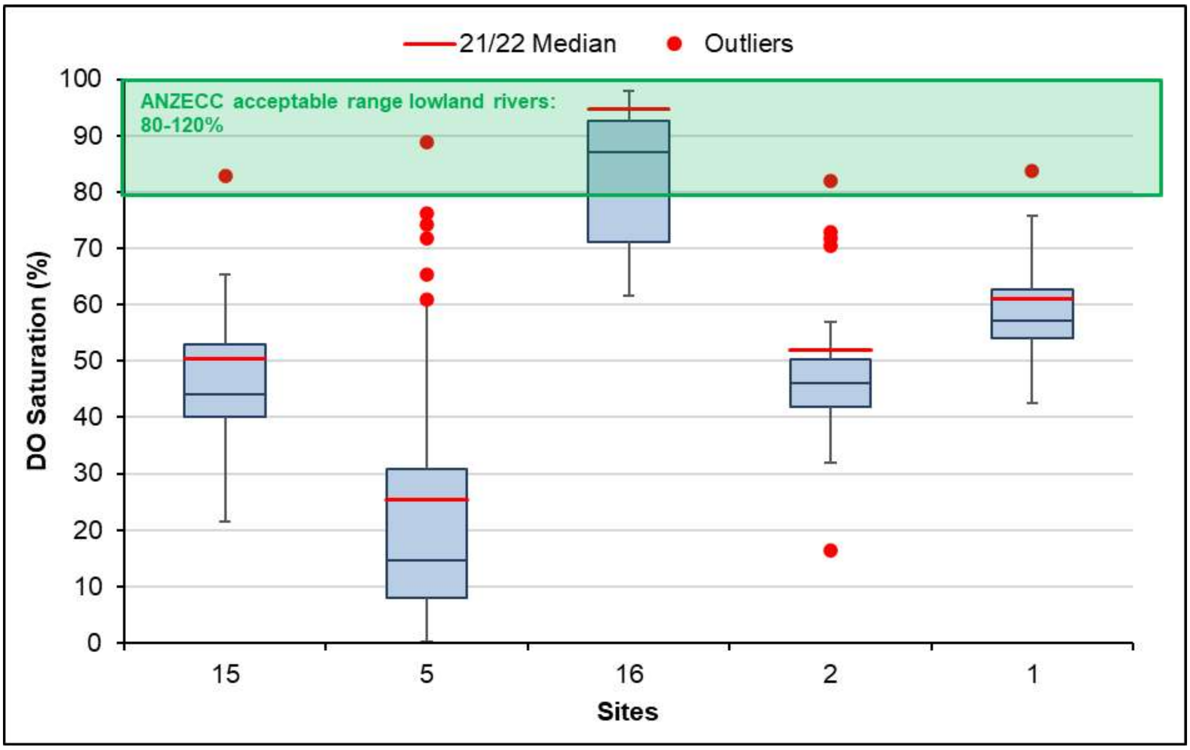


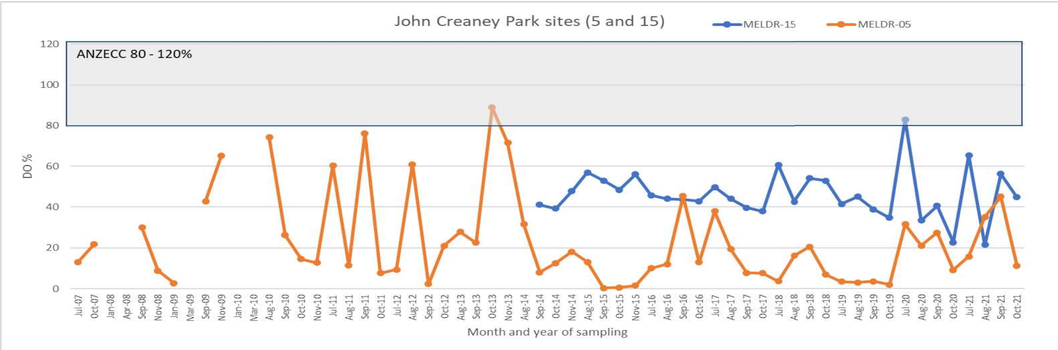
Figure 10. Box plot of DO % 2007-2020 historical median values, with a red line indicating the median value in 2021.

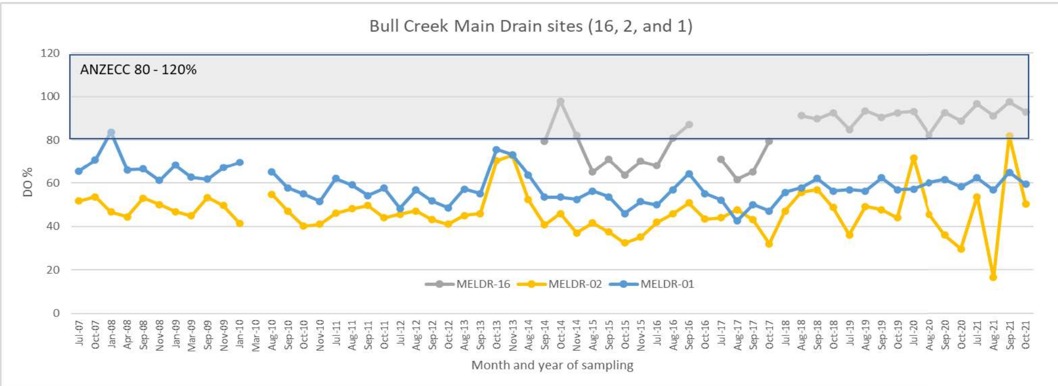
Box whisker

Fifteen of the 20 samples collected from Melville Bull Creek catchment sites in 2021 recorded dissolved oxygen (DO) saturations below the ANZECC acceptable range for lowland rivers (80-120%) and the NHMRC recreational guidelines lower limit (80%) (Figure 10 and Table D-5 in Error! Reference source not found.). Only site 16 (Downstream Elizabeth Manion Park) recorded saturations within the acceptable range on all occasions when sampled. Site 5 (John Creaney Park Outlet) recorded the lowest saturation in the section of 11.3% in October. Site 16 recorded a median DO saturation of 94.65%. Sites 15, 5, 2 and 1 recorded DO saturation medians of 50.5%, 25.45%, 52.05% and 61% respectively in 2021. All 2021 medians at sites in this drainage line were larger (from 50.5 to 94.65%) than their respective long term 2007-2020 medians (from 44.1 to 87.1%). All sites except for site 16 have recorded outliers, with site 2 recording two outliers (11.5% in August and 81.9% in September) in 2021.

Time series

The % dissolved oxygen at John Creaney Park has been very variable since sampling began, in particular before 2014 at site 5, the outlet at the park, compared to the inlet (Figures 11A and 11B). Since 2014, however, the variation has stabilised somewhat and during some months the % dissolved oxygen at the outlet (site 5) was similar to that at the inlet (site 15).





Figures 11 A and B. % Dissolved Oxygen at John Creaney Park and Bull Creek Main Drain since sampling began.

A trend suggesting the % dissolved oxygen is higher at the inlet compared to the outlet could be due to mixing of waters within the wetland. At the Bull Creek Main Drain sites, the % dissolved oxygen has mostly remained low with some variation in readings that are no doubt associated with seasonal weather conditions. At Elizabeth Manion Park pipe (site 16) the trend suggests the % dissolved oxygen has remained higher since monitoring began compared to that at the other two sites along this drain

Table 7. Descriptive statistics of % DO at John Creaney Park and Bull Creek Main Drain sites since sampling began at these sites. Includes all samples up to an including 2021.

Site	Mean	SD	n
15	41.1	11.6	31
5	23.0	21.8	55
16	83.2	11.2	29
2	41.8	10.2	59
1	58.8	7.5	59

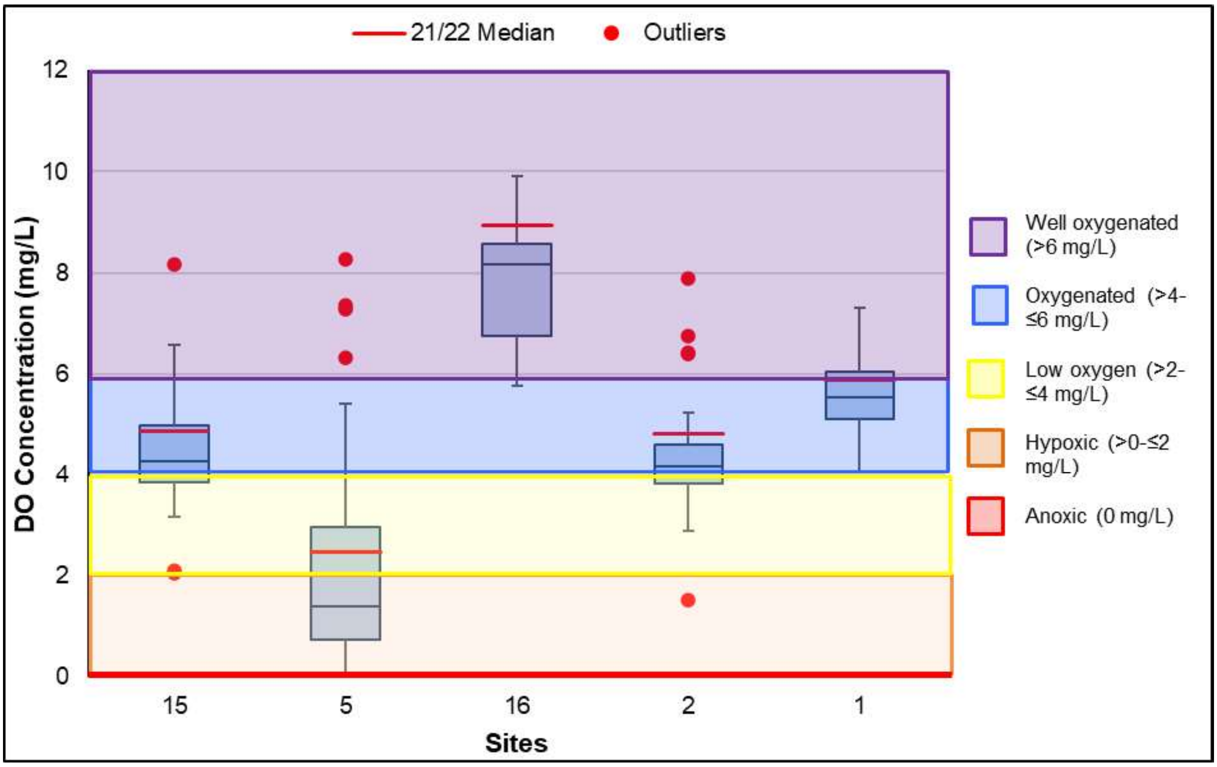


Figure 12. Box plot of DO mg/L 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Similar to % dissolved oxygen, the dissolved oxygen (mg/L) concentrations recorded at these sites in 2021, had a median DO concentration above the median DO concentrations recorded at these sites for 2007-2020 (from 1.4 to 8.16 mg/L) (Figure 12). Site 15 in 2021 recorded a median DO concentration of 2.48 mg/L deeming to be generally low oxygen water (0-2 mg/L). Sites 15, 2 and 1 recorded median DO concentrations of 4.87, 4.81 and 5.89 mg/L deeming the water at these sites be oxygenated (4-6 mg/L). One site, site 16 recorded a median DO concentration of 8.95 mg/L, classifying the water at this site to be well oxygenated (6 mg/L) (in accordance with DBCA standards [DPaW, 2015]) (Figure 12 and Table D-6 in Appendix D).

Time series

The trends in oxygen concentration (mg/L) show that since 2014, the waters at John Creaney Park outlet (site 5) was anoxic through to poorly oxygenated and quite variable, while that at the inlet (site 15) tended to be more oxygenated and stable over time (Figure 13). This could be due to the use of oxygen in the ecosystem as the water moves through the wetland to the outlet (site 5). At the Bull Creek Main Drain sites however, the oxygen concentration has remained oxygenated (site 1, Bull Creek Main Drain at Leach Highway and site 2, Brockman Park) or well oxygenated (site 11, Elizabeth Manion Park) since sampling began in 2007 as well as quite stable over time. It is possible that the movement of water at the Elizabeth Manion Park drain, that has regularly the highest DO mg/L, is resulting in the high levels of oxygen. Apart from a suggestion that oxygen concentration at site 5 may have stabilised slightly since around 2014, there are no other notable trends with time. If this is due to rehabilitation or other factors is yet to be determined.

Table 8. Descriptive statistics of dissolved oxygen (mg/L) concentrations at John Creaney Park and Bull Creek Main Drain sites since sampling began at these sites.

Site	Mean	SD	n
15	4.42	1.17	31
5	2.21	2.07	55
16	7.81	1.14	29
2	4.28	0.97	59
1	5.60	0.66	59

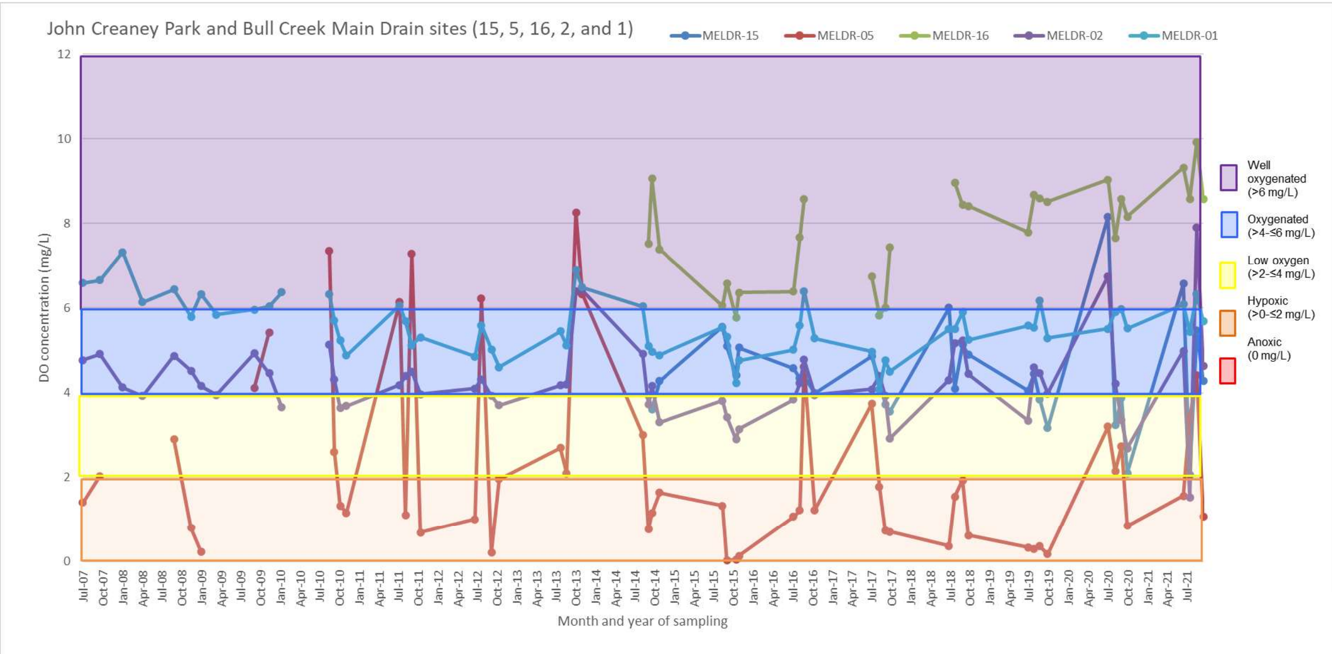


Figure 13. Dissolved oxygen (mg/L) concentrations at John Creaney Park and Bull Creek Main Drain sites since sampling began at these sites.

Electrical conductivity (EC)

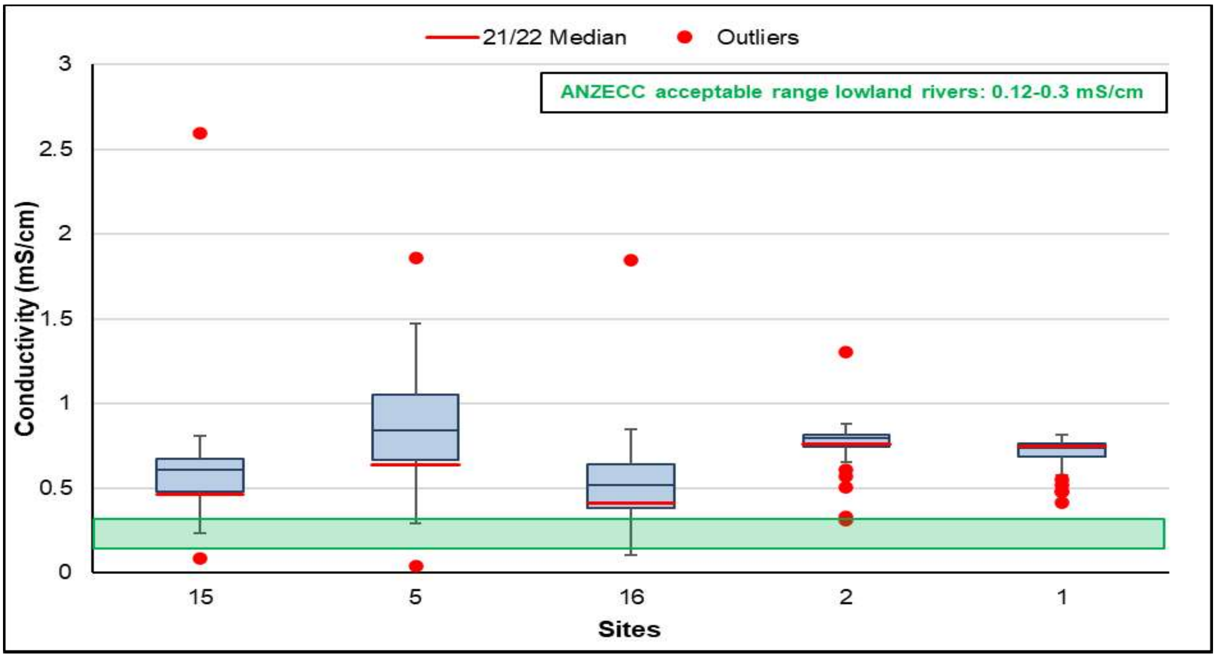


Figure 14. Box plot of conductivity 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

EC values recorded in 2021 at sites in the John Creaney Park and Bull Creek Park drainage line sites were for the majority well above the ANZECC acceptable range for lowland rivers (0.12-0.3 mS/cm). One sample from site 16 in September, was the only sample taken within the 2021 sampling period that was within acceptable range, with a reading of 0.112 mS/cm (Figure 14 and Table D-7 in Appendix D).

Time series

Apart for some July and August samples, particularly in sites 5, 15 and 11 the conductivity of all other samples have been well above the acceptable ANZECC guidelines for lowland rivers listed as fresh since sampling began, and mostly within acceptable limits for wetlands (Figure 15).

Other comparisons suggest that the conductivity at Brockman Park (site 2) and Bull Creek Park Main Drain (site 1) have remained very steady and similar throughout the sampling period. At the Elizabeth Manion Park closed pipe however, the conductivity has been slightly lower and more variable (site 16).

At all these three sites there was a decrease in conductivity in July 2020, that can be associated with the unusually high rainfall in that month. There are minor trends at various times through the sampling periods that illustrate that conductivity is closely tied with rainfall, in particular further upstream (sites 5, 15, 16) compared to downstream (sites 1, 2). It is likely that conductivity upstream (sites 15, 5 and 16) is influenced by different ions than those downstream (sites 1 in particular) that are influenced by estuarine ions.

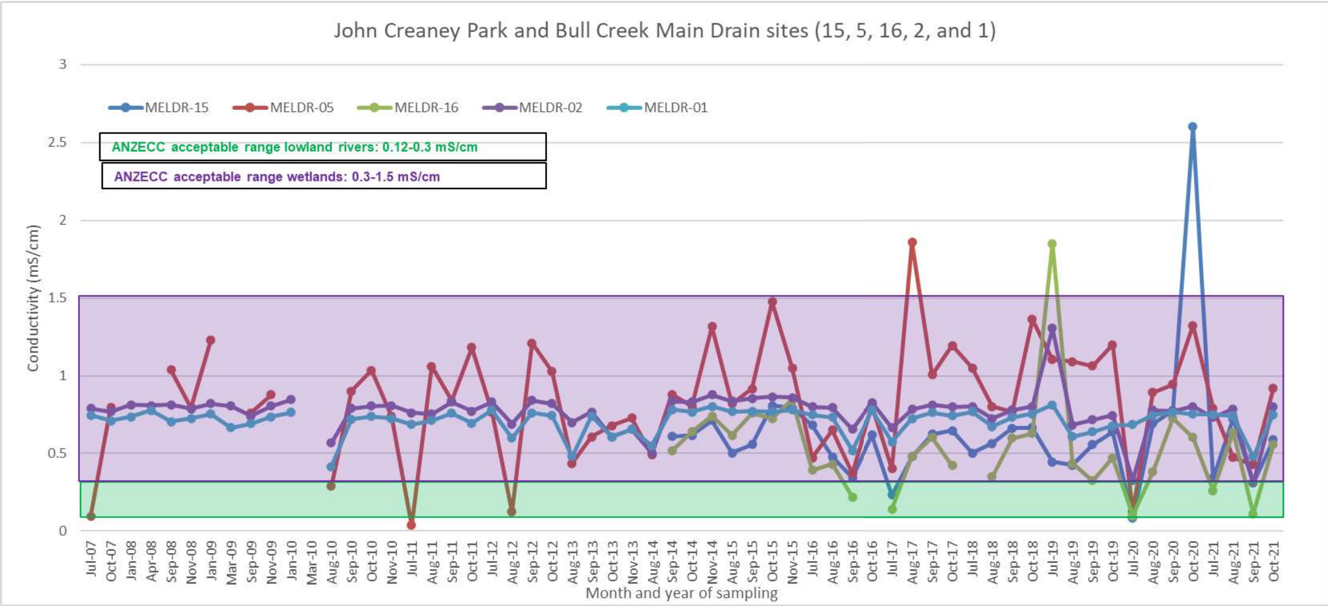


Figure 15. Electrical conductivity (mS/cm) at John Creaney Park and Bull Creek Main Drain sites (15, 5, 11. 2, and 1) since sampling began at these sites.

Table 9. Descriptive statistics of electrical conductivity (mS/cm) at John Creaney Park and Bull Creek Main Drain sites since sampling began. Includes all data up to an including 2021.

Site	Mean	SD	n
15	0.62	0.40	31
5	0.84	0.36	55
16	0.54	0.32	29
2	0.77	0.13	59
1	0.71	0.08	59

Total suspended solids (TSS)

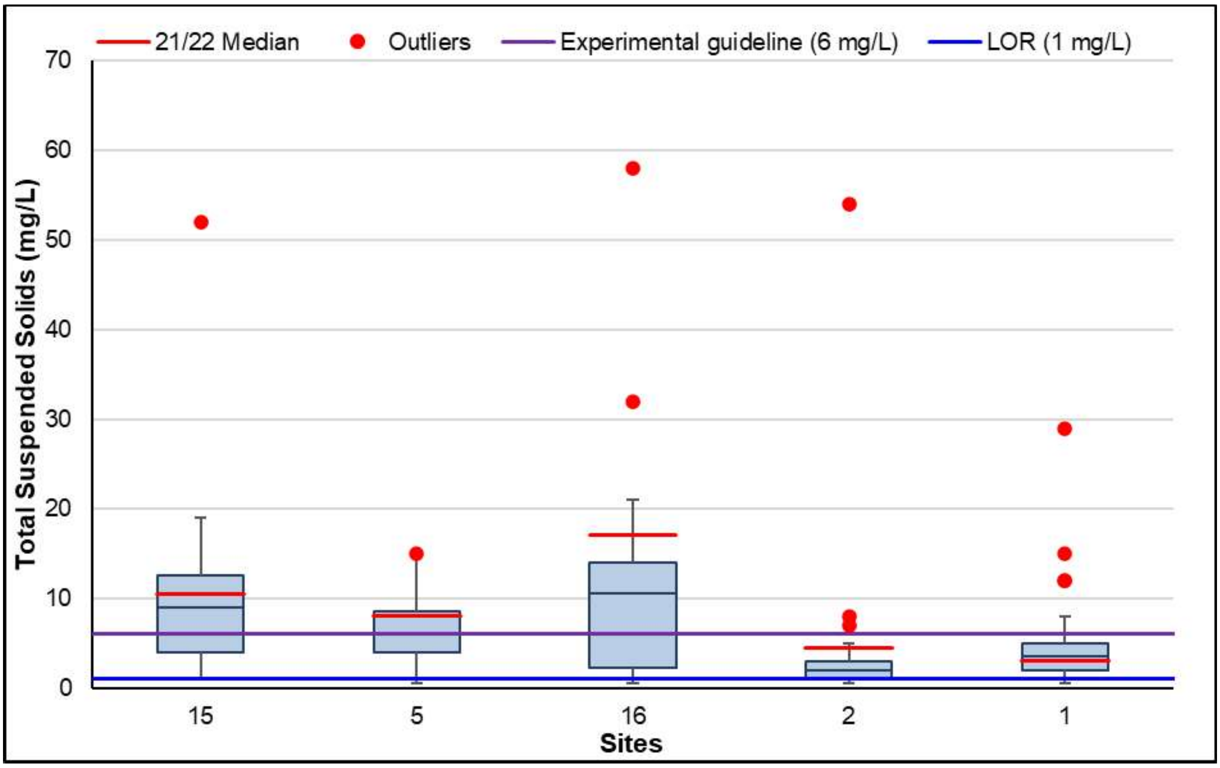


Figure 16. Box plot of TSS 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

In 2021, 12 out of the 20 samples (57% of the samples) collected from the John Creaney Park and Bull Creek Park drainage sites (1, 2, 5,15, and 16) recorded concentrations above the experimentally derived guideline (6 mg/L) (Figure 16 and Table D8 in Appendix D). Additionally, in 2021, sites 5, 15 and 16 recorded TSS concentrations that exceeded guidelines on three of the four sampling occasions.

Time series

Since sampling began at these sites), the TSS at John Creaney Park has remained overall, slightly higher, and more variable upriver at the inlet (site 15) than at the outlet (site 5) (Figure

17). Additionally, almost 40% of the samples at these two sites exceeded the experimental guideline of 6 mg/L. There are also trends suggesting the TSS was more variable and increased with time at upstream sites (15 and 16) compared to the downstream sites (1 and 2). Additionally, the historical TSS at sites 15 and 11 show concentrations above the interim guideline more than 58% of the sampling occasions for each site (63%, 69%, 77% and 59% respectively).

At the downstream sites of Bull Creek Main Drain (sites 1 and 2) the TSS has (apart from in January 2008 in particular) remained quite steady and in general below the interim guideline of 6 mg/L. This contrast with that upstream at Elizabeth Manion Park (site 16) where the TSS is quite variable and possibly also increasing with time. Overall, the TSS has remained higher upstream than downstream, and this may be due to turbulent inflow and ecological features where the water is more stationary compared to where it flows more rapidly upstream. Particulate matter may also have settled once the waters reach downstream sites.

Table 10. Descriptive statistics of TSS at John Creaney Park and Bull Creek Main Drain sites since sampling began. Includes all data up to and including that of 2021.

Site	Mean	SD	n
15	10.1	9.0	31
5	1.3	3.5	55
16	11.7	11.3	30
2	3.3	1.8	60
1	4.4	4.2	60

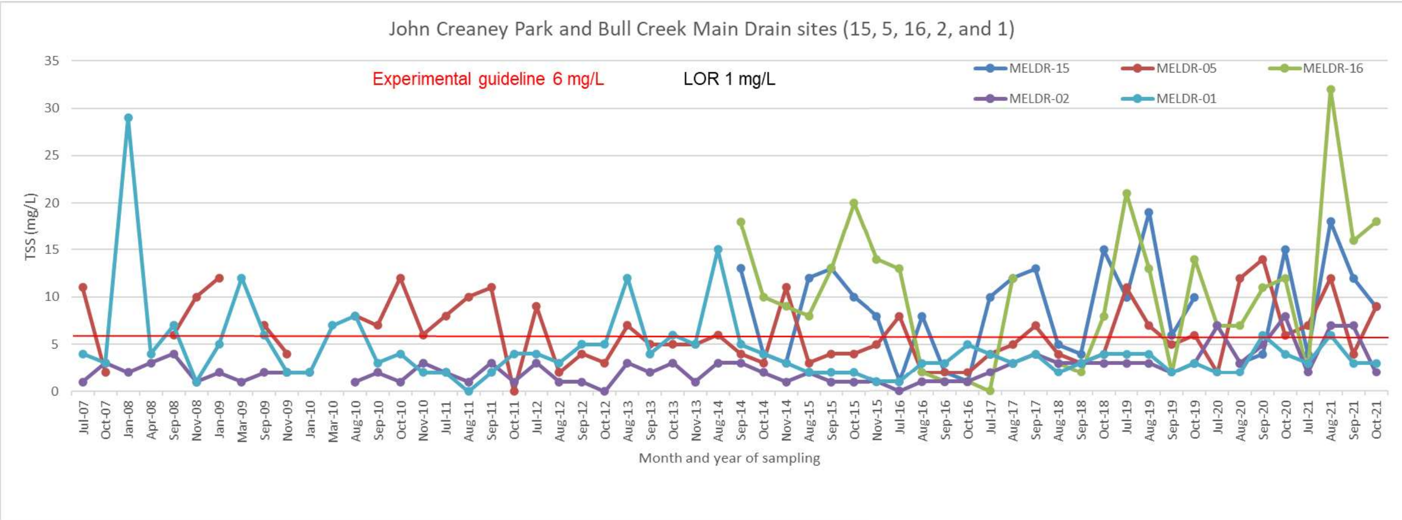


Figure 17. Total suspended solids (TSS, mg/L) at John Creaney Park and Bull Creek Main Drain sites since sampling began.

Temperature

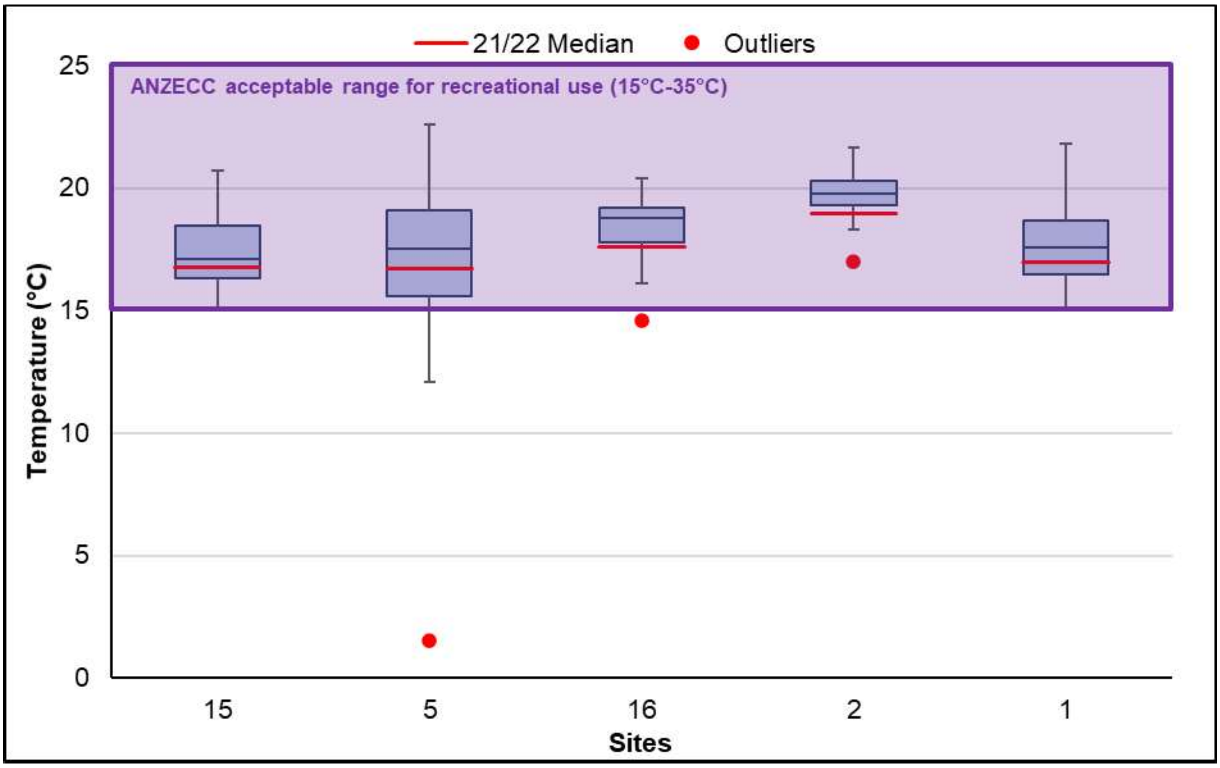


Figure 18. Box plot of pH 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Nineteen out of 20 samples in 2021 from the John Creaney Park and Bull Creek Park drainage line recorded concentrations within the ANZECC acceptable recreational range (15-35°C) and only one sample from site 16 exceeded the lower limit of this range with a temperature reading of 14.6°C in September (Figure 18). Temperatures in the surface waters of the John Creaney Park and Bull Creek Park drainage line ranged from 14.6°C at site 16 to 19.3°C in October at site 2 (Figure 18 and Table D-9 in Appendix D). Temperatures at all other sites were considered to lie within a normal seasonal range.

Time series

These results show a slight downward trend in temperature since sampling began (Figure 18A). In particular, the temperature recorded at site 5 (John Creaney Park outlet) has tended to be slightly lower and more variable than that at the other sites, while that at site 2 (Brockman Park pipe drain opening) has been slightly higher and less variable. Apart from on several occasions at the outlet at John Creaney Park and once at Elizabeth Manion Park (site 16) the temperatures at these sites has remained within the ANZECC recommended limits. The highest temperatures was recorded at site 2 in January and November 2009, which coincided with an unusually warm year in Western Australia. The slight downwards trend combined with a stabilisation in overall temperatures may indicate successful revegetation efforts in shading the wetland; but this needs to be confirmed.

Table 11. Descriptive statistics of temperature (C) at John Creaney Park and Bull Creek Main Drain sites since sampling began. Includes all data up to and including that of 2021.

Site	Mean	SD	n
5	17.38	2.54	55
15	17.39	1.52	31
1	17.60	1.44	59
16	18.40	1.30	29
2	19.76	0.91	59

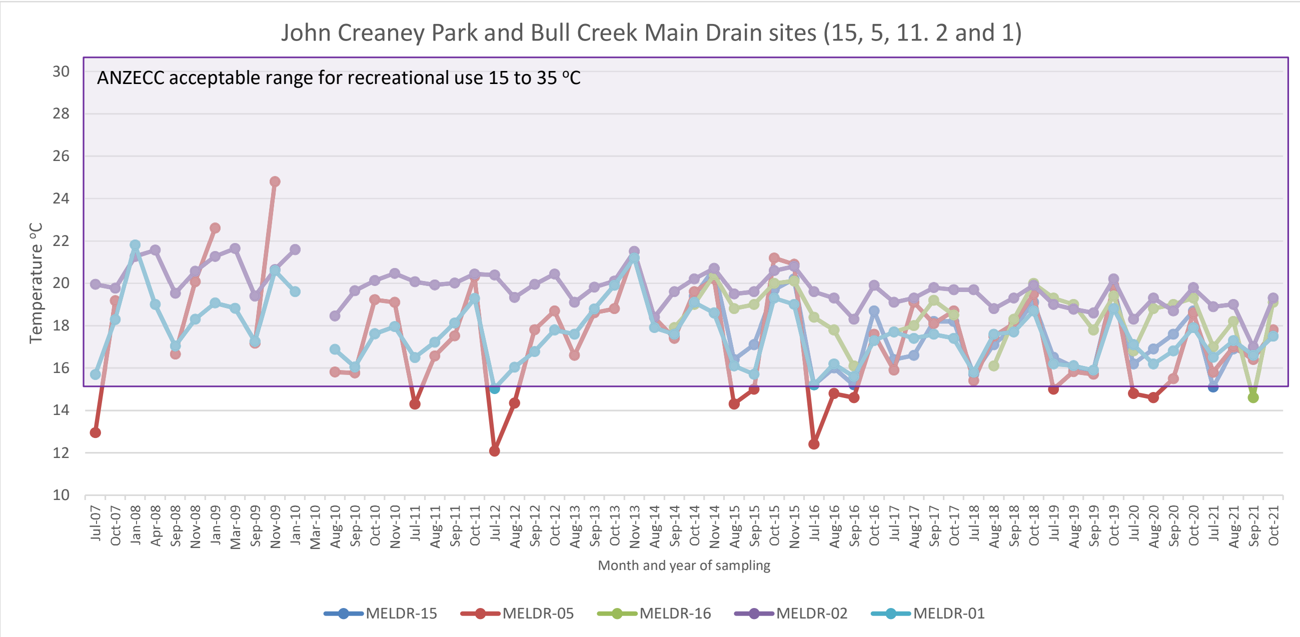


Figure 18A. Temperatures (C) at John Creaney Park and Bull Creek Main Drain sites since sampling began.

Nutrients

Nutrient concentrations recorded in Melville Bull Creek catchment sites are displayed in Table D-10 to Table D-16 in Appendix D. Table E-46 in Appendix E outlines the sources of nitrogen and phosphorus and the impacts that changes in these nutrients can have to aquatic ecosystems.

For all graphs, a value equal to half the LOR was substituted for those occasions where concentrations were recorded as 'below the laboratory limit of reporting' (<LOR) which is a standard technique (Helsel, 1990) to allow these 'unknown' values to be represented graphically and to differentiate them from those samples that recorded concentrations equal to the LOR.

Nitrogen

Total nitrogen (TN)

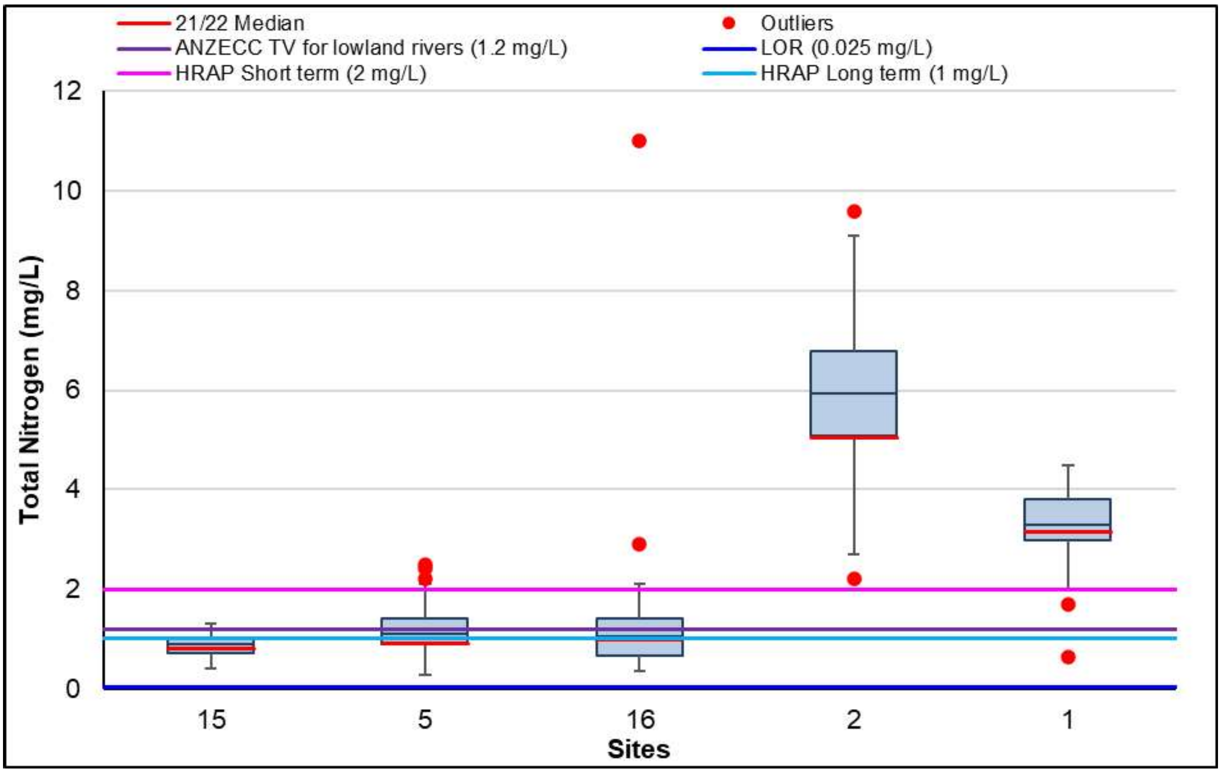


Figure 19. Box plot of total nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

TN concentrations exceeded ANZECC trigger values for lowland rivers (1.2 mg/L) in ten of 20 samples collected in 2021 from Melville Bull Creek Main Drain sites (Figure 19 and Table D-10 in Appendix D). Exceeding concentrations were recorded on all sampling occasions at sites 1 and 2 and on two sampling occasion at site 16. Eight out of 20 samples also exceeded the HRAP short term target (2 mg/L) (from sites 1, 2) and ten out of 20 samples exceeded the HRAP long term target (1 mg/L) (from sites 1, 2, and 16).

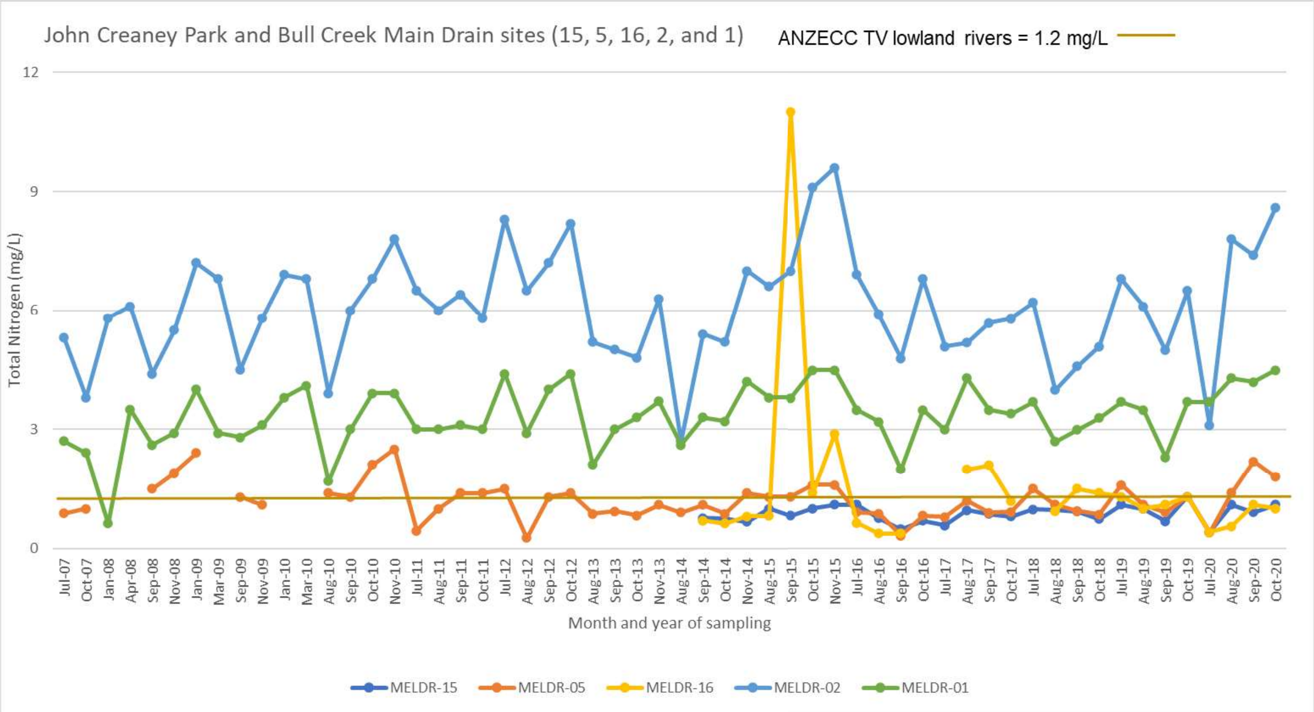


Figure 20. Total nitrogen at the Bull Creek Main Drain sites since sampling began.

Time series

The total nitrogen (TN, mg/L) at these sites has remained quite site specific over the time of sampling (since 2007) (Figure 20). The TN at the John Creaney Park inlet has shown the lowest readings and variability (site 15), while that at the outlet (site 5) has been slightly higher with a slight trend down with time. In contrast, the TN at downstream sites of the Bull Creek Main Drain; the Brockman Park pipe opening (site 2) and by Leach Highway (site 1) was high and quite variable. Apart from an outlier of 11 mg/L in September 2015 (soon after high rainfall event), the values at Elizabeth Manion Park (site 16) have been below the ANZECC trigger value for lowland rivers as well as below the HRAP short term target values. Overall, the values at both John Creaney Park sites (site 15 and 5) have remained quite stable while that at Elizabeth Manion Park (site 16) have been trending slightly lower since sampling began, while that at Brockman Park (site 2) and Bull Creek Main Drain (site 1) has remained high and above ANZECC guidelines of 1.2 mg/L and trending slightly upwards. It is therefore possible that although upstream, the TN may be reasonably stable, the TN is increasing slightly downstream in Bull Creek Main Drain.

Table 12. Descriptive statistics of total nitrogen (mg/L) at John Creaney Park and Bull Creek Main Drain.

Site	Mean	SD	n
15	0.86	0.20	31
5	1.19	0.46	55
16	1.46	1.93	28
1	3.31	0.75	60
2	5.96	1.44	60

Total oxidised nitrogen

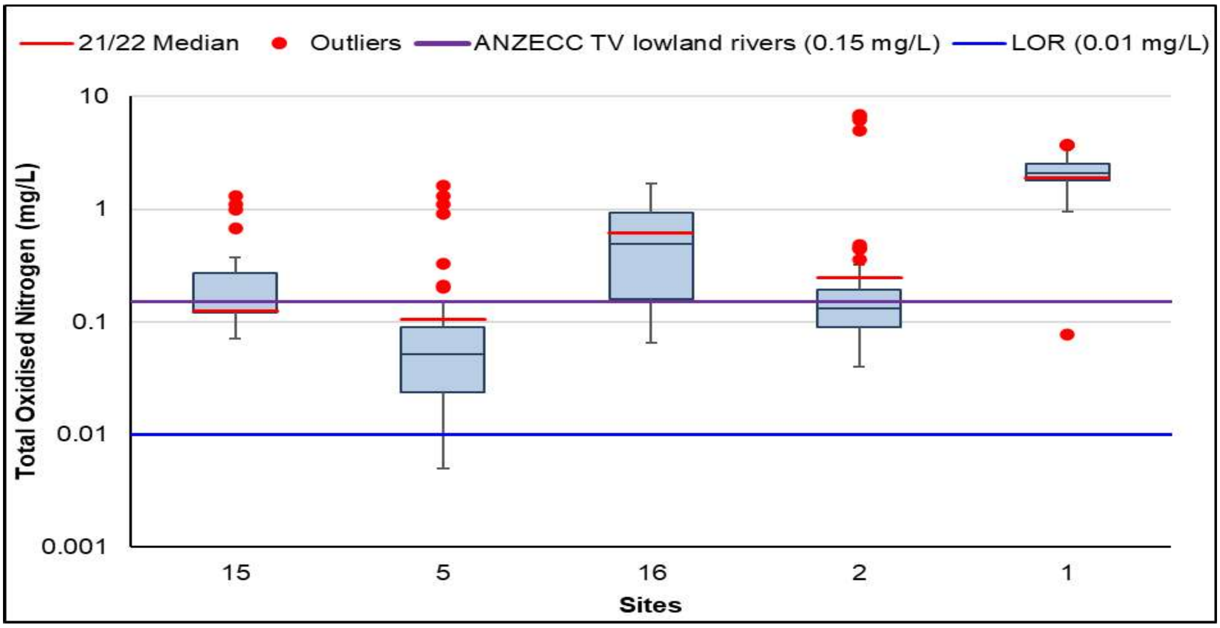


Figure 21. Box plot of total oxidised nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

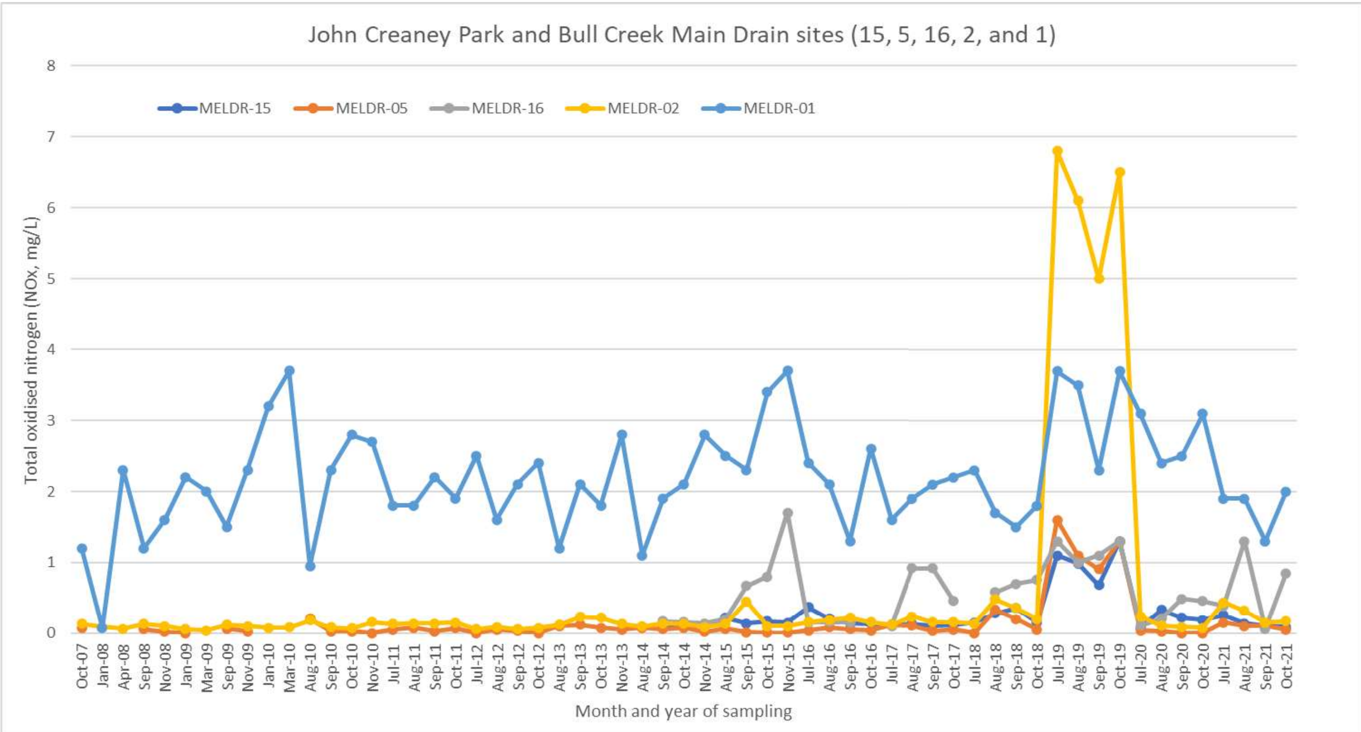


Figure 22. Total oxidised nitrogen at John Creaney Park and Bull Creek Main Drain. All five sites included.

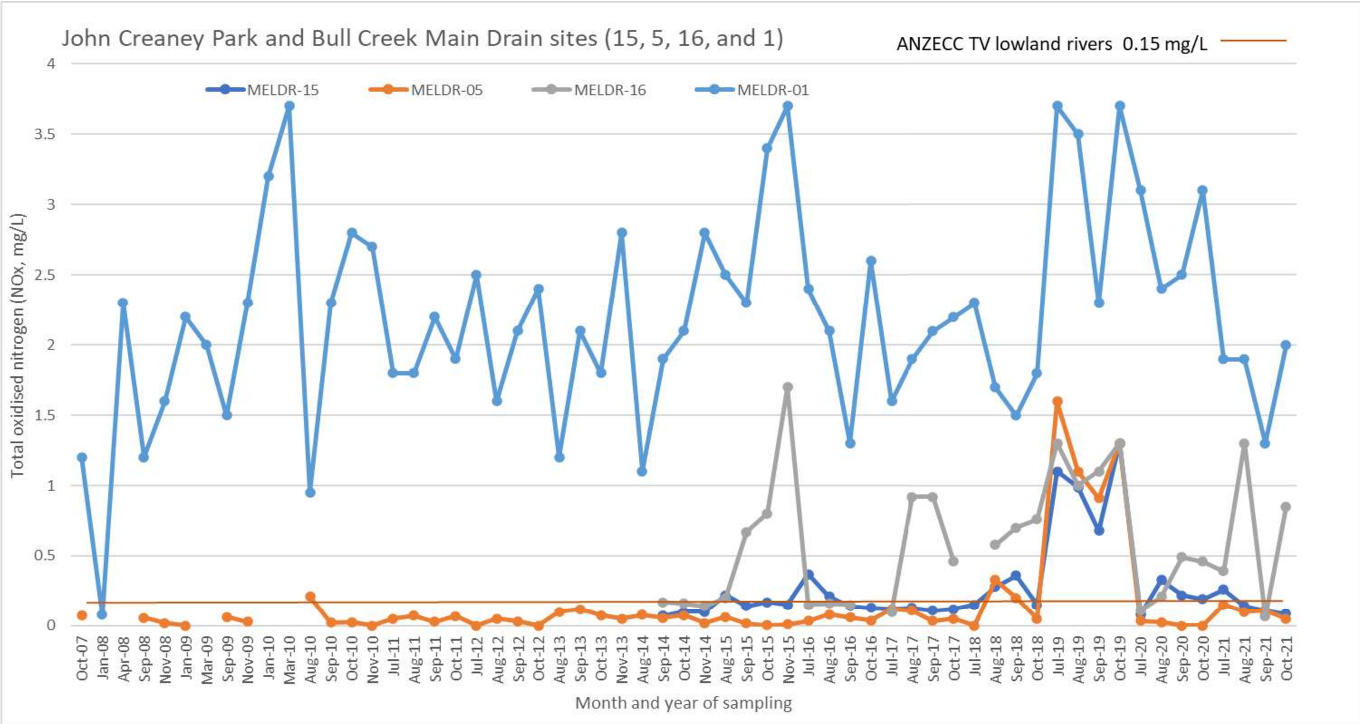


Figure 23. Total oxidised nitrogen with that of site 2 which contained most outliers, removed.

Box whisker

NOx-N concentrations above relevant ANZECC trigger values (lowland rivers: 0.15 mg/L were recorded at 13 of the 20 samples taken in 2021 (Figure 21 and Table D-11 in Appendix D). The four highest concentrations in the catchment in 2021 were recorded at site 1 (Bull Creek main drain) being 1.9 mg/L, 1.9 mg/L, 1.3 mg/L and 2.0mg/L in July, August, September, and October respectively (note; the highest concentration was almost 15 times greater than the trigger value). Site 2 also recorded NOx-N concentrations exceeding trigger values on all four sampling occasions in 2021. Sites 15 and 16 (John Creaney Park Inlet and D/S Elizabeth Manion Park, respectively) recorded NOx-N concentrations that exceeded the ANZECC guidelines on 75% of sampling occasions in July, August, and September of 2021.

Time series

Two time series plots were generated to show the NOx over time at the five sites. The first plot shows the data for all sites (Figure 22), while the second plot was created to show details of variations that were obscured due to the high values in site 2 (Figure 23, also Table 13).

Since sampling began in 2007, the NOx-N values at Bull Creek Main Drain (site 1, close to Leach Highway) have remained higher than that at any other location, with several of the peaks coinciding with summer and autumn rainfall events. All four sampling events in 2019 yielded NOx values at site 2 that were much higher than those at the other four sites. During this sampling year, the values at the other four sites were also higher. These differences associated with the known high rainfall events experienced in 2019 suggest that inflow due to rain may influence NOx at site 2 more than it does at the other four sites.

When the values at the other four sites are examined in detail, it is easier to see that the NOx-N at the John Creaney Park outlet (site 5) and to an extent also the inlet at John Creaney Park (site 15) as well as the pipe opening at Brockman Park (site 2) are sometimes or often below or close to the ANZECC trigger value of 0.15 mg/L for lowland rivers. In addition, higher values of NOx-N at the pipe at Elizabeth Manion Park (site 16) seem to be affected by first flow events to a larger extent than the other four sites. There are also trends suggesting that total oxidisable nitrogen (NOx-N) is increasing at most sites since sampling began.

Table 13. Descriptive statistics of NOx at John Creaney Park and Bull Creek Main Drain sites. Includes all data up to and including that of 2021.

Site	Mean	SD	n
5	0.169	0.336	47
15	0.281	0.305	31
2	0.549	1.497	60
16	0.597	0.448	29
1	2.180	0.732	60

Nitrogen as ammonium/ammonia

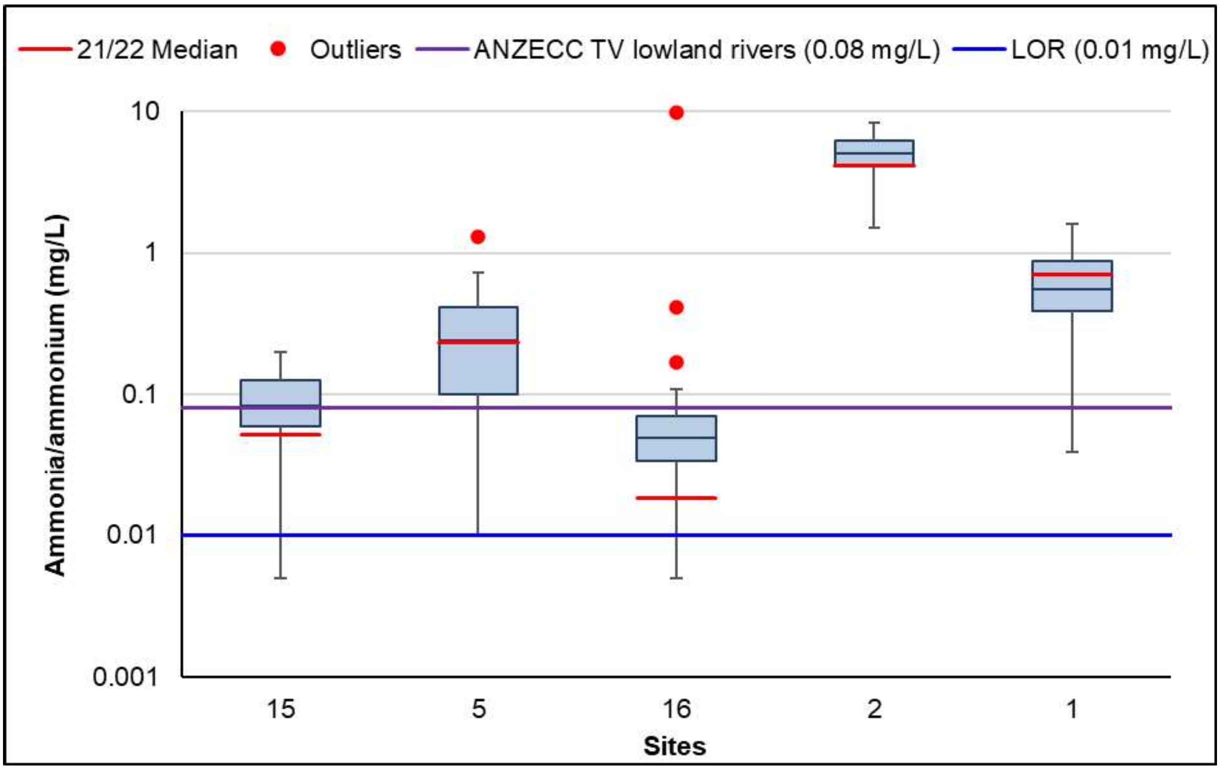


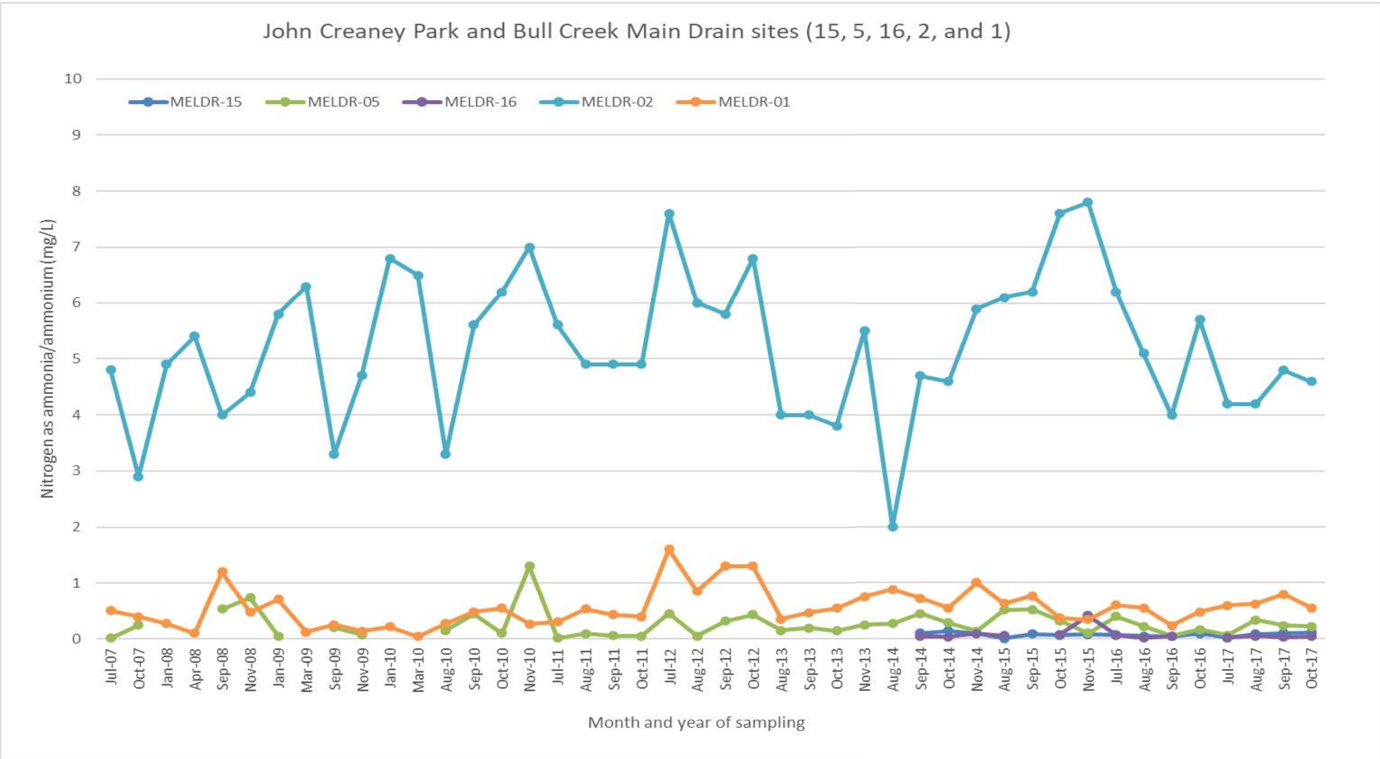
Figure 24. Box plot of ammonium/ammonia 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

The concentration of nitrogen as ammonium/ammonia (NH4+/NH3-N) in 2021 exceeded the relevant ANZECC trigger values (lowland rivers: 0.08 mg/L) in 14 out of 20 samples from across the sites (Figure 24 and Table D-12 in Appendix D). It is important to mention that the trigger value for 95% level of protection is only applicable at pH 8 and 20°C as per Table 8.3.7 in the ANZECC guidelines (ANZECC and ARMCANZ 2000) and that the concentration and therefore also the trigger value for NH4+/NH3-N decreases when pH increases.

Brockman Park, Bull Creek main drain (sites 2, and 1), recorded NH4+/NH3-N concentrations in 2021 that exceeded the trigger value for lowland rivers on all sampling occasions. Three samples from site 2 were very high (3.8 mg/L, 4.4 mg/L and 5.7 mg/L in July, August, and October respectively) with the July, August, and October samples for site 1 also recording concentrations that exceeded the NHMRC (2008) recreational trigger value of 0.5 mg/L.

Figures 25. and 26. – see two pages that follow. Ammonia and ammonium in the John Creaney Park and Bull Creek Main Drain sites. All sites are represented in Figure 25, while site 2 which had high values, is removed for clarity in Figure 26.


John Creaney Park and Bull Creek Main Drain sites (15, 5, 16, 2, and 1)
MELDR-15
MELDR-05
MELDR-16
MELDR-02
MELDR-01
Nitrogen as ammonia/ammonium (mg/L)
10
9
8
7
6
5
4
3
2
1
0
Jul-07
Oct-07
Jan-08
Apr-08
Sep-08
Nov-08
Jan-09
Mar-09
Sep-09
Nov-09
Jan-10
Mar-10
Aug-10
Sep-10
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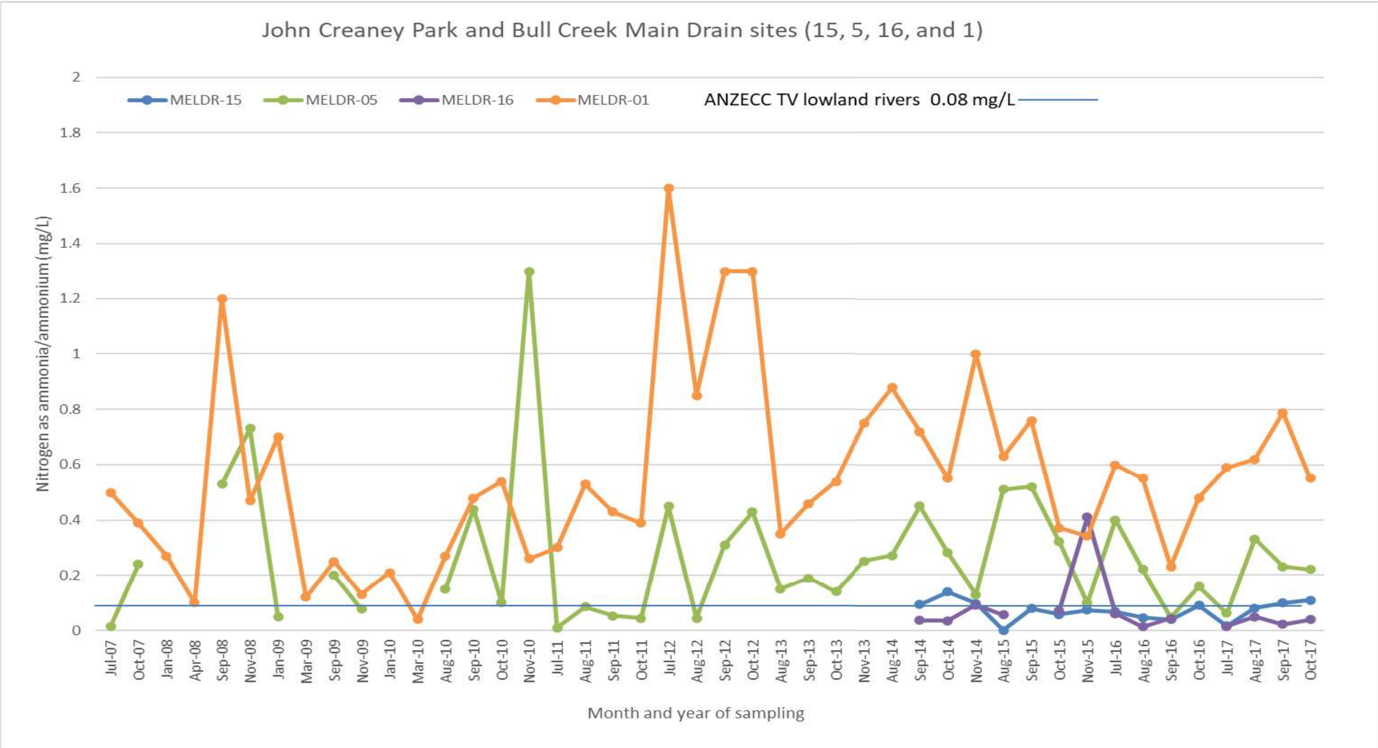
Nov-14
Aug-15
Sep-15
Oct-15
Nov-15
Jul-16
Aug-16
Sep-16
Oct-16
Jul-17
Aug-17
Sep-17
Oct-17
Month and year of sampling


John Creaney Park and Bull Creek Main Drain sites (15, 5, 16, and 1)
MELDR-15
MELDR-05
MELDR-16
MELDR-01
ANZECC TV lowland rivers 0.08 mg/L
Nitrogen as ammonia/ammonium (mg/L)
Month and year of sampling
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Jul-07
Oct-07
Jan-08
Apr-08
Sep-08
Nov-08
Jan-09
Mar-09
Sep-09
Nov-09
Jan-10
Mar-10
Aug-10
Sep-10
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Aug-17
Sep-17
Oct-17

Time series

Since sampling began in 2007, the concentration of NH4+/NH3-N in samples from Brockman Park (site 2) has remained higher and more variable than at any other site (Figures 25 and 26, Table 14). When an outlier of 9.7 mg/L at Elizabeth Manion Park (site 16 September 2015) is removed (removed from both time series figures) the concentration at this site is lower than at any of the other four sites. The high value (9.7mg/L) at Elizabeth Manion Park (site 16) was associated with rain after several days of no rain, which suggest a winter flush event. Apart from this occasion, only this site (site 16) and the John Creaney Park inlet (site 15) have consistently recorded NH4+/NH3-N values that have on average, remained below the ANZECC trigger values of 0.08 mg/L. There are slight upwards trends in the data downstream at sites 1 and 2, but no notable trends elsewhere. These results support that of oxidisable nitrogen (NOx) noted previously.

Table 14. Descriptive statistics of nitrogen as ammonium/ammonia (mg/L) at John Creaney Park and Bull Creek Main Drain since sampling began and including that of 2021.

Site	Mean	SD	n
15	0.096	0.048	29
5	0.278	0.223	55
16	0.41	1.789	28
16 without outlier of 9.7 mg/L	*0.068*	*0.075*	*27*
1	0.646	0.358	60
2	5.180	1.423	60

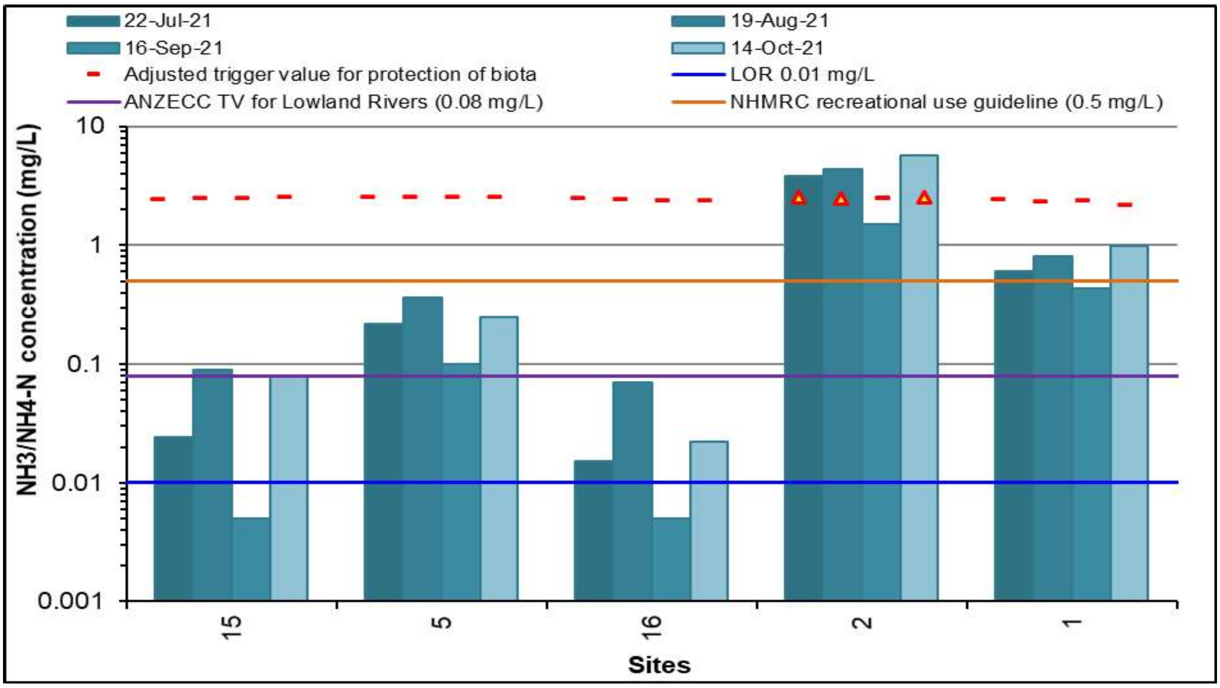

Figure 27. Ammonia/ammonium (mg/L) and associated adjusted trigger values (refers to the 95% protection level) recorded in the John Creaney Park and Bull Creek Park drainage line in 2021.

Organic nitrogen (total and dissolved)

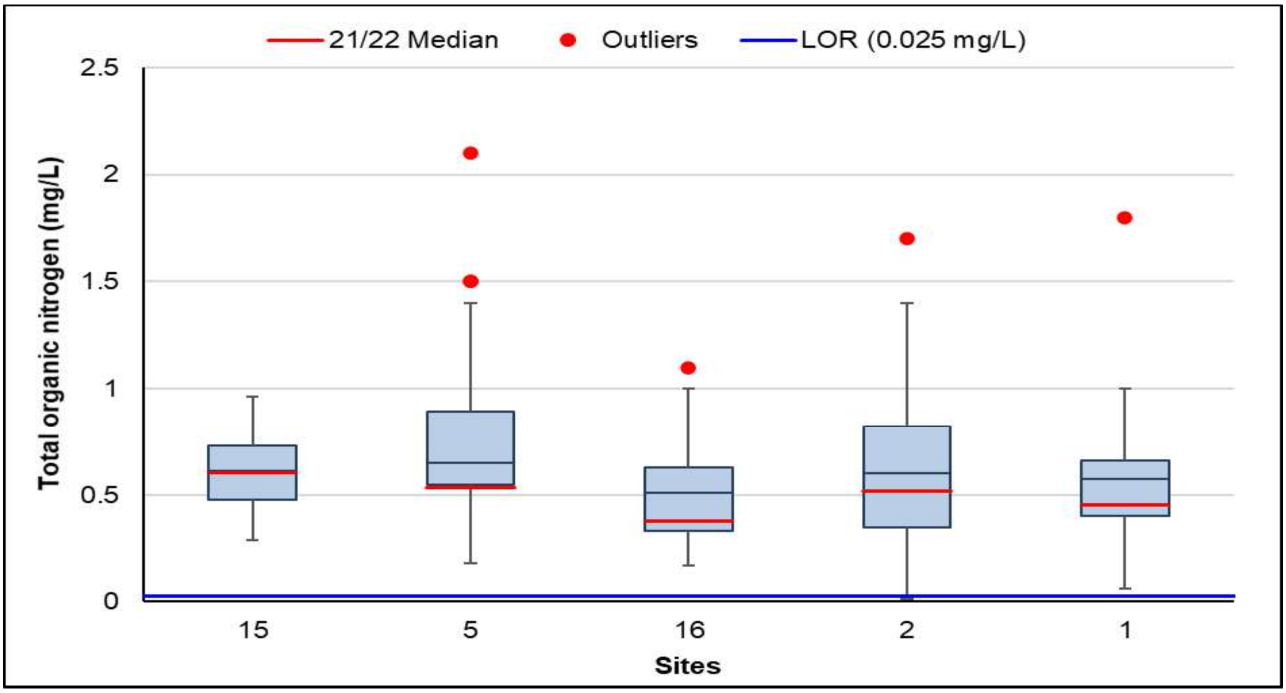

Figure 28. Box plot of total organic nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

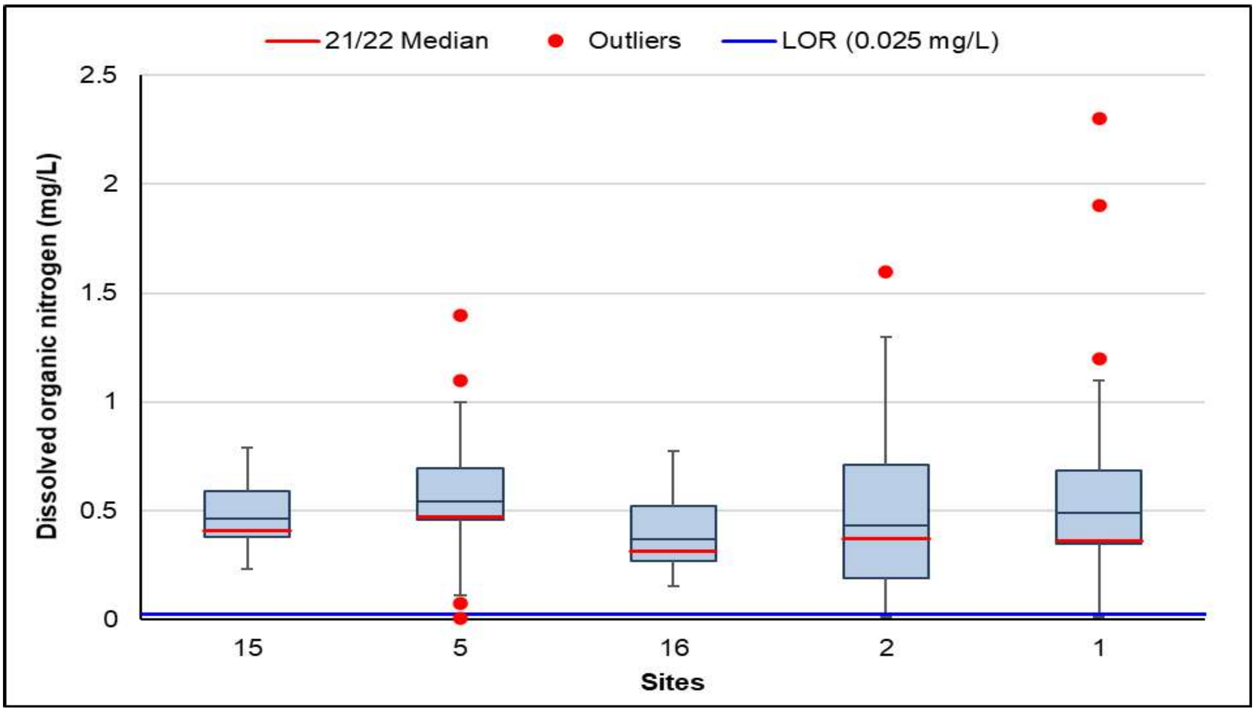

Figure 29. Box plot of dissolved organic nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

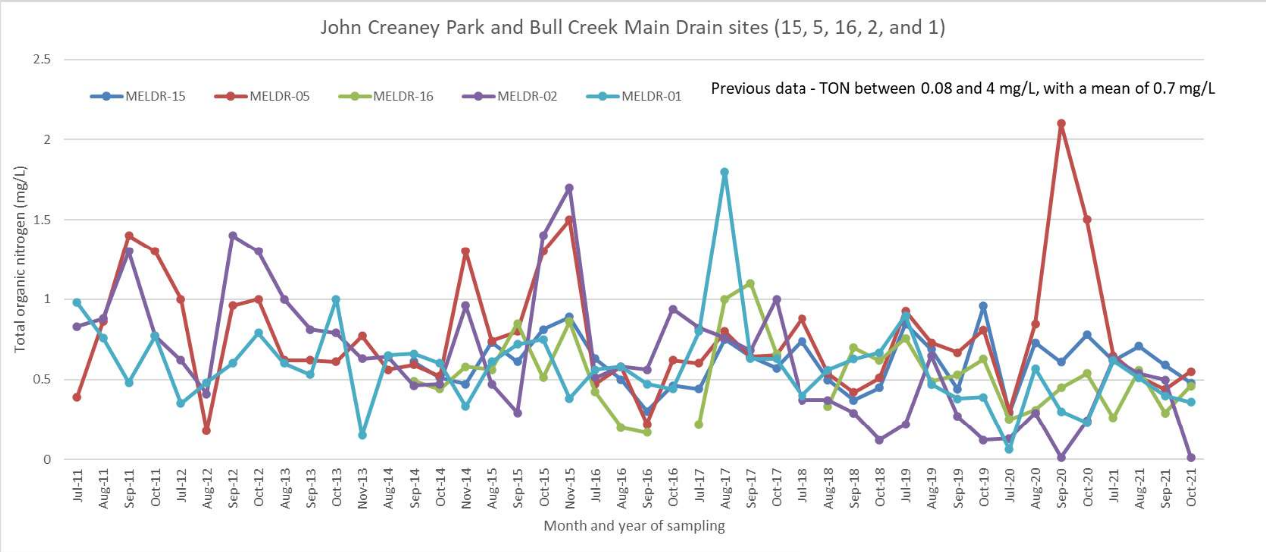

Figure 30. Total organic nitrogen at the Bull Creek Main Drain sites since sampling began.

Note; As no guideline currently exists for TON and DON it is difficult to assess the results for these parameters in terms of threats to ecosystem and/or human health. Although, there is some evidence that organic nitrogen compounds are taken up by phytoplankton and bacteria and therefore can affect composition and densities. Therefore, collecting this information may be helpful in determining source/s of total nitrogen.

Box whisker

When comparing the DON data up to and including 2020 with that of 2021, at site 2 (Brockman Park) in October 2021 was below the observable readings that equipment can measure (LOR of <0.025 mg/L) (Figures 28)). In addition, the total nitrogen remains higher than the dissolved nitrogen in 2021 at all sites (Figure 29).

Time series

Since sampling began in 2011 for the total organic nitrogen (TON) (Figure 30) and 2007 for dissolved organic nitrogen (DON), both have remained on average highest and most variable at the John Creaney Park outlet (site 5) and lowest with the next lowest variability at Elizabeth Manion Park (site 16). In September and October 2020 and again in October 2021 (site 2), as well as July 2020 in site 1, the levels of TON and/or DON has been below the observable limits for instruments (LOR 0.025 mg/L). In the absence of ANZECC guidelines for TON, the data is compared to that of previous years (range of 0.8 – 4 mg/L, mean ~0.7) and that of a New Zealand study of a range of wetlands (Uuemaa et al., 2018) where TON ranged from around 0.4 mg/L in natural wetlands through to around 4 mg/L in agricultural wetlands. It is possible that an average of around 0.7 mg/L can be used as a minimal trigger value, which would make most samples collected at these sites exceed the TON values.

The TON does, however, tend downwards at most sites since sampling began, in particular at the downstream sites (sites 1 and 2), and least at site 5. If the outlier at site 5 (September 2020, 2.1 mg/L) is removed, this location also shows a downwards trend. When the results of other nitrogen species are considered in association of TON, it may reveal how nitrogen is processed within these ecosystems and along the drains. With regards to DON; three sites, John Creaney Park outlet (site 5), Bull Creek Main Drain (site 1) and Brockman Park drain opening (site 2) showed more variation and slightly higher nitrogen since sampling began (total and dissolved) than the other sites. Overall, both the total and dissolved organic nitrogen at all sites show variation with time that could be attributed to seasonal flush events

Table 15. Summary of the total and dissolved organic nitrogen at the John Creaney Park and Bull Creek Main Drain sites. Includes all data up to an including that of 2021.

	Total organic nitrogen (mg/L)				Dissolved organic nitrogen (mg/L)			
Site	Mean	SD	n	Median	Mean	SD	n	Median
MELDR-16	0.53	0.23	29	0.51	0.40	0.17	29	0.37
MELDR-01	0.58	0.27	44	0.58	0.56	0.38	60	0.49
MELDR-15	0.60	0.17	31	0.61	0.48	0.13	31	0.46
MELDR-02	0.66	0.37	42	0.63	0.48	0.37	60	0.43
MELDR-05	0.77	0.38	44	0.65	0.57	0.24	55	0.54

Nitrogen speciation

When the speciation of nitrogen in the wetlands during 2021 is explored, the organic nitrogen (mainly as dissolved, DON) comprised the majority (or the highest proportion) of TN at most sites (Figure). However, inorganic forms of nitrogen comprised the majority (or the highest proportion) of total nitrogen at two sites:

- site 2 (Brockman Park) on average 94% for ammonia/ammonium nitrogen.
- site 1 (Bull Creek main drain) on average 67% oxidised nitrogen.

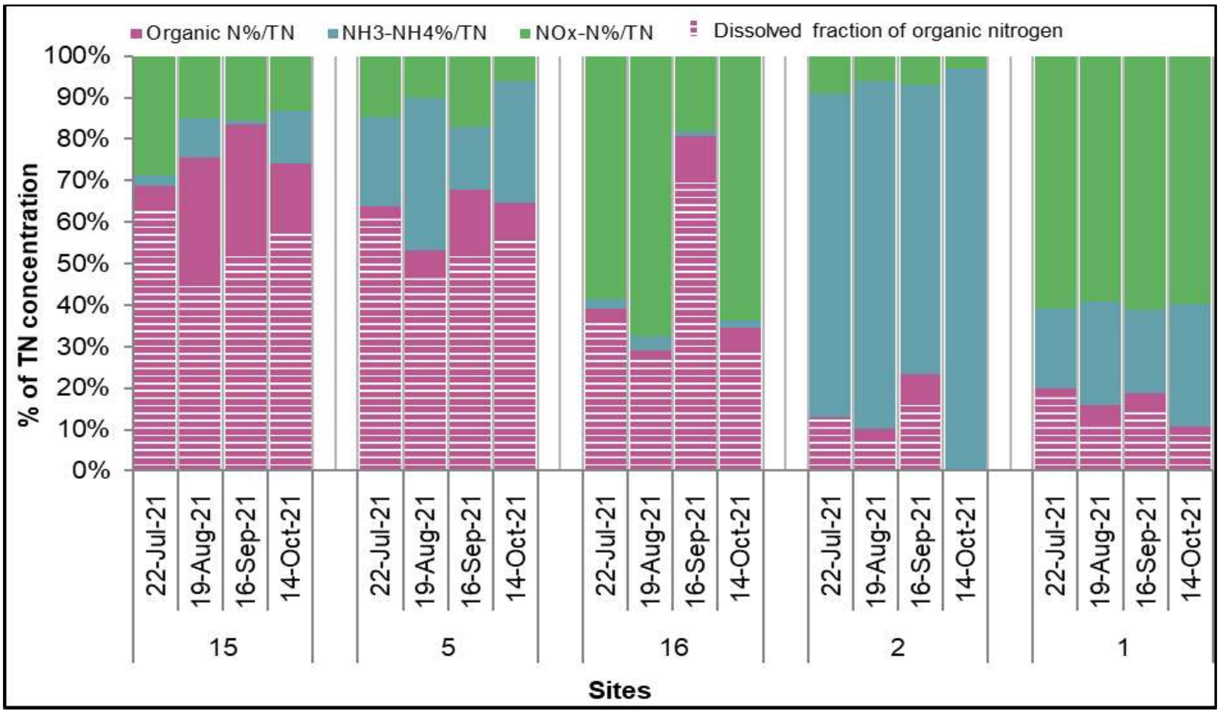

Figure 31. Nitrogen speciation in surface water at sites in the John Creaney Park and Bull Creek Park drainage line in 2021.

Phosphorus

Total phosphorus

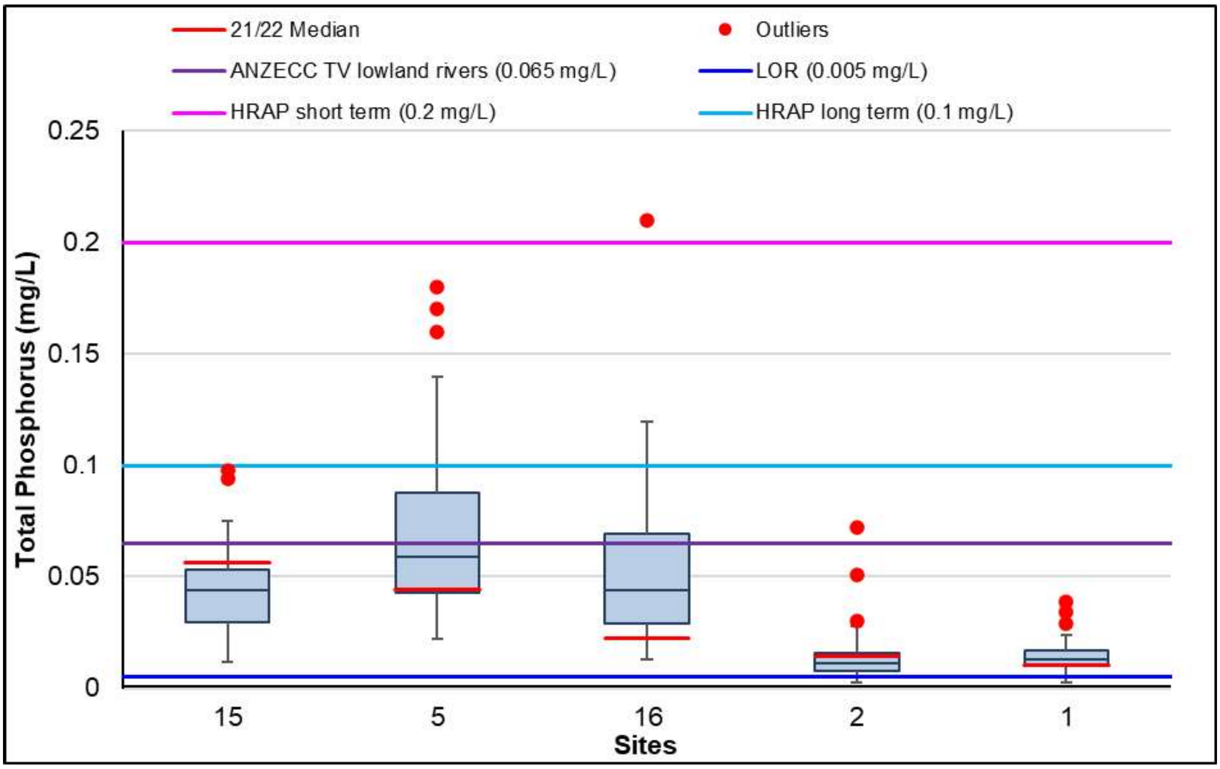

Figure 32. Box plot of total phosphorus 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total Phosphorus (TP) is a measure of both soluble and particulate forms. Some TP concentrations recorded in Melville Bull Creek catchment sites 5, 15 and 16 in particular in 2021 exceeded relevant ANZECC trigger values (lowland rivers: 0.065 mg/L) (Figure 32 and Table D-15 in Appendix D).

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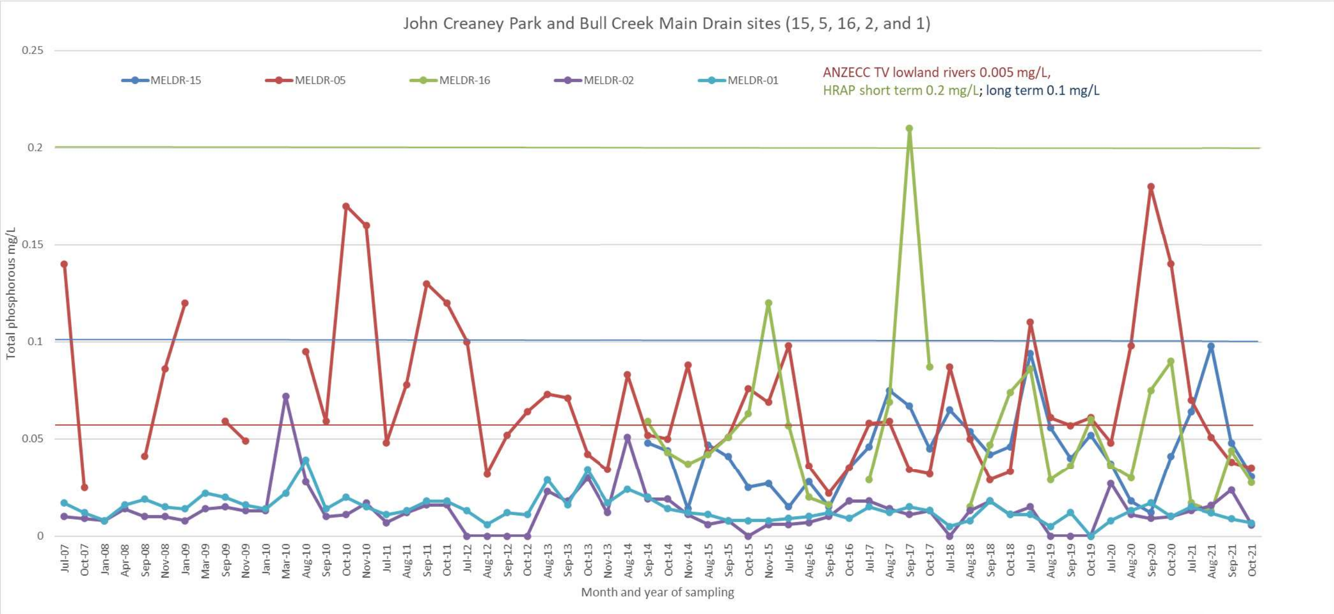


Figure 33. Total phosphorus in the John Creaney Park and Bull Creek Main Drain sites.

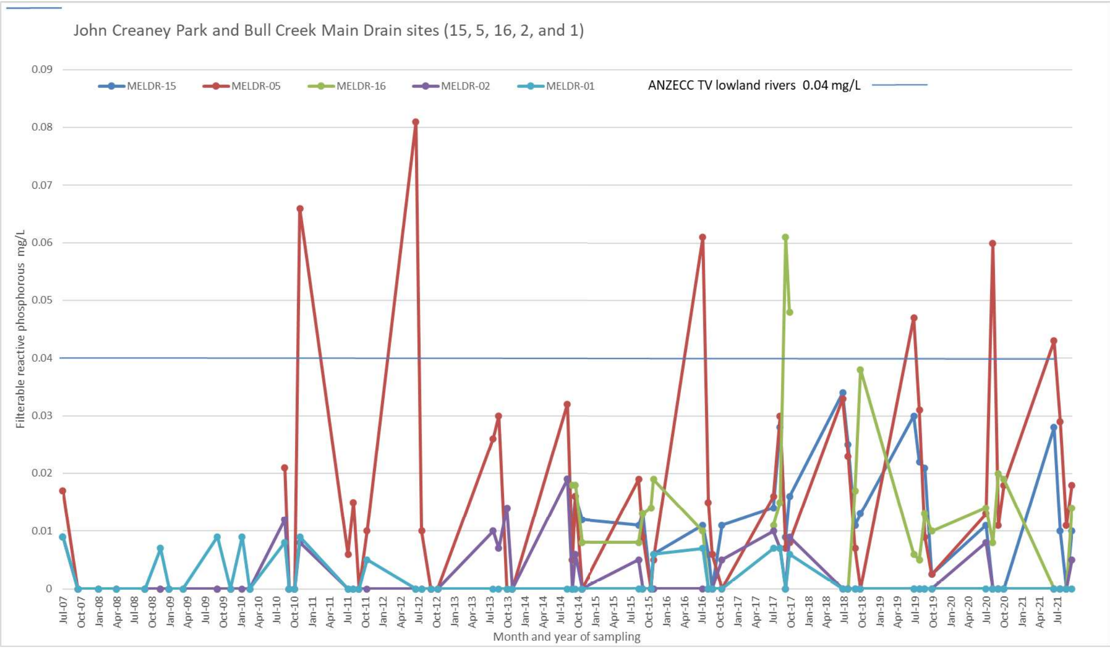


Figure 34. Total filterable reactive phosphorus in John Creaney Park and Bull Creek Main Drain sites.

Filterable reactive phosphorus

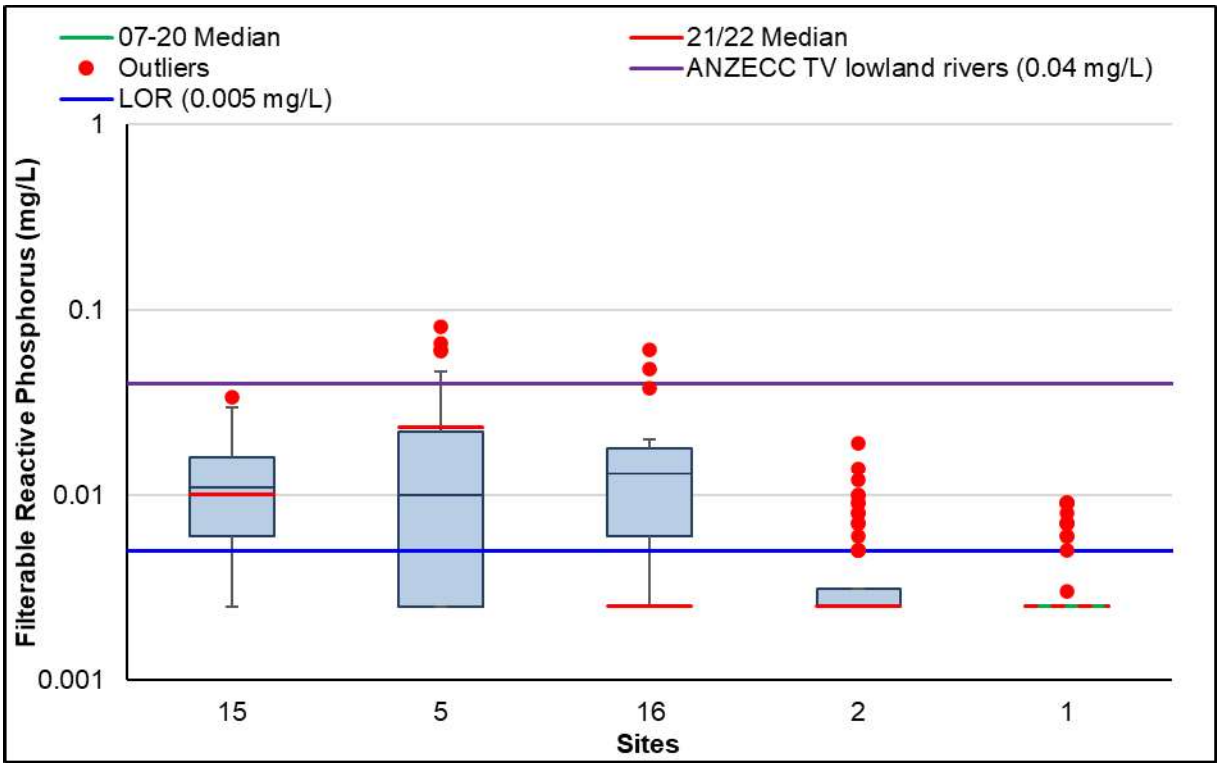


Figure 35. Box plot of FRP 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

FRP concentrations in 2021 exceeded relevant ANZECC trigger values (lowland rivers: 0.04 mg/L, wetlands: 0.03 mg/L) in 1 of 20 samples at site 5 in July (Figure 35). The FRP detected in with other samples were within acceptable levels and all samples from site 1 were below the LOR of <0.005 (Figure 35 and Table D-16 in Appendix D). The highest concentration was recorded at site 5 (0.043 mg/L in July). The lowest detectable concentration of FRP was recorded at site 2 (0.005 mg/L). Apart from samples at sites 5 in particular, the phosphorus in most samples collected in 2021 was predominately particulate forms of phosphorus (Table 16 and Figure 36)

Time series

Both total (Figure 33) and filterable reactive phosphorus (Figure 34) were regularly high and variable over the sampling time at John Creaney Park outlet (site 5) and the pipe at Elizabeth Manion Park (site 16), tending to exceed the ANZECC TV when close to a flush event due to rain. The total and filterable reactive phosphorus as well as variation in data at the other three sites, in particular at Bull Creek Main Drain (site 1) and Brockman Park (site 2) tended to be below ANZECC levels for both lowland rivers and wetlands. Overall, TP and FRP concentrations recorded at most sites in 2021 were in general similar to those recorded in the preceding 14 years of monitoring. Site 5 was the most variable and showed a possible downwards trend in TP and upwards trend in FRP since sampling began. Both filterable and total phosphorus upstream at Bull Creek Main Drain near Leach Highway (site 1) and Brockman Park (site 2) have remained low, often below detectable limits as well as trending slightly downwards. Upstream at the John Creaney Park outlet (site 5) however, both forms of phosphorus have remained high and very variable. The phosphorus concentrations at the two most upstream sites (John Creaney Park inlet, site 15, and Elizabeth Manion Park, site 16) have exceeded guidelines at occasions that can be associated with rainfall events.

Table 16. Descriptive statistics of filterable reactive and total phosphorus at John Creaney Park and Bull Creek Main Drain sites (sorted from least to most FRP). Includes all samples up to and influencing that of 2021.

	Filterable reactive phosphorus mg/L				Total phosphorus mg/L			
Site	Mean	SD	n	Median	Mean	SD	n	Median
Site 1	0.007	0.001	12	0.007	0.014	0.006	59	0.013
Site 2	0.009	0.004	15	0.008	0.015	0.011	51	0.013
Site 15	0.015	0.008	25	0.012	0.044	0.021	31	0.044
Site 16	0.018	0.013	23	0.014	0.055	0.039	29	0.044
Site 5	0.023	0.019	38	0.017	0.071	0.038	55	0.059

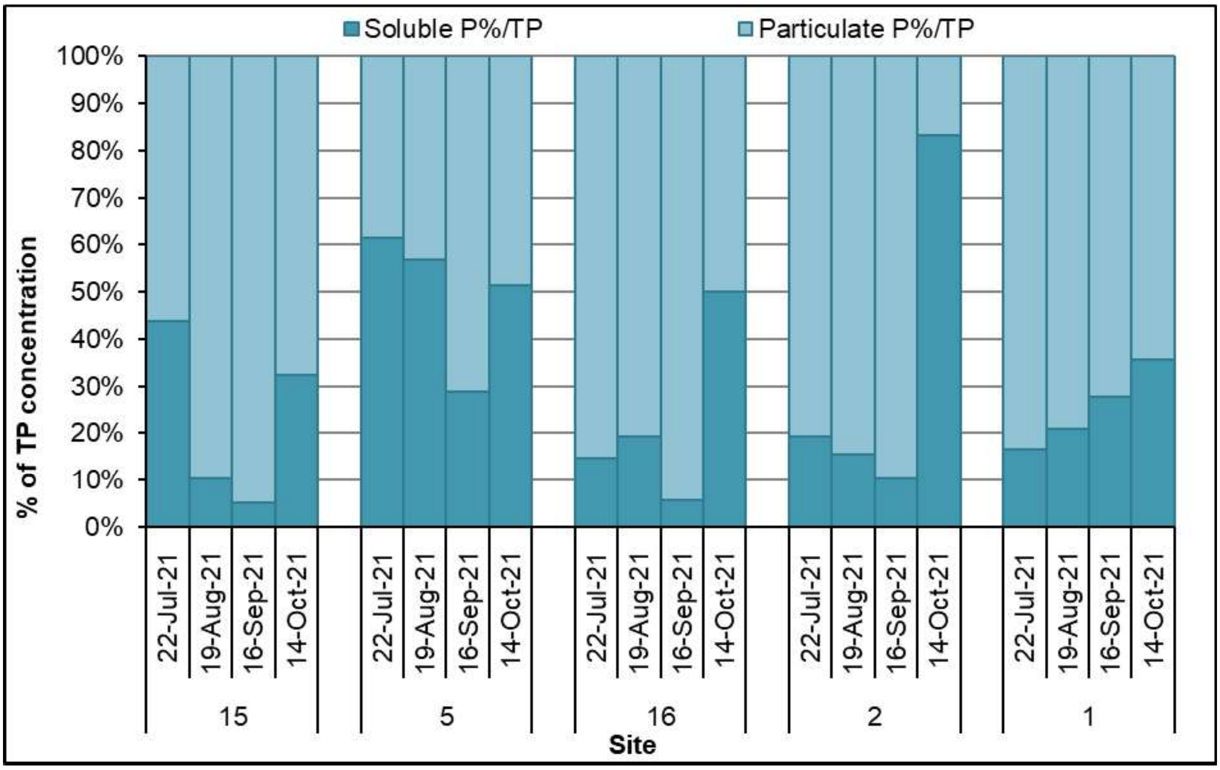


Figure 36. Phosphorus speciation in surface water at sites in the John Creaney Park and Bull Creek Park drainage line in 2021

Summary of nutrients in the water

Overall, the ranking of sites in terms of phosphorus in these wetlands is opposite to the ranking in terms of nitrogen (Table 17). At the downstream sites (sites 1 and 2), where nitrogen is the highest of all sites, the phosphorus is the lowest of all sites. This contrasts with the most upstream site, site 15 in particular, where the nitrogen is lowest of all sites, but phosphorus moderately high. The cause of this may be associated with how well ecosystems cycle these nutrients and the sources of the nutrients. Given that ecosystems are better at cycling nitrogens than phosphorus, if there were no unusual input of these nutrients along the drains, the expectation may have been to find that nitrogen would drop from upstream to downstream to a greater extent that phosphorus. But this has not been the case for these drains and the results suggest that the drains are experiences inflow of excess nutrients, and their ecosystems may be less able to manage phosphorus loads than nitrogen loads. This needs further study.

The trends observed between and within sites over time reveal that in terms of nitrogen, the upstream sites, John Creaney Park inlet (site 15) and Elizabeth Manion Park (site 16) are in a better condition than the downstream sites, Bull Creek Main Drain near Leach Highway (site 1) and Brockman Park (site 2). Understanding the trends is more complex, but if we assume that increasing organic material combined with better oxygenation, allows more oxygen to be bound to nitrogen and this may also be oxidised better further downstream. It may suggest that rehabilitation at sites is improving the nitrogen cycling, but this needs to be considered in association with nitrogen from pollutants. In terms of phosphorus, the wetlands may be less effective at assimilating these and the increases reflect increasing phosphorous due to contamination along the drain (Table 17).

Table 17. Summary of observations of nitrogen and phosphorus at John Creaney Park and Bull Creek Main Drain sites. **(Site ranking - from highest to lowest concentration, mg/L)**

Form of N	Site Ranking	Maximum to minimum	Variations with time
Total N (TN)	2, 1, 16, 5, 15	0.023 – 0.007	Slight upwards trend with time in sites 2 and 1. Slight downwards trend in sites 16, 5 and 15.
Oxidized N	1, 16, 2, 15, 5	2.180 (influenced by outlier) – 0.281	Possible increase with time, particularly in sites 1 (that remains high) and to an extent also site 16. Outliers can be associated with rainfall events.
N as NH3-NH4	2, 1, 5, 15, 16	5.180 (influenced by outlier) – 0.068	No overall trend is visible, though levels at site 2 remain high through the sampling period.
Total organic N (TON)	5, 2, 15, 1, 16	0.773 – 0.526	Slight decreasing trend since sampling began overall. Peaks can be associated with rainfall events.
Total dissolved organic N (DON)	5, 1, 2, 15, 16	0.579 – 0.402	The decreasing trend since sampling began overall is slightly more pronounced compared to TON. This is most prominent in site 15. Peaks can be associated with rainfall events.
Overall summary rank from most N to least N		1, 2, 5, 16, 15. Progressively increasing from upstream to downstream.	
Type of P	Site Ranking	Maximum to minimum	Variations with time
Total P	5, 16, 15, 2, 1	0.071 – 0.014	While high and variable in sites 5 and 2, it is trending slightly down with time in most sites, except for in site 15 where it is trending slightly upwards.
Filterable P FRP	5, 15, 16, 2, 1	0.023 – 0.007	In most sites, FRP remains similar across the sampling years. But there is a slight indication that FRP is stabilising and trending upwards in site 5.
Overall summary ranks from most P to least P		5, 15 = 16, 2, 1. Partially an opposite trend to that of N, where intermediate and downriver sites have less P than those further upstream.	

Metals

Metals in water

Hardness

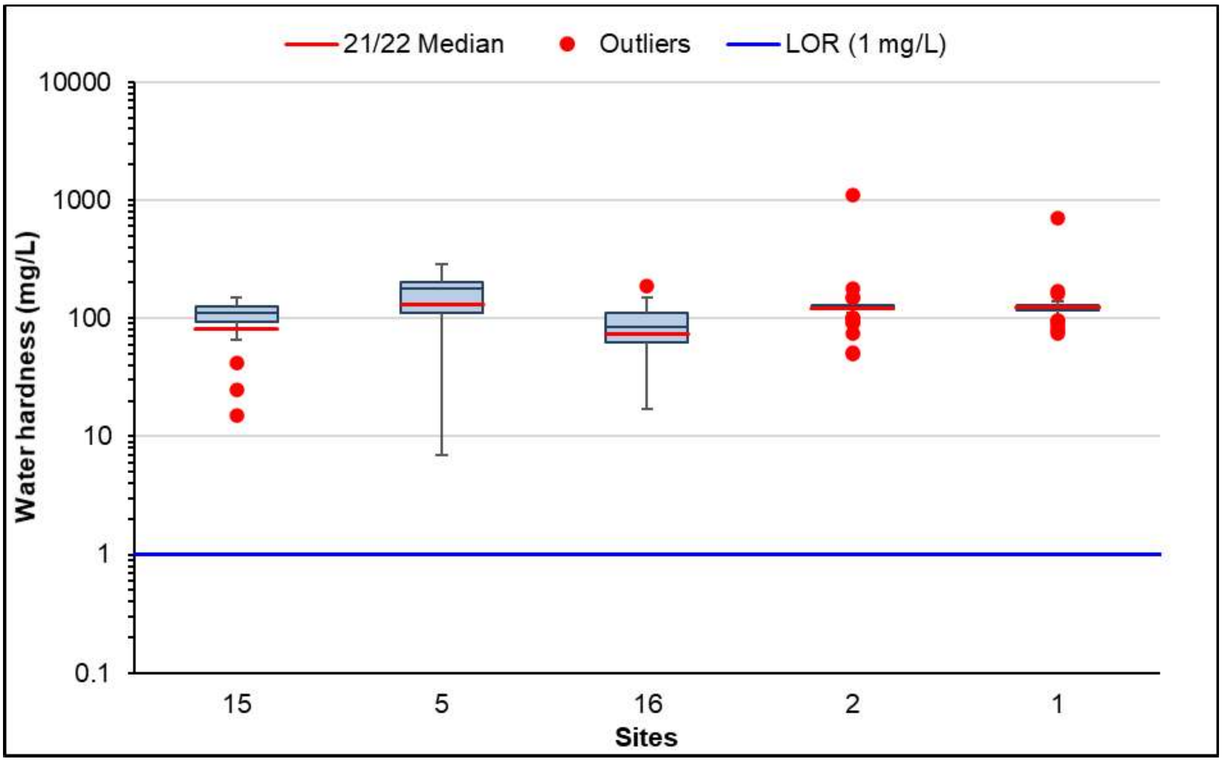


Figure 37. Box plot of water hardness 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

In 2021 water hardness in the surface water of the Melville Bull Creek catchments varied from a minimum of 42 mg/L recorded at site 15 (October) to a maximum of 140 mg/L at site 5 (August) (Figure 37 and Table D-17 in Appendix D). When classified by the ANZECC guidelines; of the 20 samples collected in 2021, 4 can be classified as Soft (0 to 59 mg/L), 7 as moderately hard (60 – 119 mg/L) and 9 as hard (120 – 179). The waters were more often soft is September and harder in October, August, and July respectively. The water was also softest is site 16 and harder in site 15, 1, 2 and 5 respectively.

Time series

Water hardness values recorded in Melville Bull Creek catchment sites in 2021 show some variation since monitoring began in 2007 (Figure 38, Table G-51 in Appendix G). Apart from outliers in November 2018 in site 2 and August 2011 in site 1, the water hardness has remained site specific with slight decreasing trends with time. Site 5 had often had the hardest and most variable water hardness (when the two outliers are removed from sites 1 and 2 data) while site 16 recorded the lowest. The trends also indicate that (when the two outliers are removed) the hardness is less variable in sites 15 and 16 (upstream) as well as the most downstream site (site 1) compared to more intermediate sites (2 and 5).

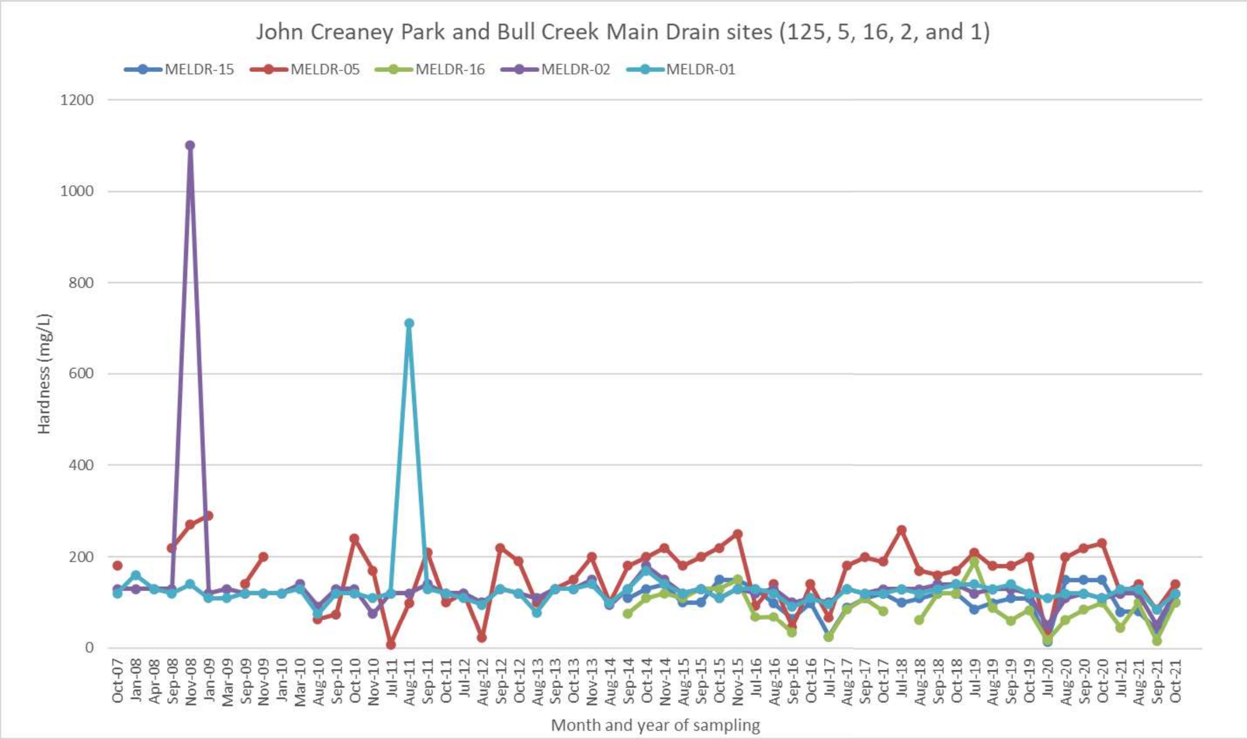


Figure 38. Hardness of water at the John Creaney Park and Bull Creek Main Drain sites.

Table 18. Descriptive statistics of the water hardness and total suspended solids at John Creaney Park and Bull Creek Main Drain sites. Includes all samples up to and including that of 2021.

	Water hardness mg/L			TSS mg/L		
Site	Mean	SD	n	Mean	SD	n
5	158	67.0	55	1.3	3.5	55
2	137	121.9	60	3.3	1.8	60
2 Without outlier	121	20.1	59	Not relevant		
16	88	39.2	29	11.7	11.3	30
15	104	33.8	31	10.1	9.0	31
1	131	77.2	60	4.4	4.2	60
1 without outlier	121	11.7	59	Not relevant		

TSS overall was highest upstream than downstream with variation in TSS across the sampling season having been higher downstream (sites 1 and 2) than upstream (sites 15 in particular) (Table 18). There is also a trend suggesting TSS was decreasing at Bull Creek Main Drain near Leach Highway (site 1), and this seems to stabilise after 2014. There were, however, slight upwards trends in TSS at all other sites.

These insights may be associated with stream flow rate downriver and rainfall events that may influence hardness and TSS downstream more than upstream, but this needs to be examined further.

Aluminium

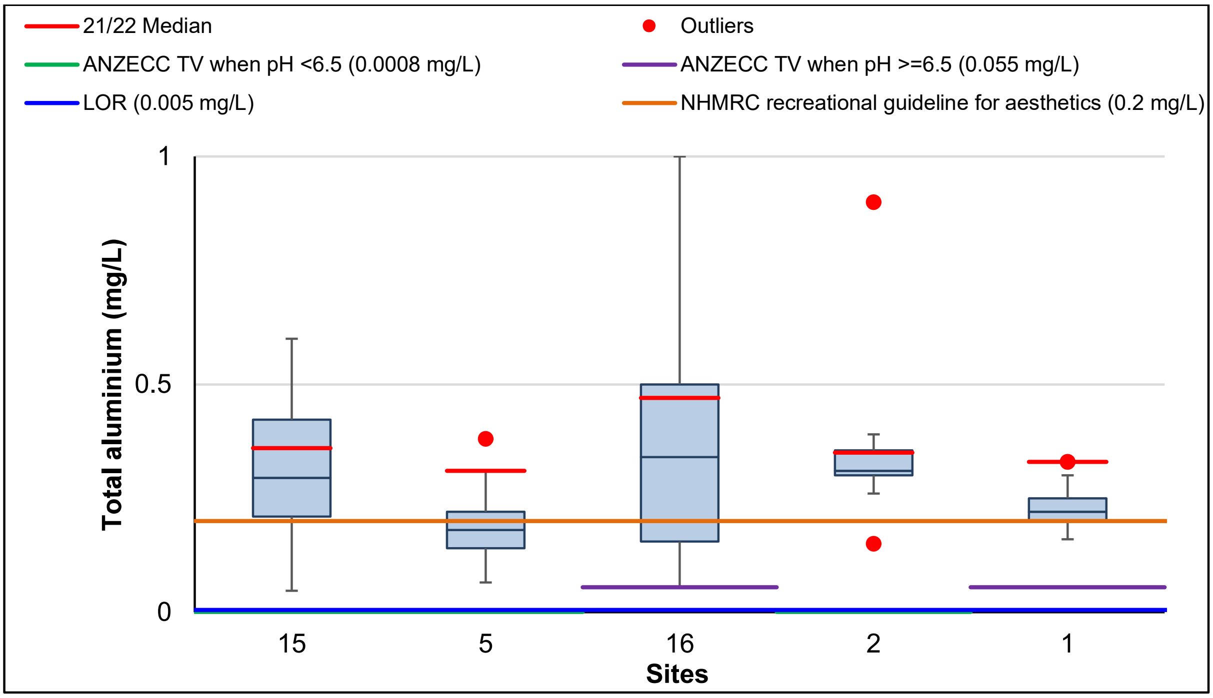


Figure 39. Box plot of total aluminium 2007-2020 historical median values, with a red line indicating the median value in 2021.

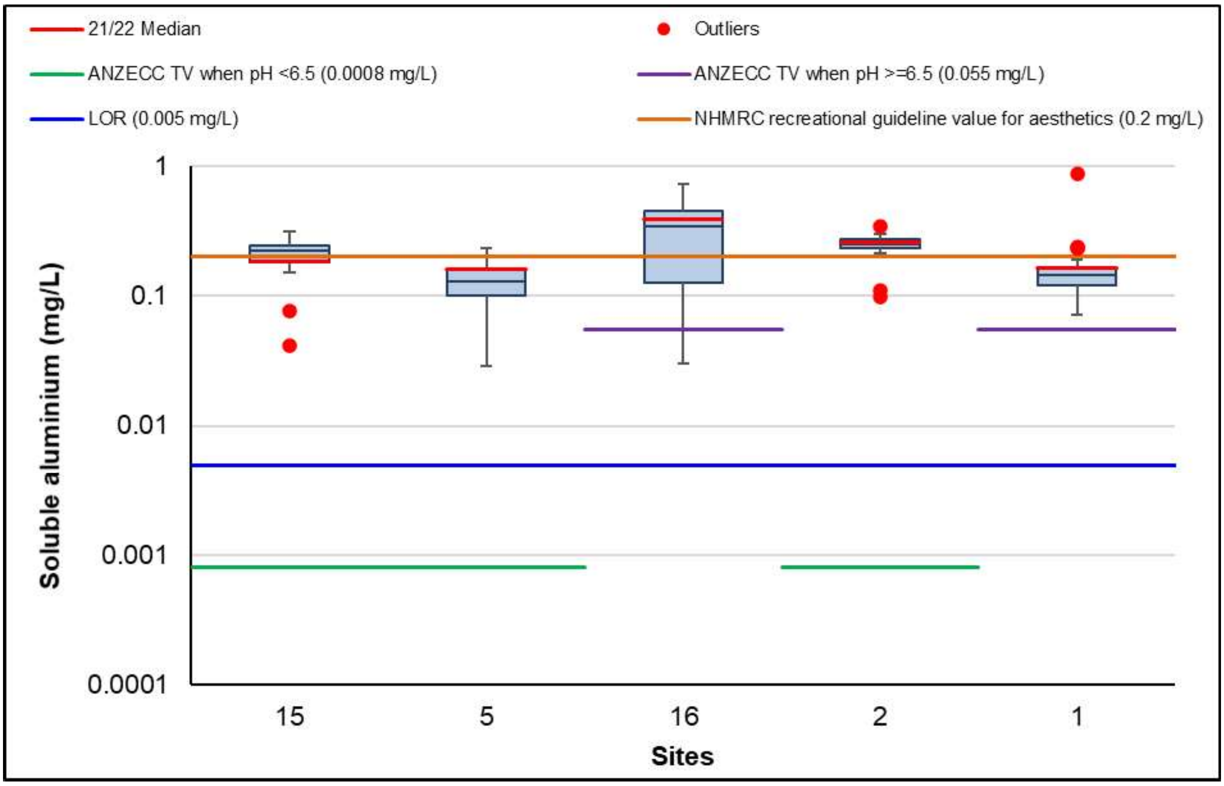


Figure 40. Logarithmic box plot of the median soluble aluminium nitrogen (mg/L) recorded in 2021 at sites in the John Creaney Park and Bull Creek Park drainage line. Box plots refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

Concentrations of total aluminium were high across the catchment in 2021, with all 5 sites in exceedance of the ANZECC trigger value for 95% level of protection of 0.055 mg/L for samples with pH > 1.5, as well as the low reliability interim value for freshwater protection of 0.0008 mg/L (Figure 39 and Table D-18 in Appendix D). In addition, all 5 sites exceeded the NHMRC guideline value for aesthetics (0.2 mg/L).

Considering that soluble aluminium corresponds to the concentrations available for biological uptake and potential impact on the biota; it is important to highlight that at site 1 aluminium was predominantly present as soluble (≥60%) during the July 2021 sampling event.

Time series

Since sampling began in 2007, and although soluble aluminium has remained lower than total aluminium, both total (Figure 41) and soluble aluminium (Figure 42) in these wetlands have exceed environmental and aesthetic trigger values, particularly downriver following rainfall events. Changes in one parameter reflects changes in the other, though to different extents. Additionally, there are trends suggesting that these parameters are becoming more variable and increasing at the upstream sites, in particular site 16, compared to that at other sites. The high variability at the downstream sites, 1 and 2, compared to the upstream sites, 15 and 11 (Table 19), are no doubt due to outliers that occur at rainfall and subsequent inflow events and affect downstream sites to a larger extent than upstream sites. As there is, however, no obvious association of aluminium with pH (see Main Report), it is more likely therefore, that these differences are due to increasing urban inflow upstream as well as rain fall events downstream.

Table 19. Descriptive statistics of total and soluble aluminium at John Creaney Park and Bull Creek Main Drain. Includes all samples up to and including that of 2021.

	Total aluminium (mg/L)				Soluble aluminium (mg/L)			
site	Mean	SD	n	Median	Mean	SD	n	Median
5	0.184	0.069	34	0.18	0.131	0.046	43	0.13
1	0.305	0.472	39	0.22	0.157	0.106	52	0.15
15	0.313	0.143	16	0.20	0.206	0.068	20	0.22
2	0.380	0.297	39	0.31	0.246	0.050	28	0.25
16	0.409	0.285	15	0.34	0.306	0.194	19	0.34

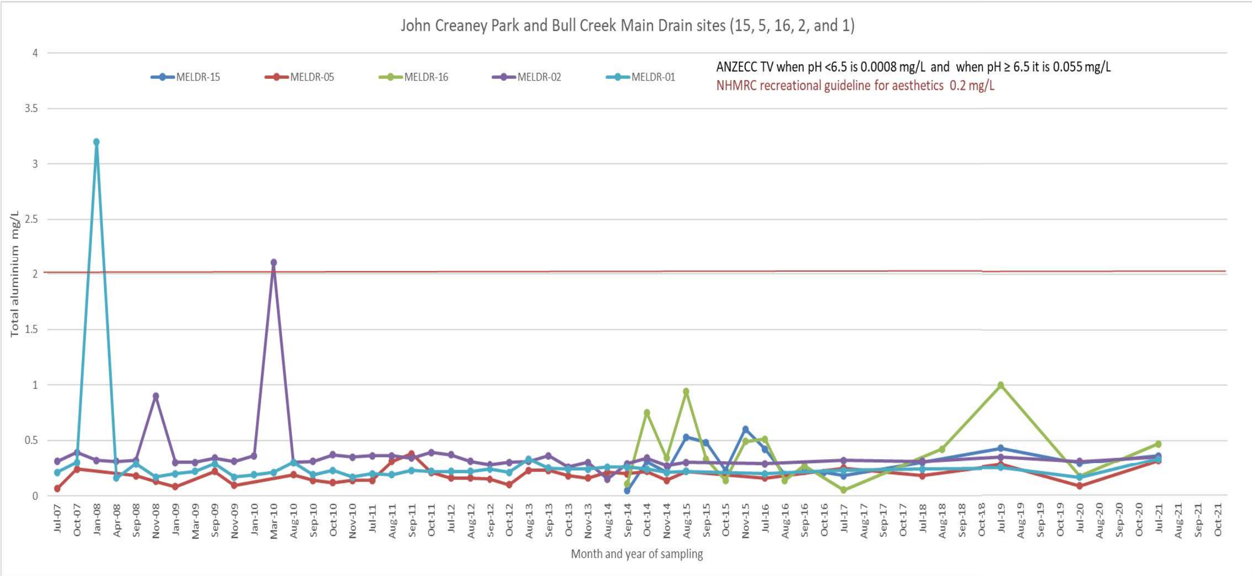


Figure 41. Total aluminium at the Bull Creek Main Drain sites since sampling began.

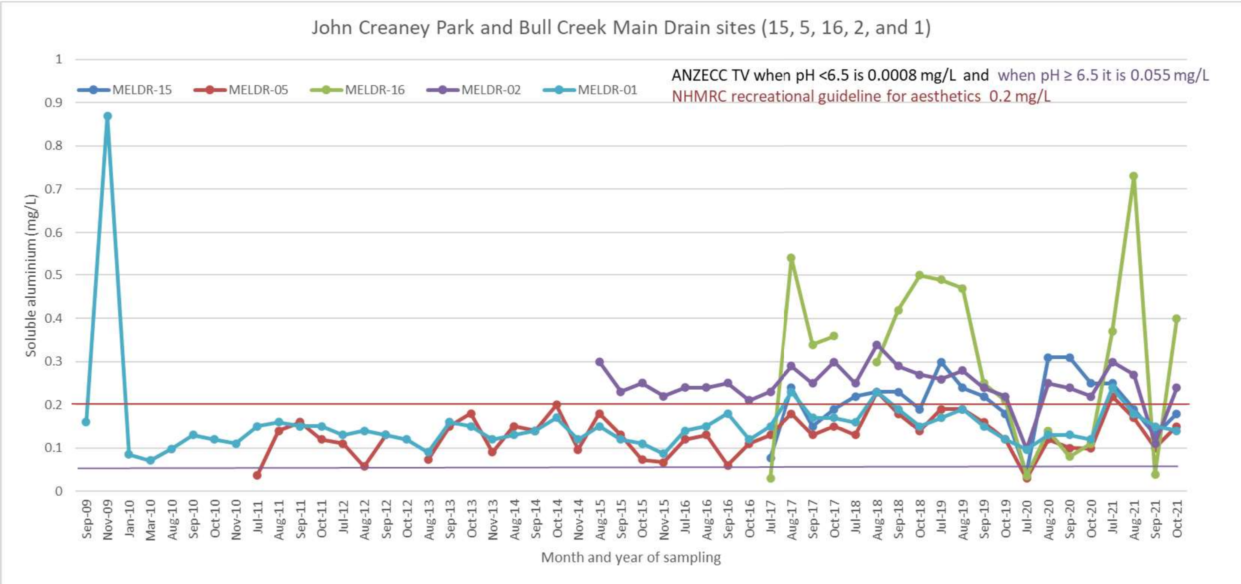


Figure 42. Soluble aluminium at the Bull Creek Main Drain sites since sampling began.

Chromium

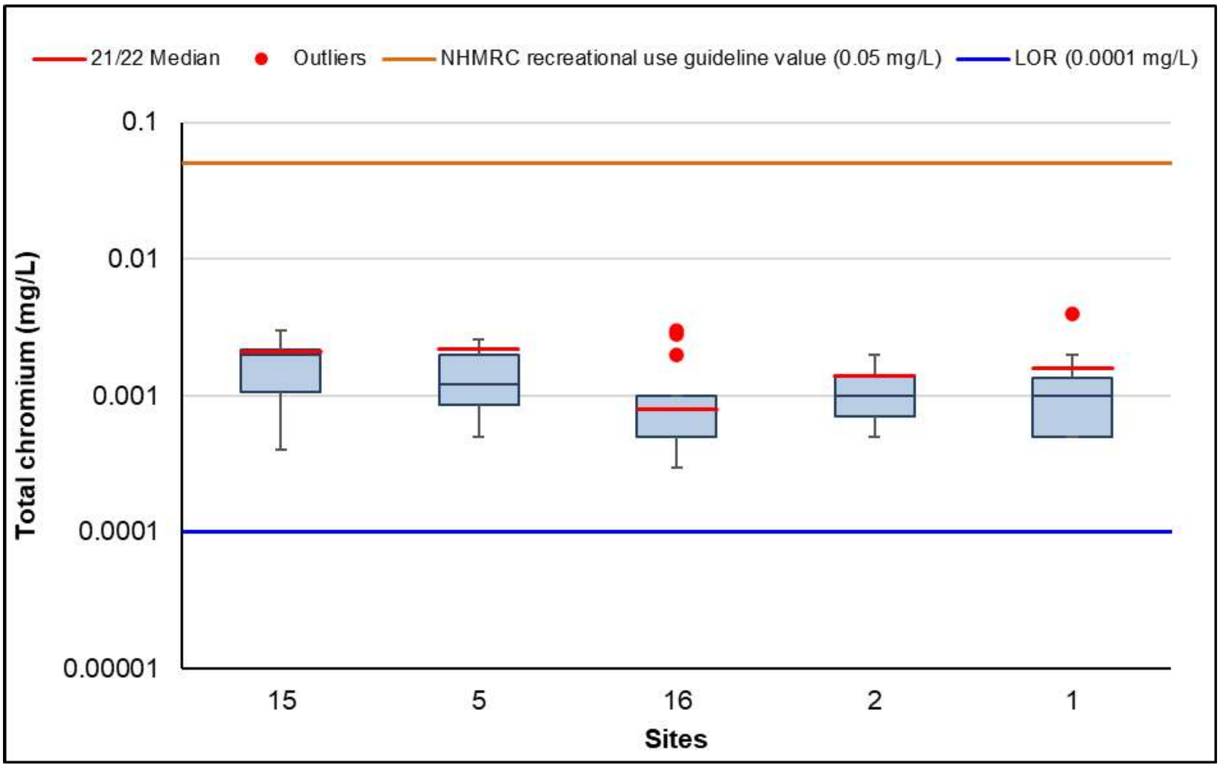


Figure 43. Box plot of total chromium 2007-2020 historical median values, with a red line indicating the median value in 2021.

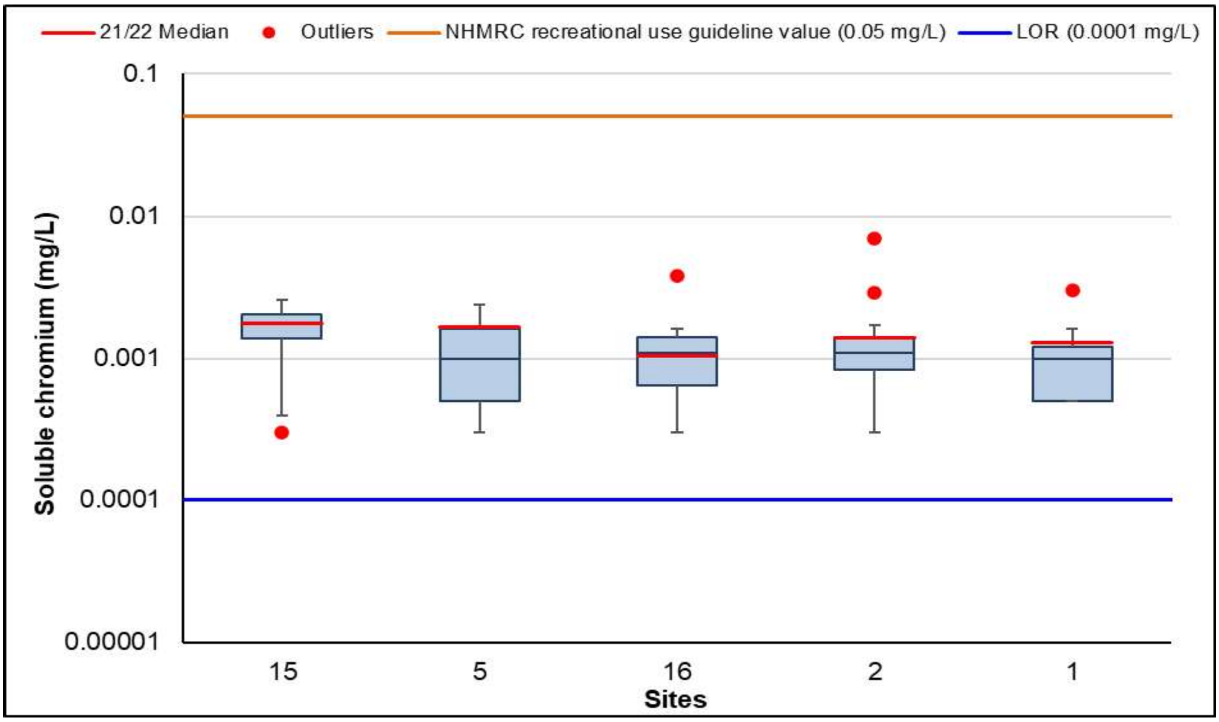


Figure 44. Box plot of soluble chromium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total chromium and soluble chromium (where both include Cr3+ and Cr6+ chromium fractions) concentrations recorded at all the John Creaney Park and Bull Creek Park drainage line sites were below ANZECC hardness adjusted trigger values for 95% protection of biota (unmodified trigger value for chromium: 0.0033 mg/L) in 2021 (Figures 43 and 44Figure and Tables D-20 and D-21 in Appendix D. The trigger value for Cr3+has been selected (and not Cr6+) as in natural water Cr3+ is the predominant species present due to a range of factors. The trigger value for chromium is affected by water hardness. Therefore, the modified trigger values shown on the graph vary, dependent on the water hardness concentration recorded at each site.

During sampling in 2021, the highest total chromium concentration of 0.0022 mg/L was recorded at site 5 in July and the highest soluble chromium concentration of 0.0019 mg/L was recorded at site 15 in July. The lowest total chromium concentration of 0.0008 mg/L was recorded at sites 16 in July. The lowest soluble chromium concentration of 0.0004 mg/L was recorded once in September at site 16. No sites recorded values equal to or below the LOR. No total or soluble chromium concentration exceeded the NHMRC recreational guideline value for health (0.05 mg/L).

Time series

Total (Figure 45) and soluable chromium (Figure 46) concentration have always been below adjusted ANZECC trigger values (adjusted in conduction with impacts of water hardness) since sampling of this parameter began in 2009. Additionally, there were several times when the levels of soluble Chromium were close to or below the LOR of 0.0001 mg/L (recorded as zero in Figure 46). There is a slight trend that the total and soluble chromium (Cr3) is increasing in the water (Figures 45 and 46 and Table 20).

Table 20. Descriptive statistics of total and soluble chromium at John Creaney Park and Bull Creek Main Drain.

	Total chromium mg/L			Soluble chromium mg/L		
Site	Mean	SD	n	Mean	SD	n
15	104	33.8	31	0.00164	0.0006	20
5	158	67.0	55	0.00132	0.0005	34
16	88	39.2	29	0.00116	0.0008	19
2	137	121.9	60	0.00145	0.0013	24
1	131	77.2	60	0.00119	0.0004	31

Several data points fall close to, at or below the detectable limit (LOR), in particular those from Bull Creek Main Drain near Leach Highway (MELDR-01) between 2009 and 2017 (Figures 45 and 46). Additionally, while there are high outliers, these are not clearly associated with rainfall events (BOM historical data). The variability of total chromium is also higher downstream compared to upstream, but such an observation was not made with respect to soluble chromium. Additionally, since 2017, the soluble levels of chromium ions tended to increase at most sites with a suggestion that it is also decreasing slightly as the water progresses downstream. Given that conversion of Cr4 ions into Cr3 and Cr2 ions occurs naturally in the presence of iron and bacteria in healthy wetlands, this may be a result of improved environmental conditions since 2017.

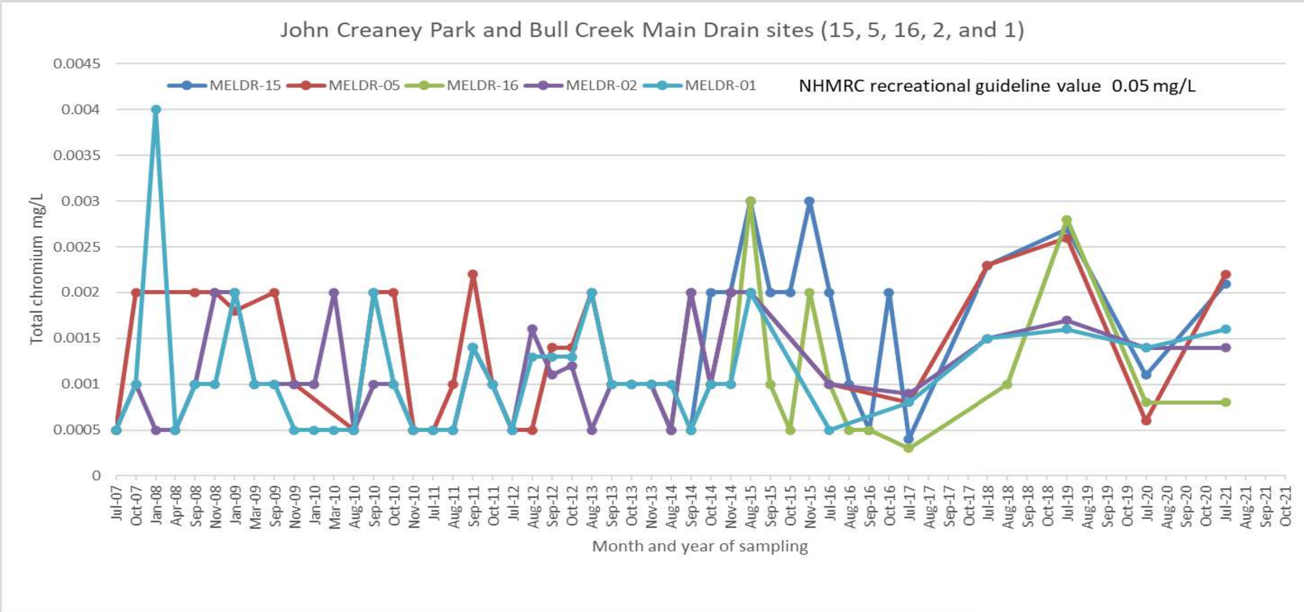


Figure 45. Total chromium at the Bull Creek Main Drain sites since sampling began.

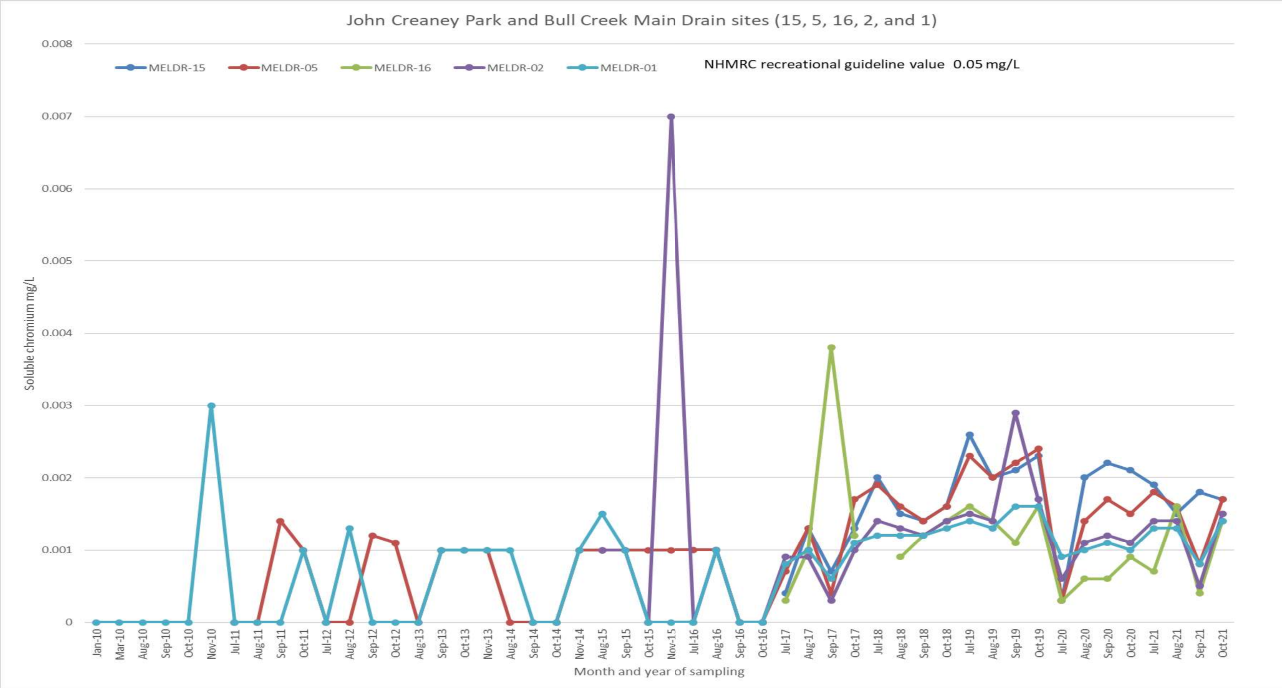


Figure 46. Soluble chromium at the Bull Creek Main Drain sites since sampling began.

Copper

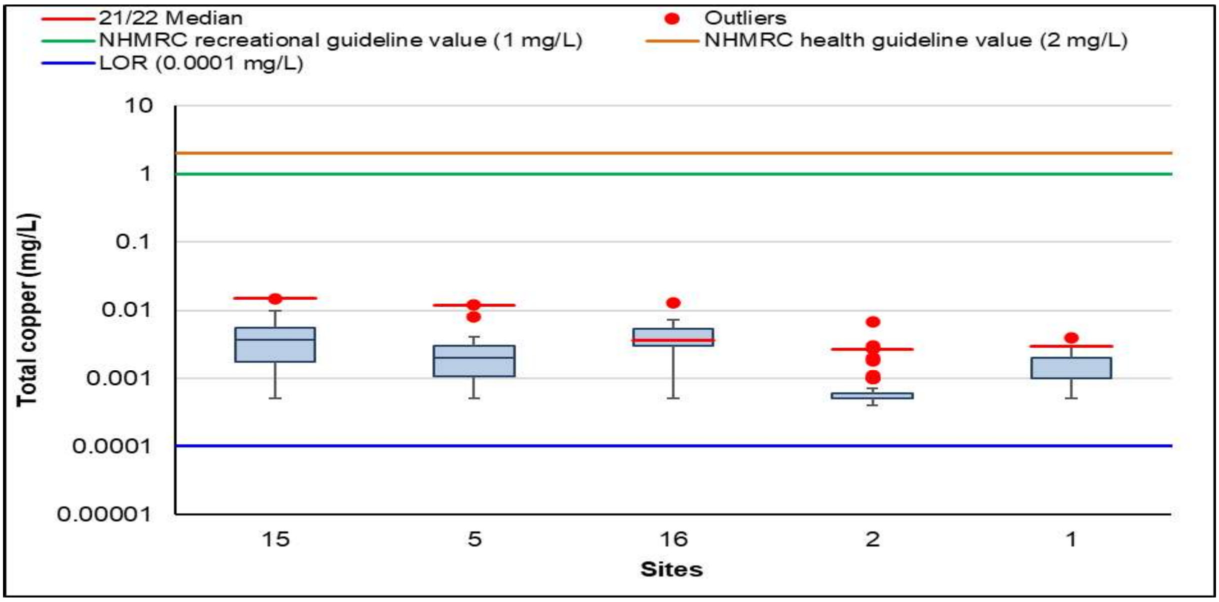


Figure 47. Box plot of total copper 2007-2020 historical median values, with a red line indicating the median value in 2021.

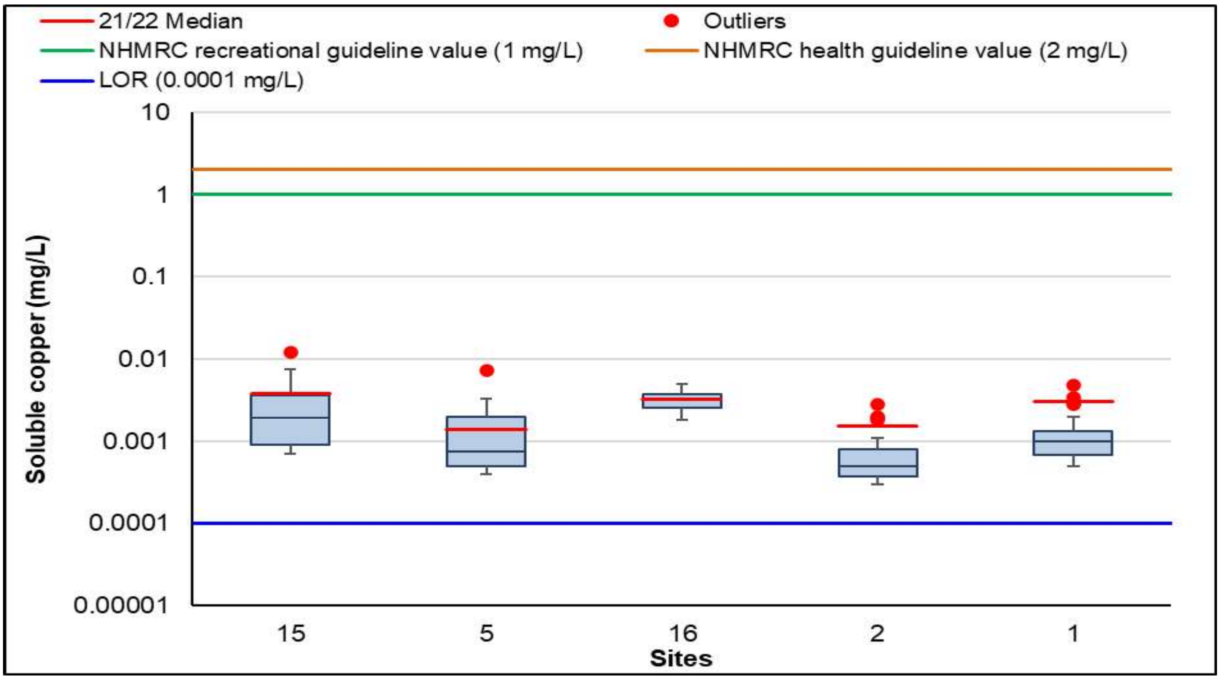


Figure 48. Box plot of soluble copper 2007-2020 historical median values, with a red line indicating the median value in 2021. Data adjusted for hardness.

Box whisker

The ANZECC unmodified trigger value for copper in water for 95% level of protection is 0.0014 mg/L (Figure 47). The 95% protection trigger value for copper is affected by water hardness. Therefore, the modified trigger values (Figure 48) shown on the box whisker plots vary, according to the water hardness concentration recorded at each site. For the details and calculations see Tables D-22 and D-23 in Appendix D. Concentrations of total and soluble copper had higher than usual exceedances of the hardness adjusted ANZECC trigger values for 95% protection of biota in July 2021 when this metal was analysed. Total copper exceeded the hardness adjusted ANZECC trigger value at 3 out of 5 sites (sites 5, 15 and 16), with the highest value (0.015 mg/L) recorded at site 15 and the lowest value (0.0027 mg/L) recorded at site 2. The total copper at these sites exceed the ANZECC 95% protection limits, with most also exceeding the 80% limit of 0.0025 mg/L.

Soluble copper exceeded the hardness adjusted ANZECC trigger value at 4 out of 5 sites in 2021, mainly in July, and just under 50% of the time in September. The highest value recorded was 0.0120 mg/L at site 15 in July 2021, and the lowest value recorded was 0.0005 mg/L at site 5 in October (Table D 23 in Appendix D). No total or soluble copper concentration exceeded the NHMRC recreational guideline for aesthetic value (1 mg/L) or health value (2 mg/L) (Figures 47 and 48).

Time series

Total and soluble copper concentrations recorded in the John Creaney Park and Bull Creek Park drainage line sites in 2021 was higher compared to values recorded in the preceding 14 years of monitoring (Table 21, Figures 49 and 50). Apart from site 1, the other sites along the branch upstream, including the Bull Creek Main Drain (sites 15, 5 and 2) had several exceedances for total and soluble copper. Copper levels at site 15 (John Creaney Park inlet) appear to be higher than copper levels coming from site 16 (downstream Elizabeth Manion Park) branch.

The time series plots (not adjusted for hardness) also show that total copper and the variability of total copper has increased since sampling began in 2007, but more so after 2014, in upstream sites and at the intermediate site (site 5) to a larger extent than at downstream sites (in particular site 1). Although soluble copper has also increased in a similar manner at upstream sites more than at downstream sites, the amount of soluble copper in the waters at all sites has become more variable since sampling began, in particular since 2011. Peaks of both total copper and soluble copper tend to coincide with rainfall events. These results may indicate that metals washed into drains remain is upstream sites in these two forms for a longer time than they do at downstream sites, and this may be due to streamflow. The origin of this copper is uncertain, and the role that silts and organic matter have in binding copper as it flows through sites also needs further understanding.

Table 21. Descriptive statistics of total and soluble copper at the Bull Creek Main Drain sites. Includes all data up to and including that of 2021.

	Total copper mg/L			Soluble copper mg/L		
Site	Mean	SD	n	Mean	SD	n
15	0.00457	0.00393	16	0.00291	0.00277	20
5	0.00256	0.00221	34	0.00159	0.00132	31
16	0.00442	0.00296	15	0.00327	0.00085	19
2	0.00091	0.00112	39	0.00086	0.00070	20
1	0.00140	0.00075	39	0.00141	0.00082	40

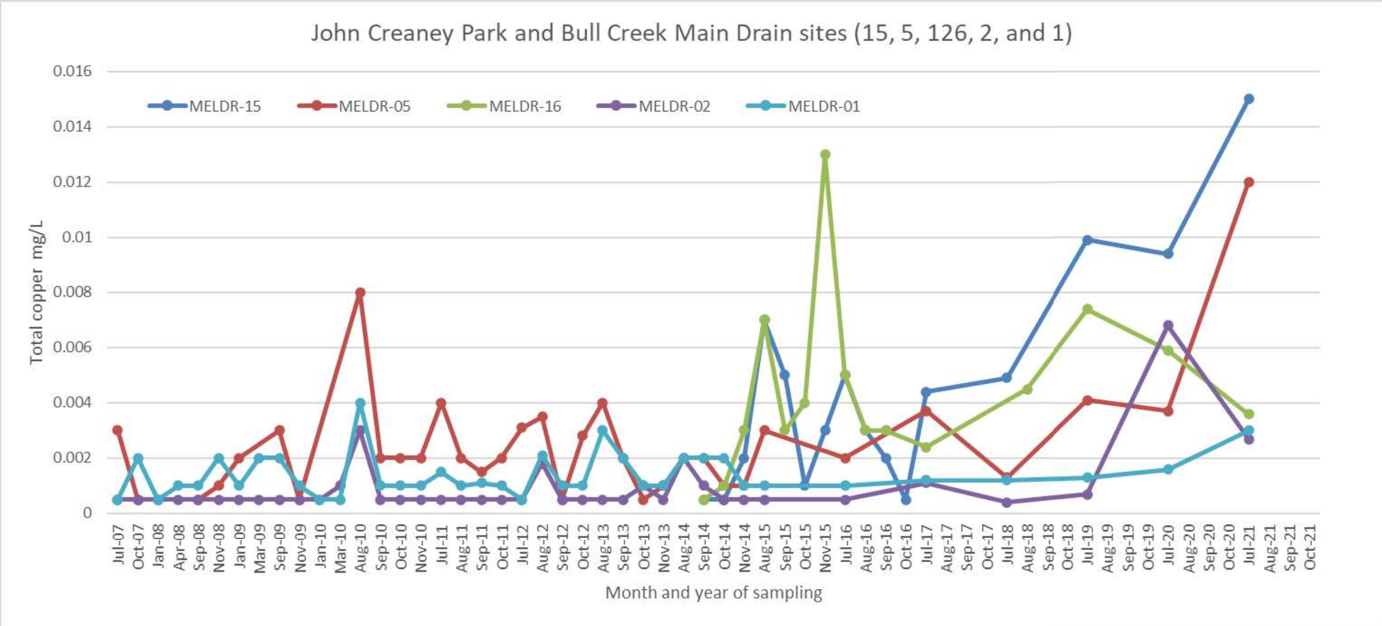


Figure 49. Total copper at the Bull Creek Main Drain sites since sampling began.

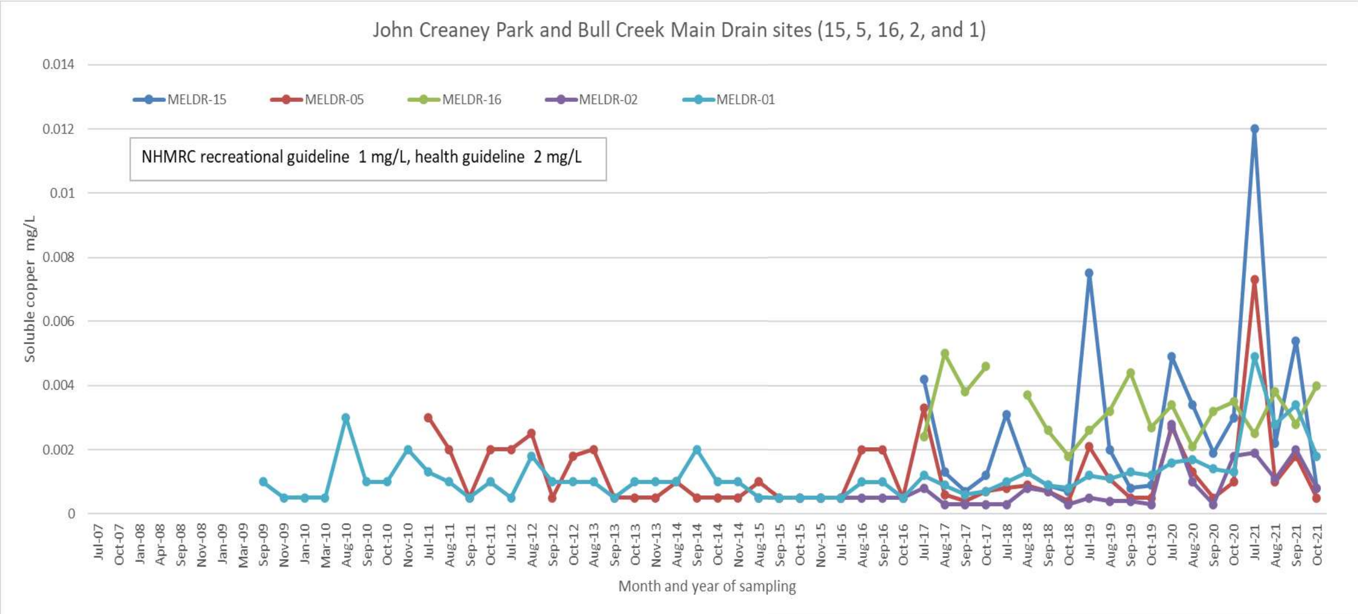


Figure 50. Soluble copper at the Bull Creek Main Drain sites since sampling began.

Iron

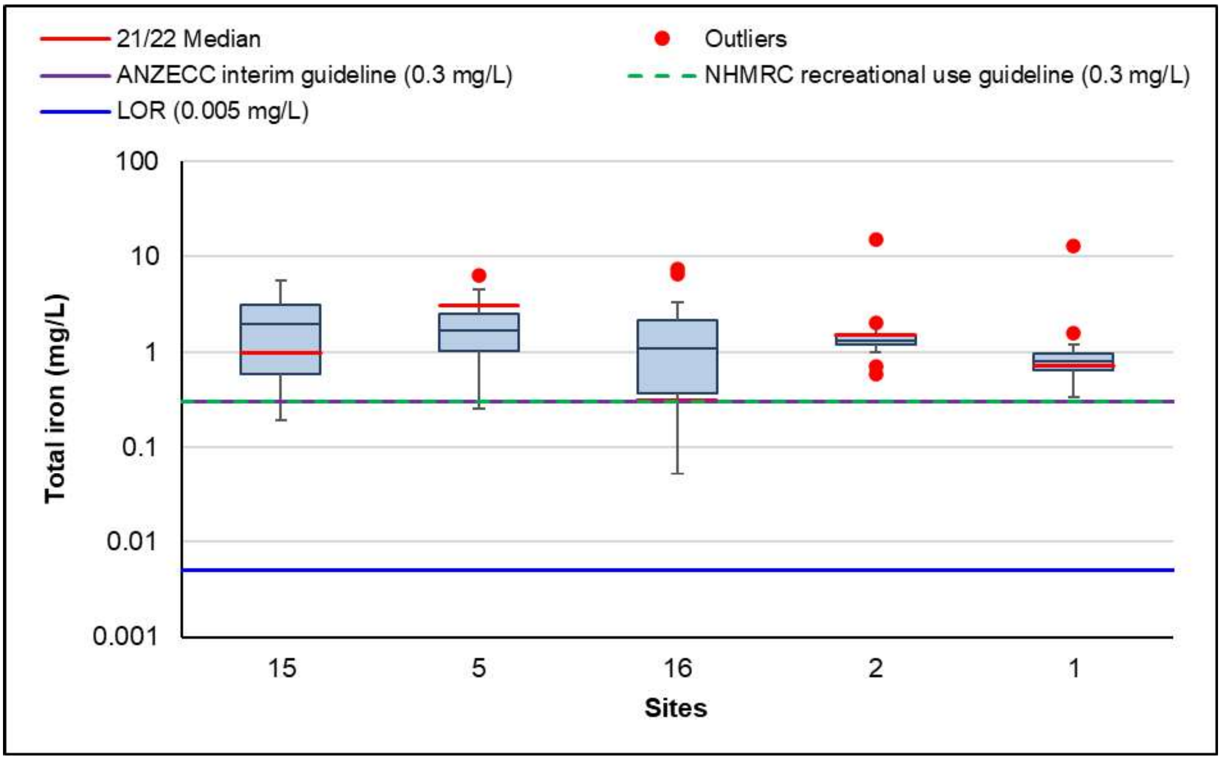


Figure 51. Box plot of total iron 2007-2020 historical median values, with a red line indicating the median value in 2021.

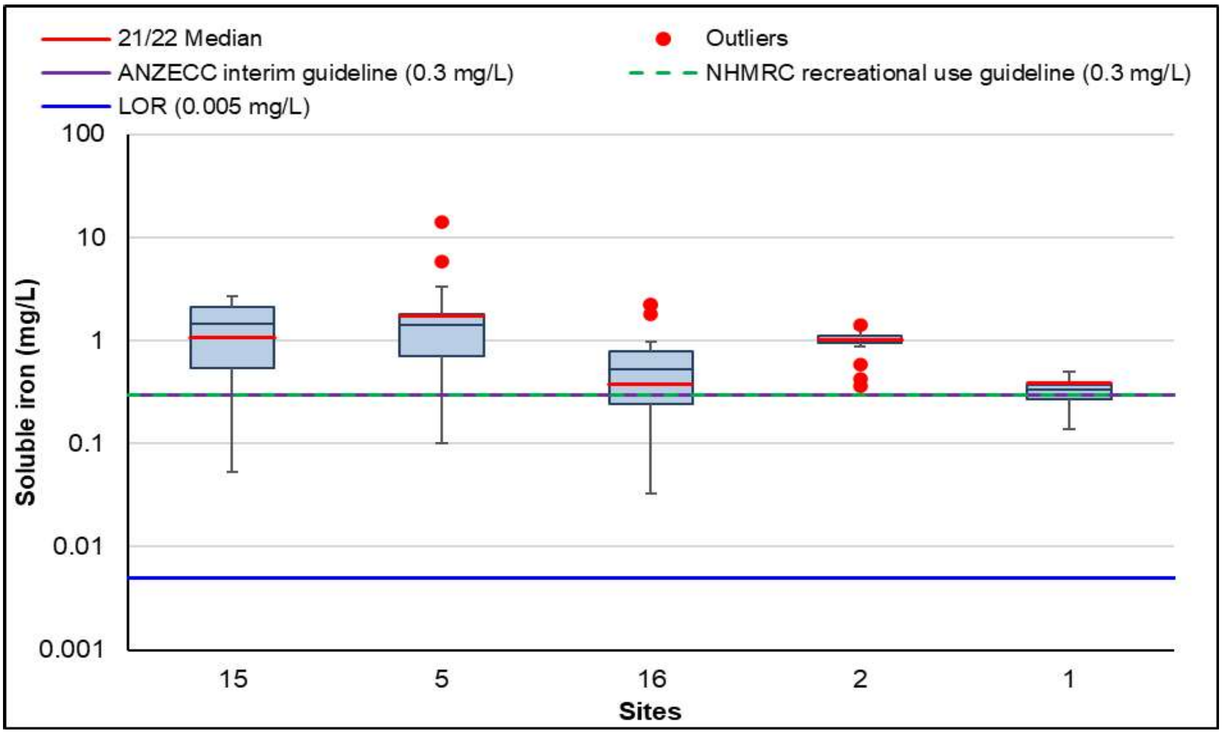


Figure 52. Box plot of soluble iron 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

ANZECC & ARMCANZ advise there continues to be insufficient data at this stage to determine a reliable trigger value for iron in freshwater ecosystems. The current Canadian guideline level is 0.3 mg/L, which could be used if required and seen to be an issue. Due to this, it is difficult to gauge the severity of any potential impact arising from the concentrations recorded in the water collected at the John Creaney Park and Bull Creek Park drainage line sites.

All of the John Creaney Park and Bull Creek Park drainage line sites recorded total iron concentrations exceeding the ANZECC interim guideline value for iron (0.3 mg/L) in 2021 and 18 of 20 samples from all sites recorded soluble iron concentrations exceeding the interim guideline value for iron (Figures 51 and 52 and Tables D-24 and D-25 in Appendix D). The highest total (3.1 mg/L) and soluble (2.70 mg/L) iron concentrations were at site 5 in July. The lowest total iron concentration (0.31 mg/L) was recorded at site 16 in July and the lowest soluble iron concentration (0.065 mg/L) was recorded at site 16 in September.

Time series

Total and soluble iron concentrations recorded in the John Creaney Park and Bull Creek Park drainage line sites in 2021 show mostly similar trends as those recorded in the preceding 14 years of monitoring (Figures 53 and 54, and Table G 52 in Appendix G). Throughout the 14-year monitoring period, total iron concentrations have almost always exceeded the interim trigger value at sites 15, 5, 16 and 2, but not as frequently at site 1.

Apart from occasional outliers in downstream sites, both the total and soluble iron has tended to be highest and most variable at site 5 compared to the other sites. The levels of total and soluble iron at sites 15 and 16 upstream is showing a slight trend downwards with time, while the levels of both forms of iron have remained reasonable stable since sampling began. Overall, soluble iron is trending slightly downwards as the drain progresses downriver. Note that outliers in site 1 (August 2007), site 2 (March 2010) and site 5 (July 2011, August 2020) influence the calculations of means and variability of readings. There were no similar outliers in the upstream sites, suggesting that rainfall events may have a larger impact on inflow of iron downstream than upstream.

Table 22. Descriptive statistics of total and soluble iron at John Creaney Park and Bull Creek Main Drain. Includes all data up to and including that of 2021.

	Total iron mg/L			Soluble iron mg/L		
Site	Mean	SD	n	Mean	SD	n
15	1.98912	1.3939	34	1.347	0.809	20
5	1.87487	2.20765	15	1.450	1.048	42
16	1.67949	2.17778	39	0.702	0.651	19
2	1.13051	1.94133	39	1.006	0.227	28
1	3.16923	1.09501	13	0.328	0.075	52

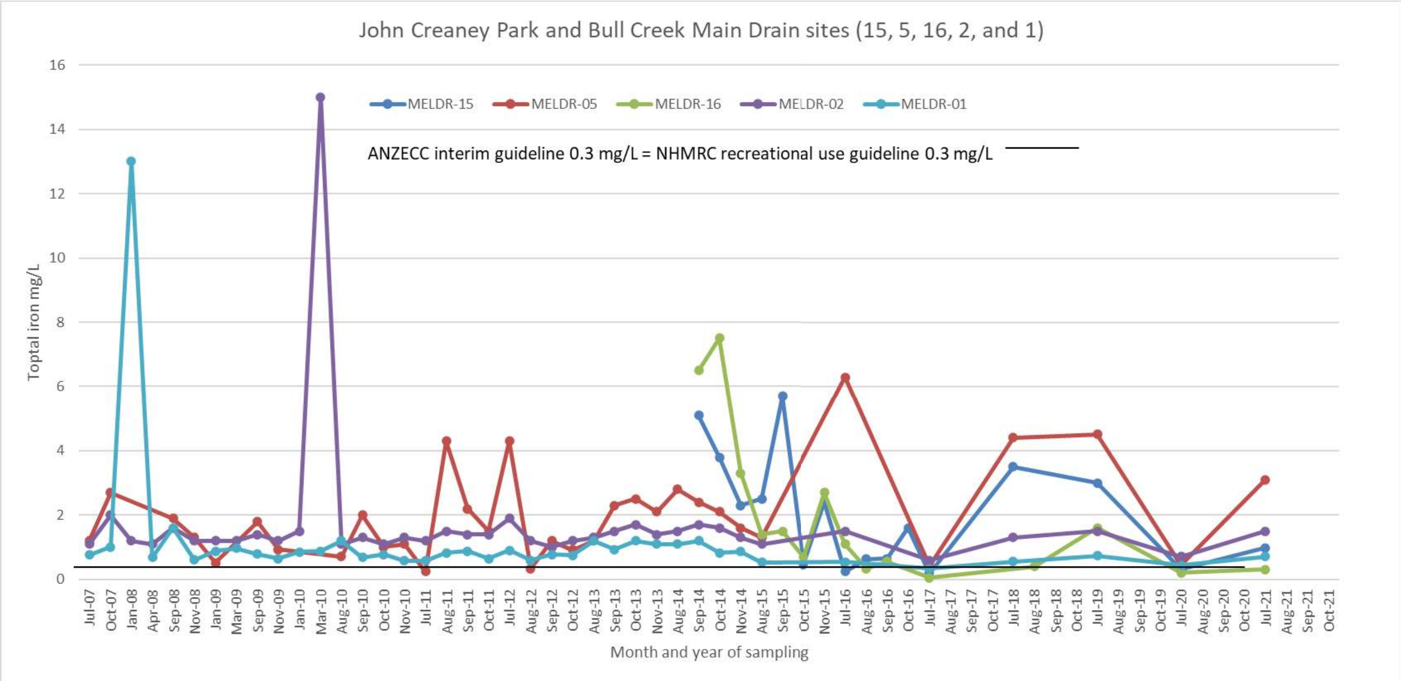


Figure 53. Total iron at John Creaney Park and Bull Creek Main Drain sites.

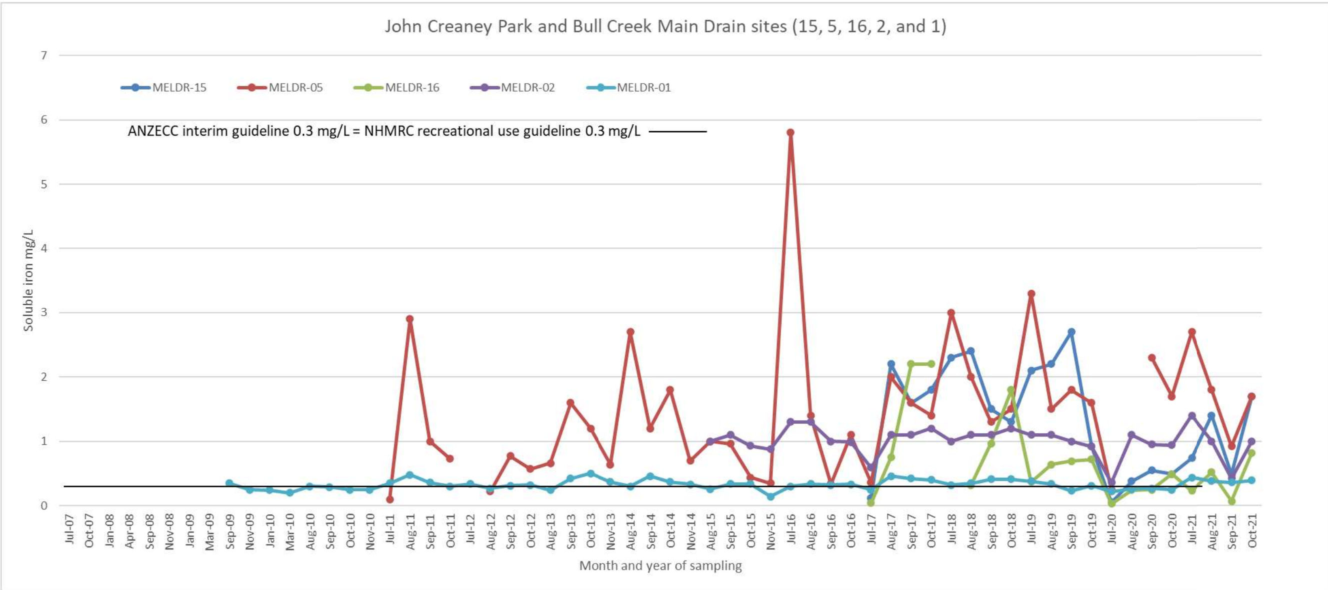


Figure 54. Soluble iron in John Creaney Park and Bull Creek Main Drain sites. Note; outlier August 2020 of 14.00 mg/L, MELDR-05, was removed from this plot.

Lead

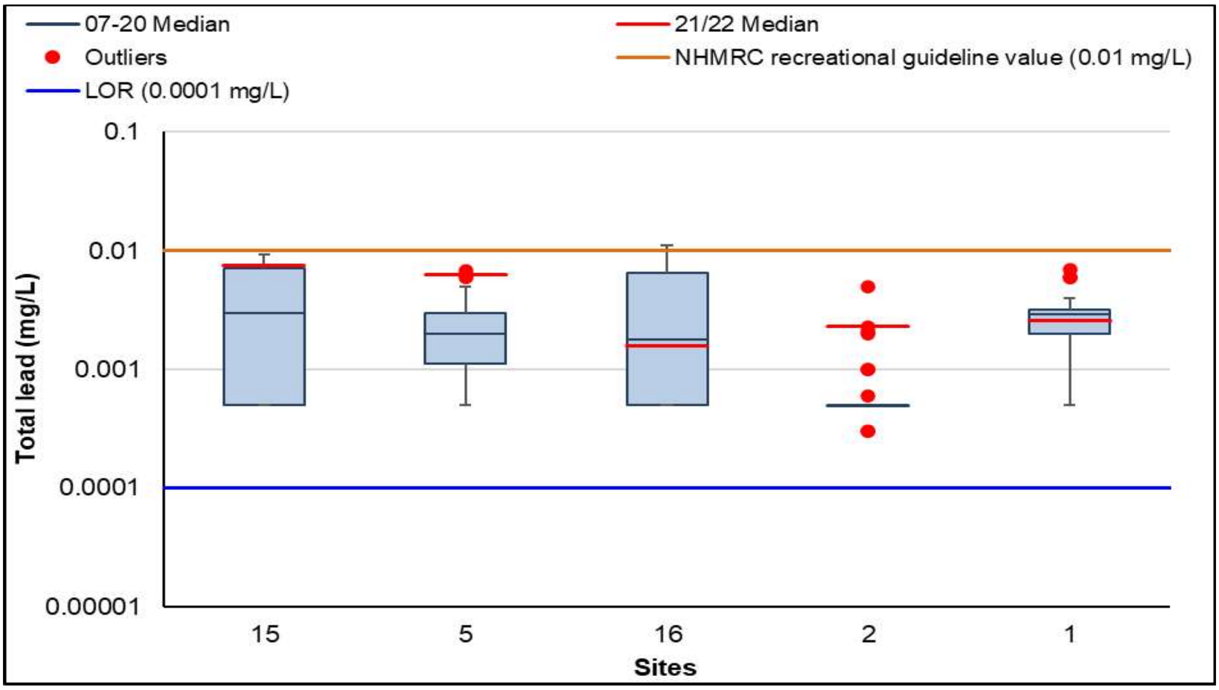


Figure 55. Box plot of total lead 2007-2020 historical median values, with a red line indicating the median value in 2021.

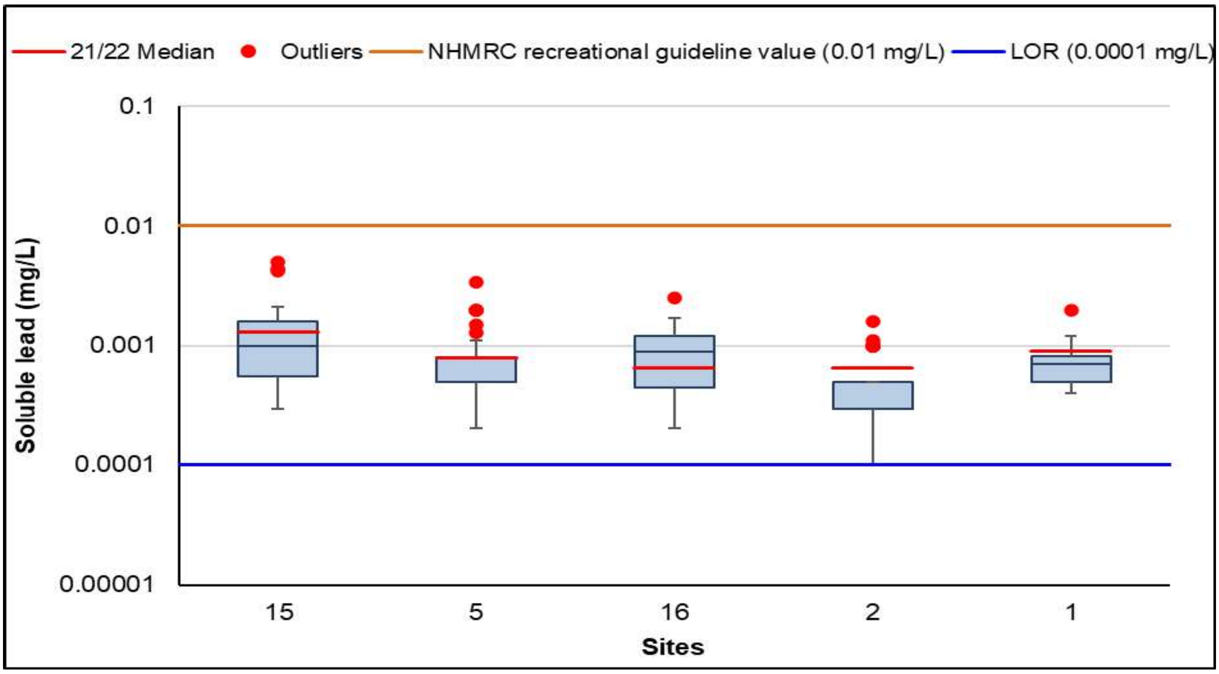


Figure 56. Box plot of soluble lead 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

None of the samples collected from the John Creaney Park and Bull Creek Park drainage line sites in 2021 recorded total lead concentrations above adjusted ANZECC trigger values for 95% protection of biota (unadjusted trigger value: 0.0034 mg/L) (Figures 55 and 56 and Tables D-26, D-27 in Appendix D). Only one sample collected from the John Creaney Park and Bull Creek Park drainage line sites in 2021 recorded soluble lead concentrations above the adjusted ANZECC trigger values for 95% protection of biota (unadjusted trigger value: 0.0034 mg/L). The highest total lead concentration (0.0076 mg/L) was recorded at site 15 in July and the highest soluble lead concentration (0.0050 mg/L) was recorded at site 15 in July. The lowest total lead concentration of 0.0016mg/L was recorded at site 16 in July. Only one site recorded soluble lead concentrations less than the LOR (0.0001 mg/L), being site 2 in July.

Time series

Total (Figure 57) and soluble (Figure 58) lead concentrations recorded in the John Creaney Park and Bull Creek Park drainage line sites in 2021 are not consistently similar to those recorded in the preceding 14 years of monitoring (Table G-53 in Appendix G). Concentrations of total lead exceeding the hardness modified trigger values have sporadically been recorded throughout the 14-year sampling period at sites 5 in July, and for the first time at site 15 also in July 2021.

Table 23. Descriptive statistics of total and soluble lead at the Bull Creek Main Drain sites. Includes all data up to an including that of 2021.

	Total lead mg/L			Soluble lead mg/L		
Site	Mean	SD	n	Mean	SD	n
15	0.0039	0.0034	16	0.00152	0.00140	19
5	0.0026	0.0017	34	0.00074	0.00060	44
16	0.0040	0.0049	15	0.00095	0.00054	19
2	0.0008	0.0008	39	0.00051	0.00029	52
1	0.0028	0.0014	39	0.00073	0.00031	28

While there are indications that total and soluble lead are trending downwards along the drainage lines, there are also variations in this that are no doubt due to site specific conditions. For example, at the upstream sites 15 and 16 total lead was higher than at downstream sites. However, at site 15, the soluble lead was higher and seemed more influence by rainfall events, that at site 16 where the soluble lead seemed to be trending downwards with time. In addition, the largest variation in soluble lead seems to be occurring in all sites since 2017, while total lead levels at downstream sites 1 in particular, seem to be trending down with time.

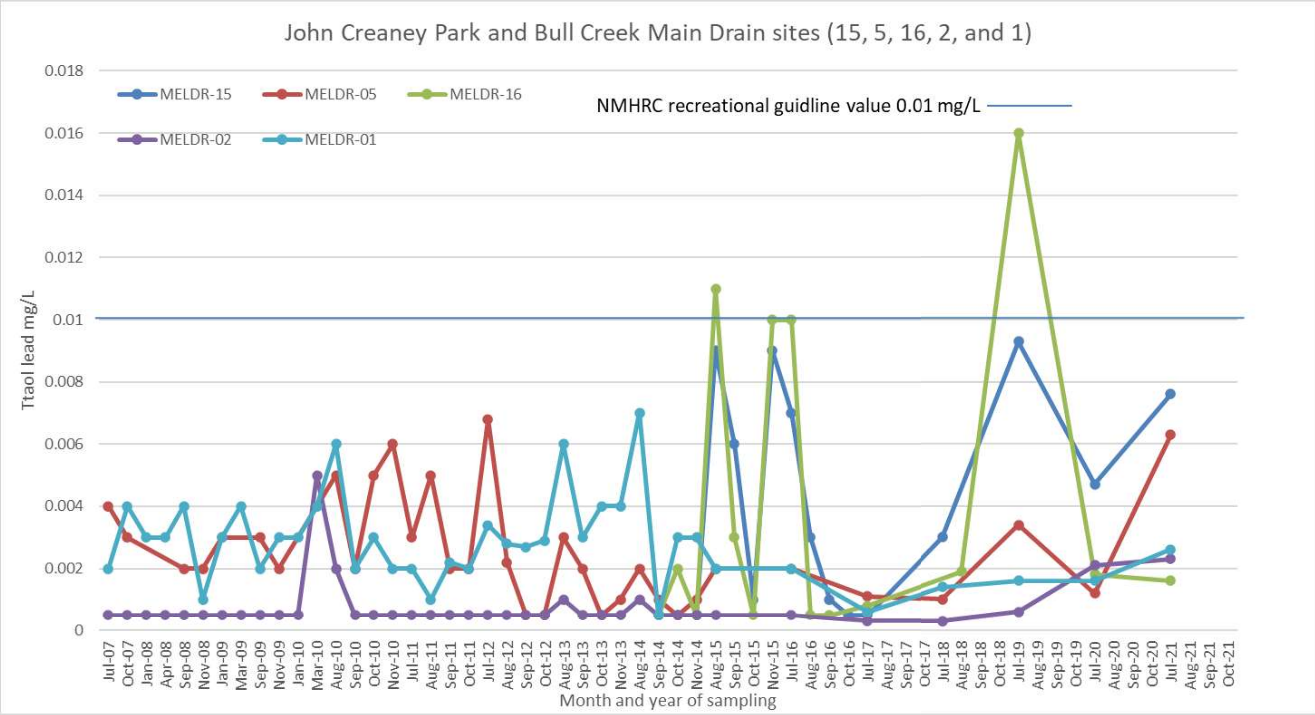


Figure 57. Total lead at the Bull Creek Main Drain sites since sampling began.

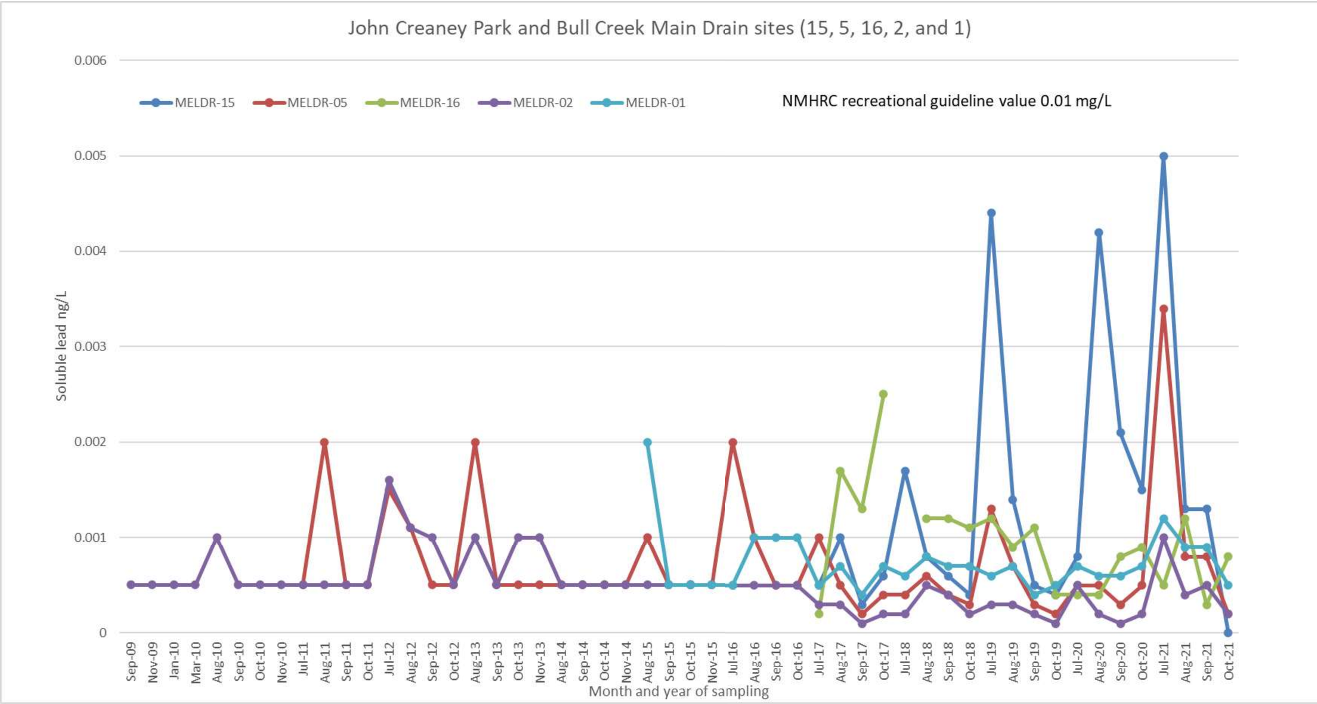


Figure 58. Soluble lead at the Bull Creek Main Drain sites since sampling began.

Zinc

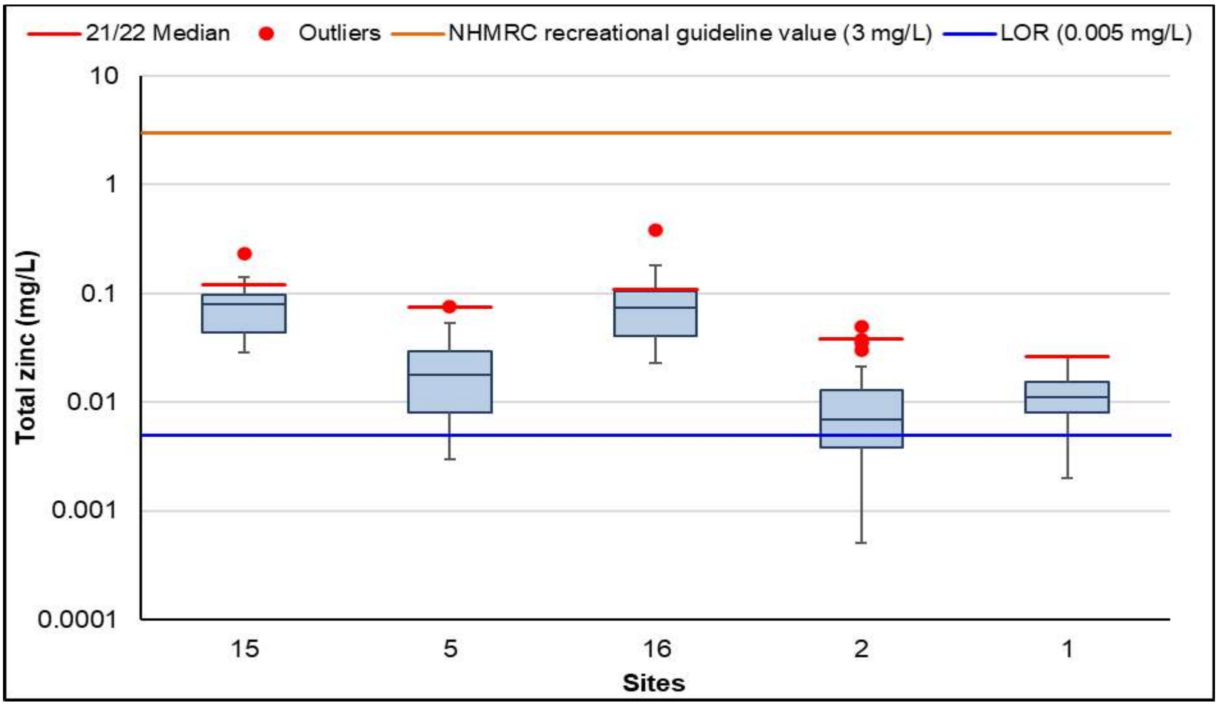


Figure 59. Box plot of total zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

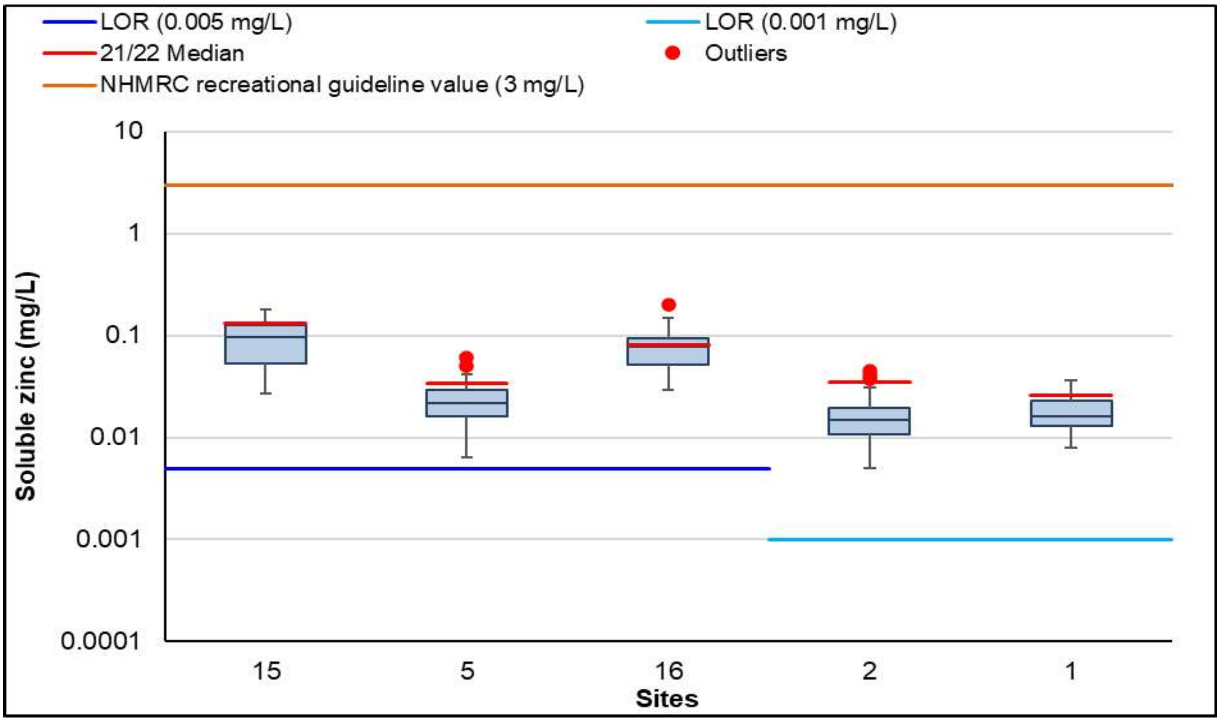


Figure 60. Box plot of soluble zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Concentrations of total zinc exceeded hardness adjusted ANZECC trigger values for 95% level of protection (unmodified trigger value: 0.008 mg/L) at 4 of the 5 John Creaney Park and Bull Creek Park drainage line sites in July 2021 (Figure 59 and Table D-30 in Appendix D. Two sites (sites 15 and 16) out of 5 had samples that recorded soluble zinc concentrations exceeding hardness adjusted ANZECC trigger values on all sampling occasions (Figure 60 and Table D 31 in Appendix D). The highest total zinc concentration was 0.12 mg/L in July in site 15 while the lowest concentration for soluble zinc (0.022mg/L) in site 5 within the October sampling event. No total or soluble zinc concentration exceeded the NHMRC recreational guideline for aesthetic value (3 mg/L).

Time series

Soluble (Figure 61) and total (Figure 62) zinc concentrations recorded in 2021 are similar in downstream sites 1 and 2 during the 14 years of monitoring (Table G-53 in Appendix G), although more exceedances for both total and soluble zinc have been recorded in 2021 than in the preceding three years (similar to that recorded in 2016). Sites 15 (John Creaney Park inlet) and 16 (downstream Elizabeth Manion Park) on the upstream branches of the Bull Creek Main Drain have generally recorded total zinc and soluble zinc concentrations exceeding hardness adjusted trigger values, and the highest concentrations in the catchment, since 2014 and 2017 respectively when analysis of these parameters was initiated at these sites. There is also a trend suggesting that soluble zinc may be increasing with time at sites 15 and 16. Despite this, concentrations recorded at downstream sites 2 and 1 (Brockman Park and Bull Creek Main Drain respectively) have generally not exceeded trigger values and are significantly lower (excluding the July 2020 and 2021 sample of site 2).

In addition to being higher upstream, the total and soluble zinc are also more variable upstream than downstream, suggesting there are site specific condition and turnover of zinc at these sites (Table 24).

Table 24. Descriptive statistics of total and soluble zinc at the John Creaney Park and Bull Creek Main Drain sites. Includes data up to and including that of 2021.

	Total zinc mg/L			Soluble zinc mg/L		
Site	Mean	SD	n	Mean	SD	n
15	0.0841	0.0491	16	0.09420	0.045	20
5	0.0215	0.0160	34	0.02337	0.011	44
16	0.0944	0.0866	15	0.08147	0.041	19
2	0.0107	0.0110	39	0.01665	0.008	52
1	0.0120	0.0053	39	0.01775	0.006	28

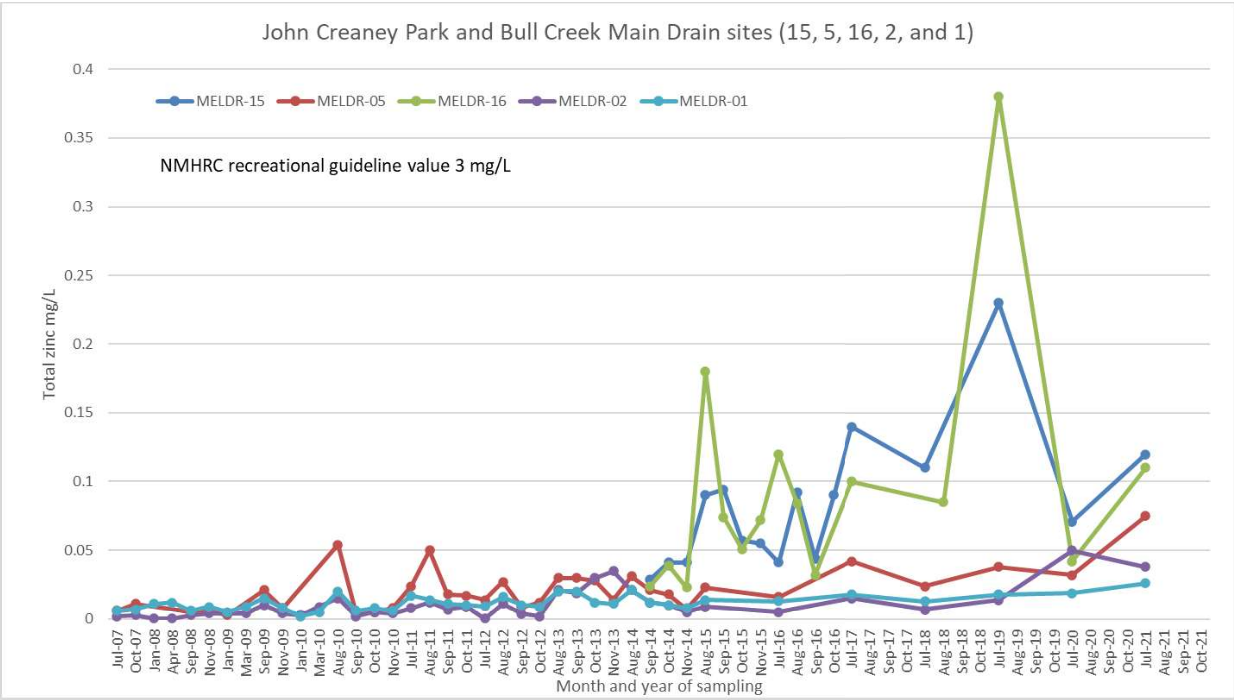


Figure 61. Total zinc in John Creaney Park and Bull Creek Main Drain sites.

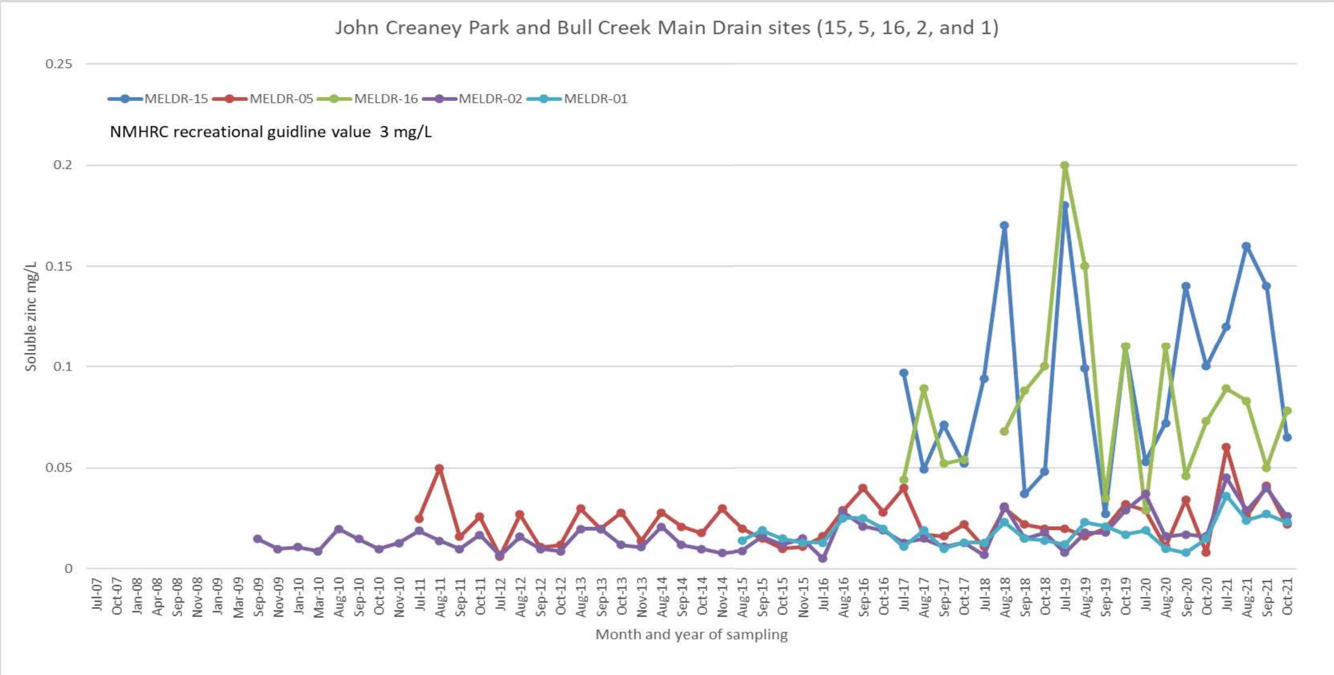


Figure 62. Soluble zinc in John Creaney Park and Bull Creek Main Drain.

Arsenic

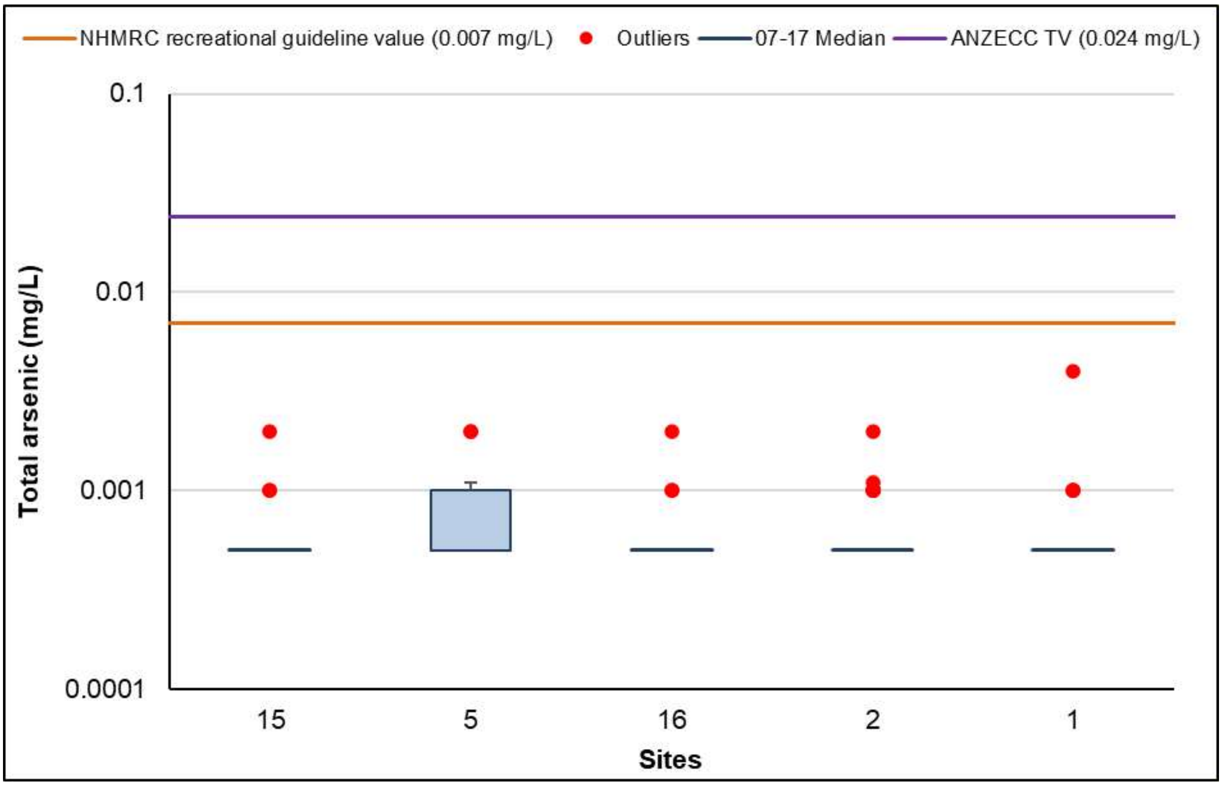


Figure 63. Box plot of total arsenic 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total (Figure 63) and soluble arsenic concentrations were below the ANZECC trigger value (of 0.024 mg/L for 95% level of protection of biota) (ANZECC and ARMCANZ 2000) and the NHMRC recreational use guideline value for arsenic in water (of 0.007 mg/L for health value) (NHMRC 2008). There were no samples collected within the John Creaney Park and Bull Creek Park drainage line that were tested for Arsenic in the 2021 sampling events. Note; soluble arsenic was not plotted due to low and large number of LOR values.

Time series

The low values and large numbers of LOR values of arsenic in all wetlands make it difficult to infer changes with time. Regardless of this however, the different site conditions that either allow accumulation of arsenic in upstream wetlands or the influence of rainfall on inflow further downstream is supported by analyses of other metals. The complex association between pyritic wetlands, acid, iron, rainfall, and revegetation of wetlands need to be further understood as well as the influence of fine sediment particles to which metals can adhere. The slight downwards trend overall, may indicate that the wetlands are becoming healthier, inflow of arsenic entering them from anthropogenic or groundwater sources is decreasing, arsenic is gradually flowing out of the system or being bound in fine sediments.

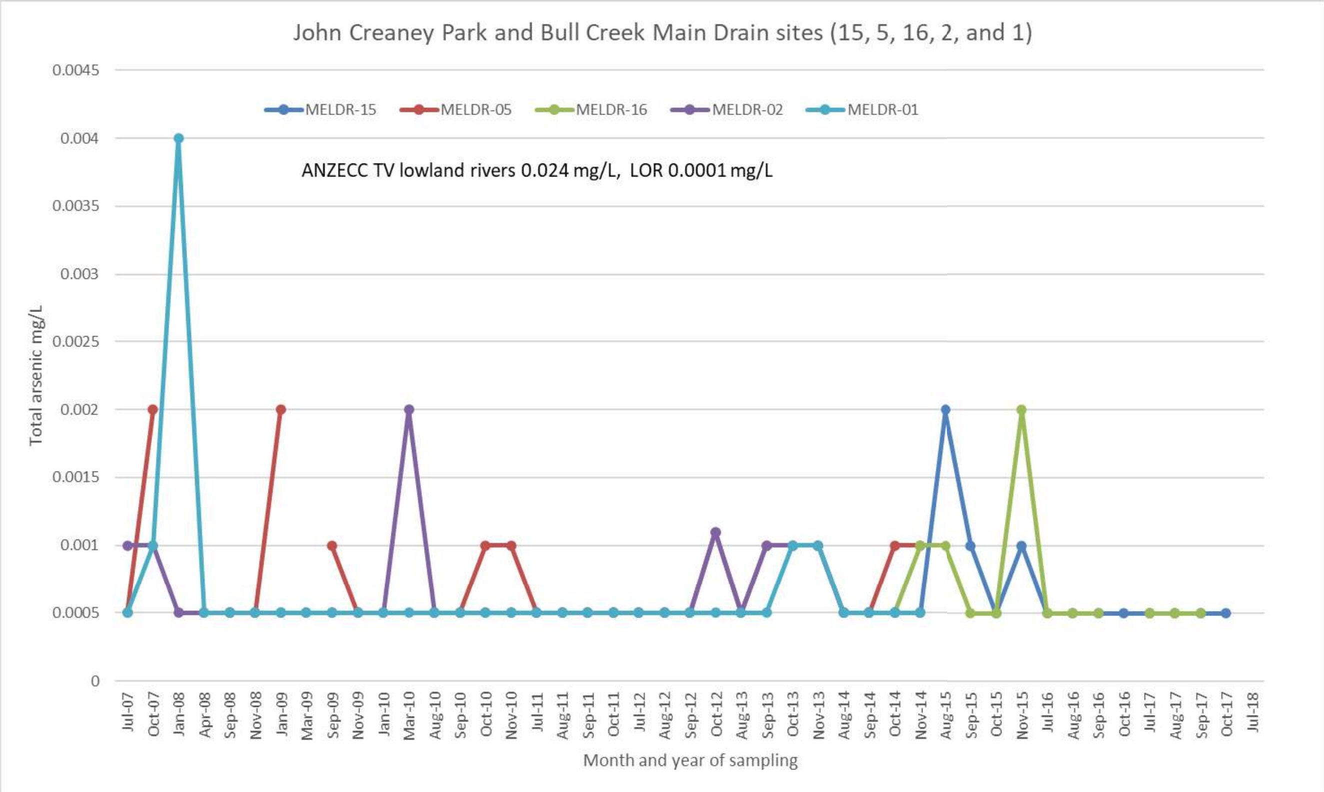


Figure 64. Total arsenic in John Creaney Park and Bull Creek Main Drain sites.

Metals in sediment

Metals in sediments will first be displayed in box whisker plots to compare results from 2021 with the average values since sampling of sediments began in 2013. Additional brief notes on trends are also made. This is followed by overall summaries of all metals per site to display trends and site differences.

Note; sediments were sampled in sites 1, 2 and 5 (Bull Creek Main Drain near Leach Highway, Brockman Park, and the outlet at John Creaney Park respectively), but not at sites 15 and 16 (inlet at John Creaney Park and Elizabeth Manion Park).

Aluminium

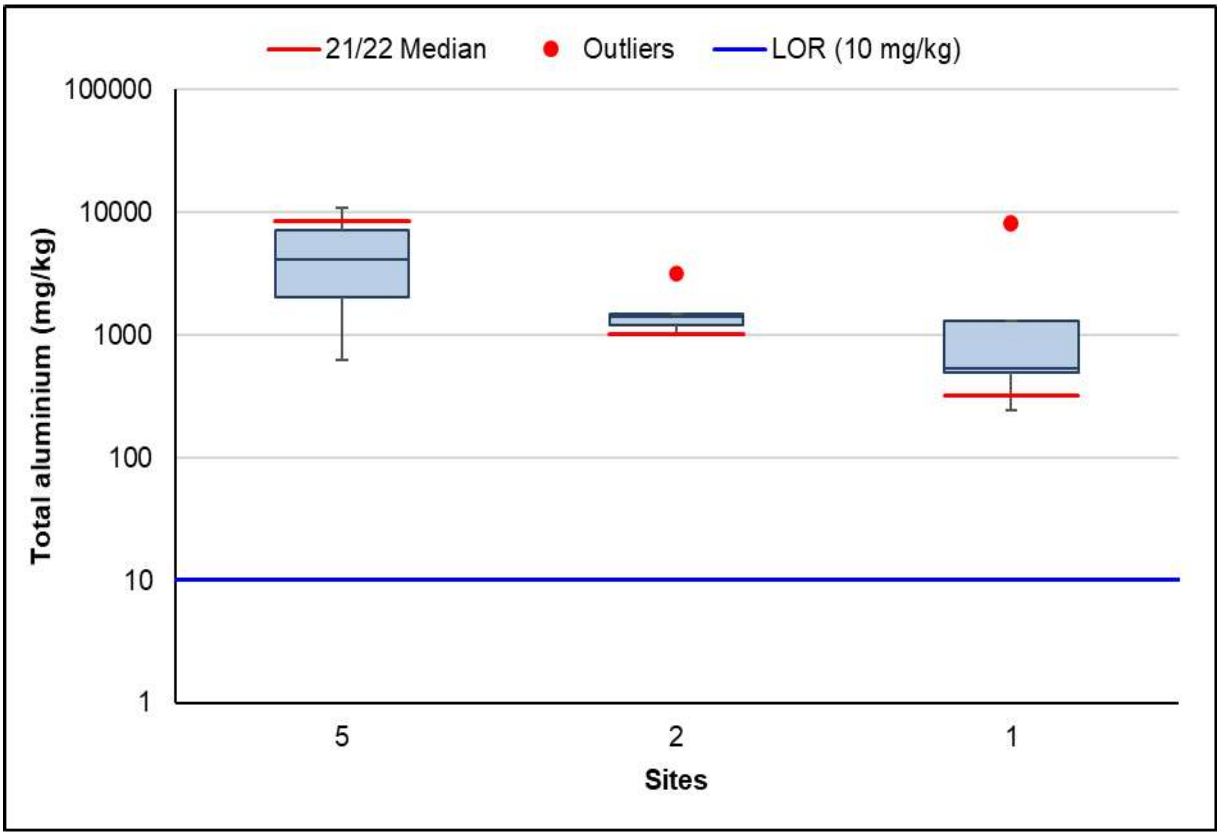


Figure 65. Box plot of sediment total aluminium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Sediment total aluminium concentrations in 2021 varied across the catchment, with the highest concentration of 8,490 mg/kg recorded at site 5 and the lowest concentration of 325 mg/kg at site 1 (Figure 65 and Table D-36 in Appendix D). Total aluminium concentrations have varied greatly in sediment of John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) over the last nine years of monitoring, with a slight downwards trend in sites 1 and 2 (Table H-55 in Appendix H). These results suggest that aluminium is accumulating in sediments at the outlet in John Creaney Park, but a gradually decreasing at downstream sites.

Arsenic

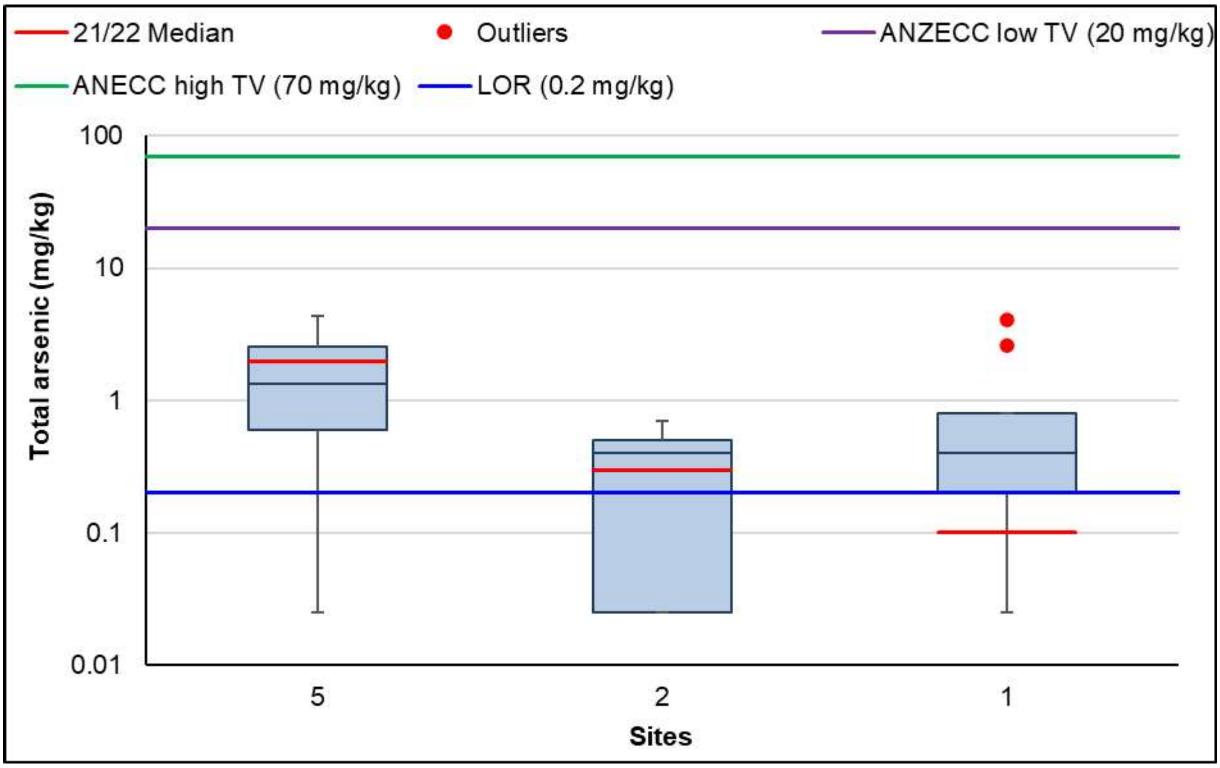


Figure 66. Box plot of sediment total arsenic 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total arsenic concentrations in sediments in 2021 were all below the ANZECC default low (20 mg/kg) and high (70 mg/kg) trigger values (Figure 66 and Table D-37 in Appendix D). The highest concentration of 2.0 mg/kg was recorded at site 5 in October 2021, followed by 0.3 mg/kg at site 2. Site 1 recorded the lowest concentrations below the LOR (0.2 mg/kg) of 0.100 mg/kg. Total arsenic concentrations in the John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) have been below the ANZECC lower trigger values of 20 mg/L throughout the nine years of monitoring (Table H-55 in Appendix H).

Trends

There is a slight trend suggesting arsenic increased between 2013 and 2016 in site 1 after which it has been decreasing. In sites 2 and 5 however, the opposite trend may be occurring. The cause of these differences are however unclear.

Chromium

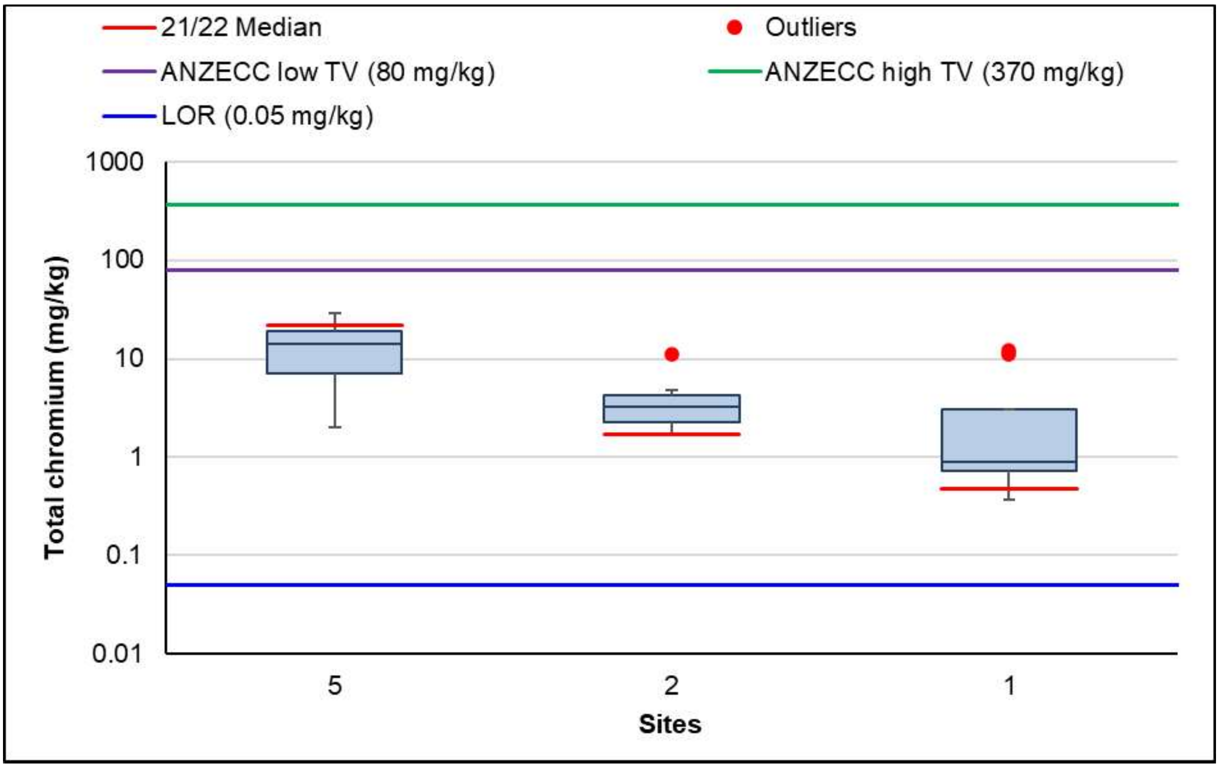


Figure 67. Box plot of sediment total chromium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total chromium (including Cr3+ and Cr6+) concentrations in sediment at all the John Creaney Park (site 5) and Bull Creek Park drainage line (sites 1 and 2) were below ANZECC low (80 mg/kg) and high (370 mg/kg) trigger values in 2021 (Figure 67 and Table D-38 in Appendix D). The highest concentration in the catchment was 22 mg/kg was recorded at John Creaney Park (site 5) and the lowest concentration of 0.470 mg/kg was recorded at Bull Creek Park drainage line (site 1). Total chromium concentrations in sediment at the John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) have been generally low throughout the nine years of monitoring (Table H-55 in Appendix H).

Trends

Chromium in site 1 has, after an increase between 2013 to 2011, been decreasing. In contrast, the chromium levels in sites 2 show a slight overall decrease since 2013 while that in site 5 may be increasing since 2013. These differences and their cause needs further examination.

Copper

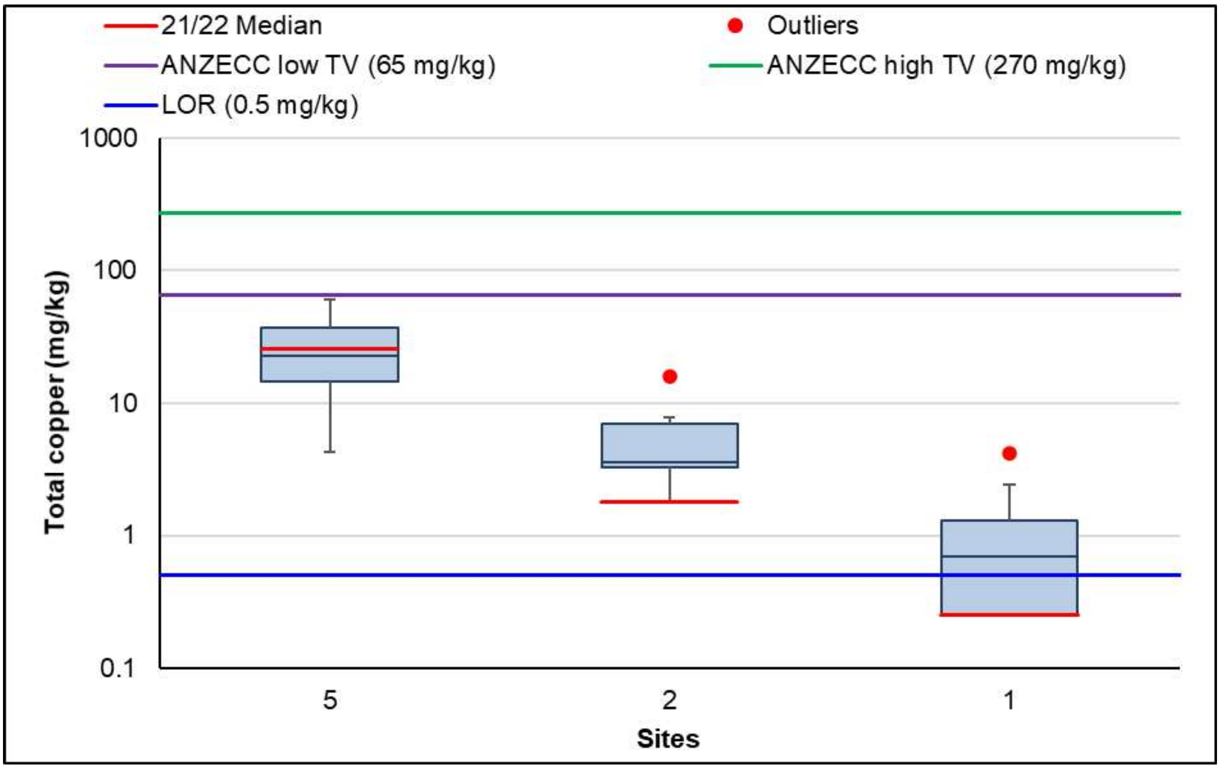


Figure 68. Box plot of sediment total copper 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

All total copper concentrations in sediment collected from all the John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) in 2021 were below ANZECC low (65 mg/kg) and high (270 mg/kg) trigger values (Figure 68Figure and Table D-39 in Appendix D). The highest concentration in the catchment of 26mg/kg was recorded at John Creaney Park (site 5) with the lowest concentration of 0.47 mg/kg at Bull Creek Park drainage line (site 1). Total copper concentrations in sediment at the John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) have been generally low in the previous nine years of monitoring (Table H-55 in Appendix H).

Trends

Overall, and apart from some outliers, the trends suggest copper is decreasing in sites 1 and 2, but not at site 5 since sampling began in 2013, where there is a slight upwards trend in copper.

Iron

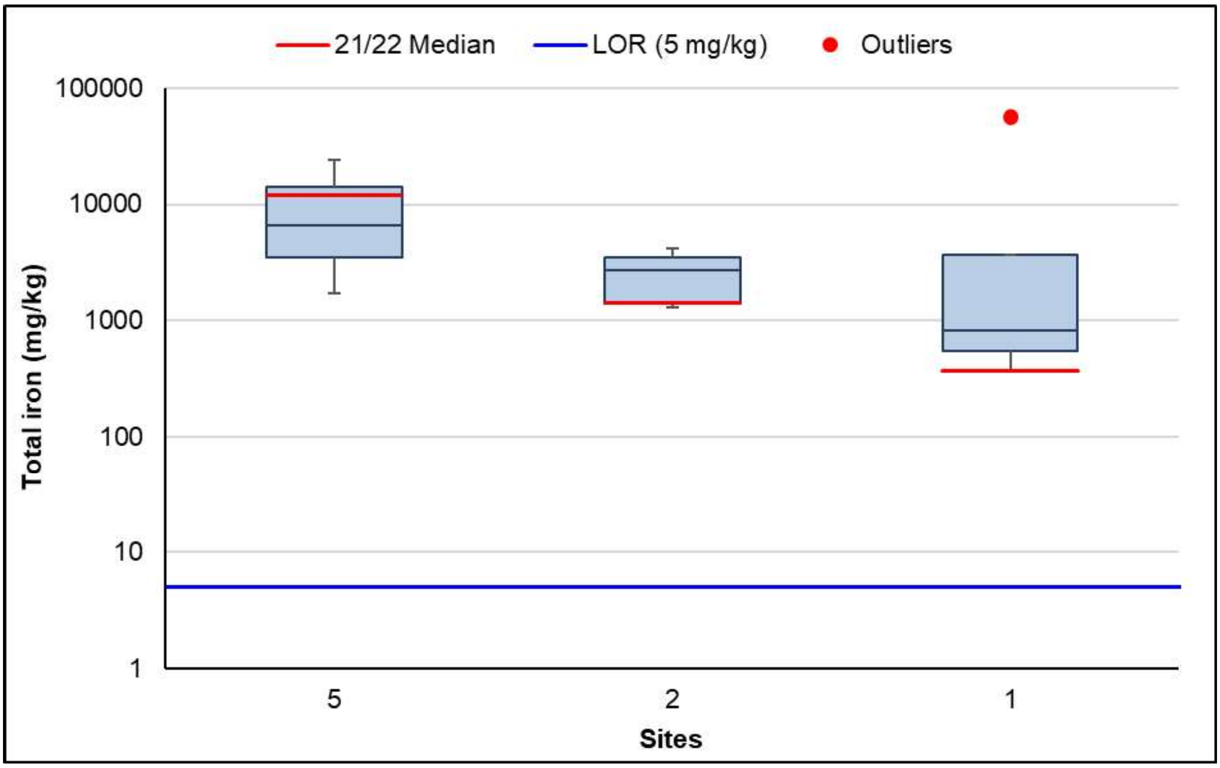


Figure 69. Box plot of sediment total iron 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

No guideline currently exists for iron concentrations in sediment; therefore, it is difficult to gauge the severity of any potential impact arising from the concentrations recorded in the sediment collected from John Creaney Park (site 5) and Bull Creek Park drainage line (site 1). In 2021, the total iron concentrations in sediment were variable (Figure 69 and Table D-40 in Appendix D). The highest concentration of 12,000 mg/kg was recorded at John Creaney Park (site 5) and the lowest concentration of 370 mg/kg was recorded at Bull Creek Park drainage line (site 1).

Trends

Since sampling of sediments began in 2013, iron concentrations were high at Bull Creek Main Drain (site 1) in October 2015 (51.000 mg/L), 2016 (57,000 mg/L) and in John Creaney Park (site 5) in October 2018 (24,000 mg/kg), 2020 (21,000 mg/kg) and 2021 (12,000mg/kg). These records exceeded other concentrations of iron recorded throughout the Bull Creek Park drainage line and at other Melville sites (Table H-56 in Appendix H).

Iron rich soils and coffee rocks associated with groundwater are common in some areas of Bassendean sands and are associated with acid sulphate soils. The pH of the waters at site 1 was however, on average 6.9, suggesting that at site 1 (where the iron levels were much higher than at other sites) the iron is accumulating in the sediment. Its origin, whether from iron rich soils, urbanization or simply being at the end of a drain can explain these high levels of iron. A recent study concerning the impact of iron on the growth of plants (Saaltick, Dekker, Eppinga, Griffioen, & Wassen, 2017), found that even at over 20,000 mg/kg dry weight of total iron in iron rich sediments, the plant growth is plant specific. While metal levels in Western Australian soils and sediments are often low, iron has an important role in cycling of chemicals in wetlands. The origin and movement of iron and the impact this high iron levels have on the ecosystem requires further work.

Lead

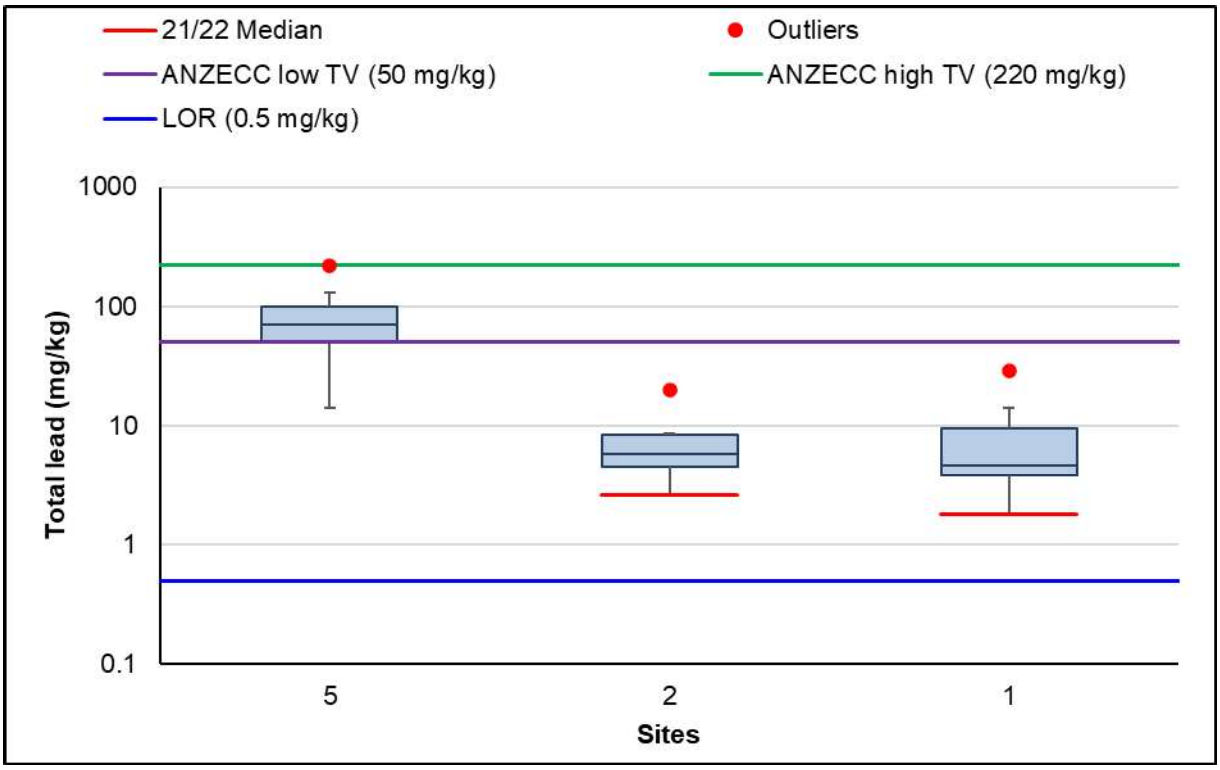


Figure 70. Box plots of sediment total lead 2007-2020 historical median values, with the red line indicating the median value in 2021.

Box whisker

Two out of 3 lead concentrations in sediments collected John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) in 2021 were below the ANZECC low trigger value (50 mg/kg). John Creaney Park (site 5) recorded a concentration of 50 mg/kg which is above the ANZECC low trigger value (Figure 70 and Table D-41 in Appendix D). No samples collected recorded an exceedance of the high trigger value (220 mg/kg). The lowest concentration of 1.8 mg/kg was recorded at the Bull Creek Park drainage line (site 1).

Trends

Overall, seasonal trends in the total lead concentrations in sediment collected in 2021 were similar to those collected in the preceding nine years of monitoring (Table H-56 in Appendix H). Concentrations exceeding the low trigger value have been recorded John Creaney Park (site 5) on at least one sampling occasion throughout the nine-year monitoring period. This occurred in seven out of eight sampling occasions, where these records, that exceeded the ANZECC lower trigger value, actually equalled ANZECC higher trigger value in 2013. The trends observed in total lead concentrations suggest that lead at sites 1 and 2 are decreasing. But this trend is not clear in site 5.

Mercury

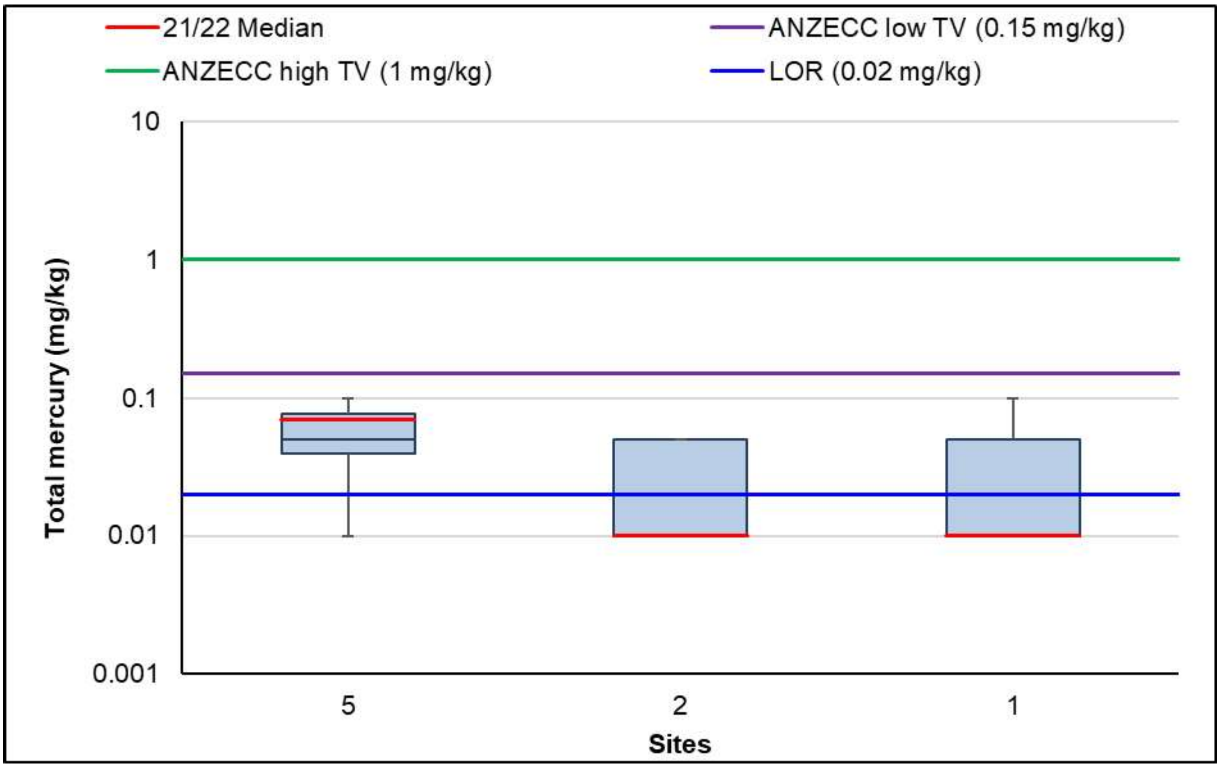


Figure 71. Box plot of sediment total mercury 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

All total mercury concentrations in sediments were below the ANZECC low (0.15 mg/kg) and high (1.0 mg/kg) trigger values at John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) in 2021 (Figure 71 and Table D-42 in Appendix D). Only site 5 (John Creaney Park) recorded a concentration greater than the LOR (0.02 mg/kg) with a concentration of 0.070 mg/kg. Concentrations of total mercury in sediment of the Melville Bull Creek catchment throughout the nine years of monitoring have generally been low and below the LORs (Table H-56 in Appendix H).

Trends

Although mercury may be trending down in site 1, this is not clear as the levels were very low and different to that observed in site 5.

Nickel

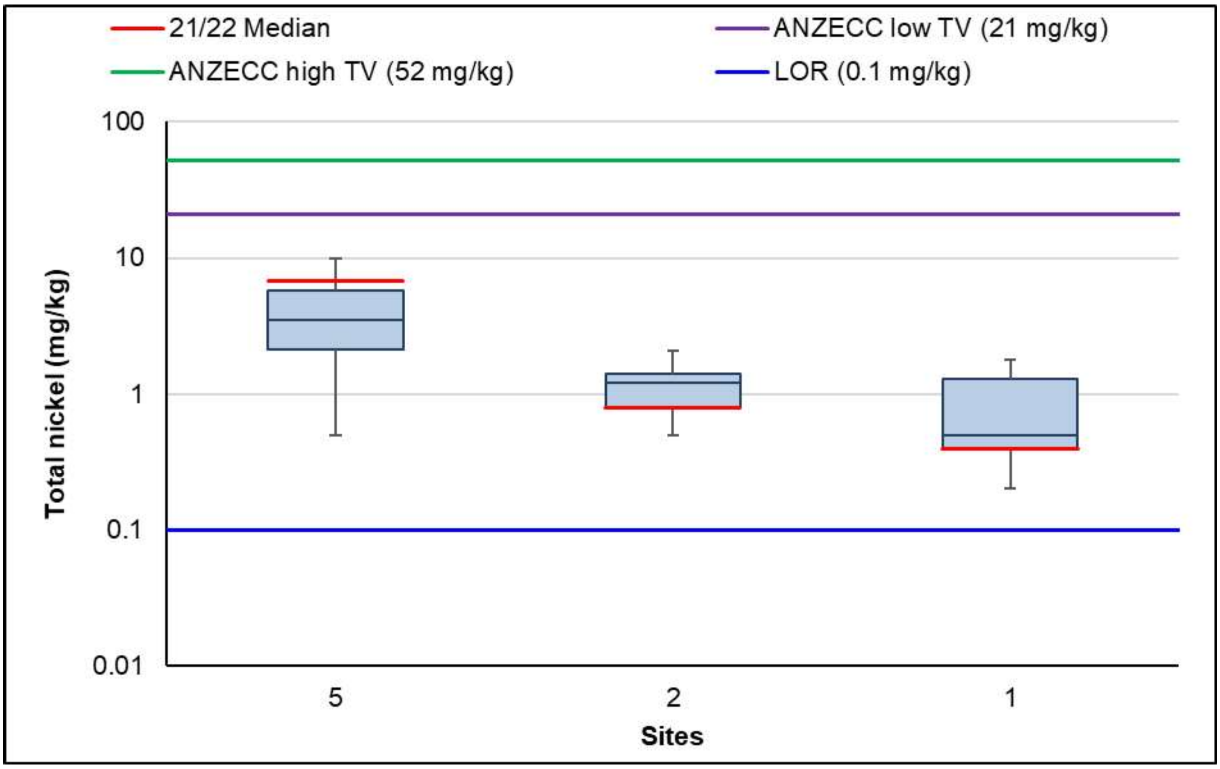


Figure 72. Box plot of sediment total nickel 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

All total nickel concentrations in sediments were below the ANZECC low (21 mg/kg) and high (52 mg/kg) trigger values at John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) in 2021 (Figure 72 and Table D-43 in Appendix D). The highest total nickel concentration of 6.8 mg/kg was recorded at site 5 and site 1 recorded the lowest concentration (0.4 mg/kg).

Trends

Concentrations of total nickel in sediment in the Melville Bull Creek catchment and John Creaney Park over the past nine years of monitoring have generally been low (Table H-56 in Appendix H). There is a trend that total nickel at sites 1 and 2 are trending down with time but increasing slightly in site 5.

Selenium

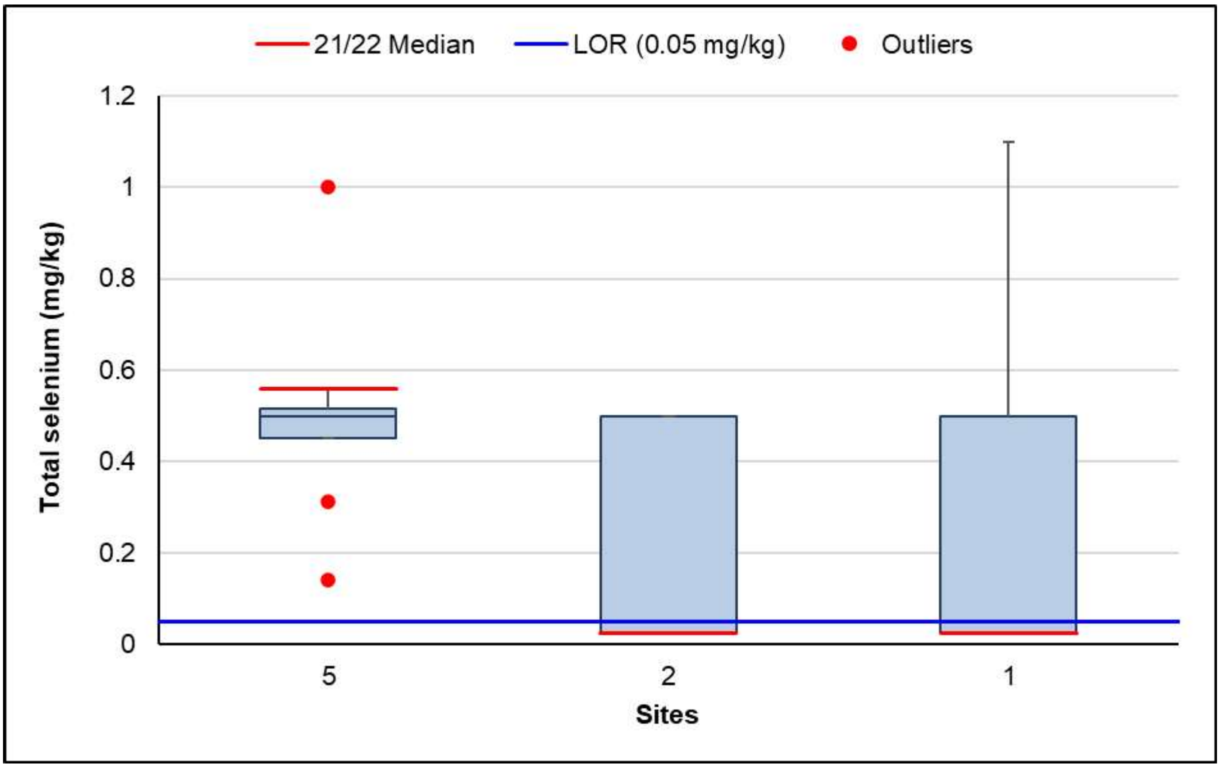


Figure 73. Box plot of sediment total selenium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Sediments can be a significant source of selenium in fish and invertebrates. Toxic effect threshold levels for selenium in freshwater sediment, for food chain organisms according to ANZECC & ARMCANZ 2000 criteria is 3 mg/kg and 4 mg/kg, respectively (Lemly, 1993).The highest selenium concentration (0.560 mg/kg) was recorded at John Creaney Park (site 5) while Bull Creek Park drainage line (site 1) and Brockman Park (site 2) had concentrations below the LOR (0.05 mg/kg) (Figure 73 and Table D-44 in Appendix D). None of the sediment samples within John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) exceeded the ANZECC & ARMCANZ 2000 trigger value.

Trends

Total selenium concentrations recorded in 2021 show some differences in trends between sites since sampling began (**Error! Reference source not found.**Table H-57 in Appendix H). In particular that the selenium in site 5 (John Creaney Park outlet) remains similar each year, while that in sites 1 and 2 (Bull Creek Main Drain and Brockman Park) have been very low since 2011.

Zinc

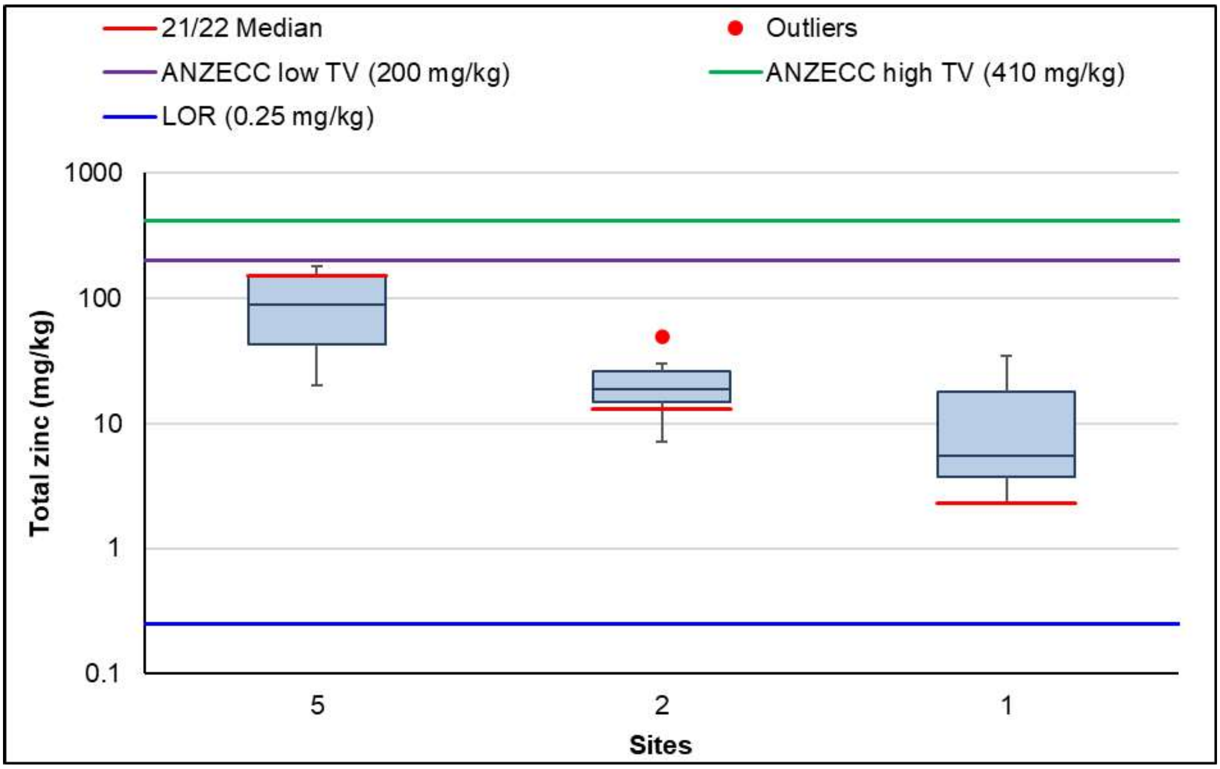


Figure 74. Box plot of sediment total zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Concentrations of total zinc in sediment throughout the John Creaney Park (site 5) and Bull Creek Park drainage line (site 1) in 2021 were low, with all concentrations below ANZECC low (200 mg/kg) and high (410 mg/kg) trigger values (Figure 74 and Table D-45 in Appendix D). The highest concentration (150 mg/kg) was recorded at John Creaney Park (site 5) and the lowest 2.3 mg/kg at Bull Creek Park drainage line (site 1).

Trends

Although there is a slight decreasing trend for zinc in site 1 since sampling began), the concentrations of total zinc in sediments recorded in 2021 are similar to those recorded in the preceding eight years of monitoring (Table H-57 in Appendix H).

Summary of sediment metals and combined metal plots

The total metals without adjustment for hardness were used to explore variations between metal concentrations of the sites (Table 25). When the metals in sediments are examined based on time for each site where sediment was sampled, the sites can be grouped into two different types. The first type, representing a downstream site (site 1, Bull Creek Main Drain near Leach Highway) has levels of most metals up to ten times as concentrated than at the other sites (site 5, John Creaney Park outlet, and site 2, Brockman Park).

Table 25. Summary of levels of pH in the water and metals in the sediments in sites 1, 5 and 2 since sampling began and up to and including 2021.

Site	Mean and median pH (n) of water (ANZECC pH TV for lowland rivers = 6.5 – 8.0)	Metal trends in sediments
1. Bull Creek Main Drain near Leach Highway	6.90 and 6.87 (59)	Fe, Al were very high in sediments. Other metals slightly lower or similar to other sites. Apart from some peaks in 2015 and 2011 most metals have been trending down since 2011.
5. John Creaney Park outlet	6.50 and 6.4 (55)	Fe and Al similar to site 2 and much lower than site 1. Apart from some troughs in 2015 and 2017, the metal concentrations show a very slight upwards trend, but this is not clear.
2. Brockman Park	6.30 and 6.28, (59)	While Fe and Al concentrations at this site are similar to that at site 5, the concentrations of other metals are slightly lower than at site 5, and often more comparable to site 1 than site 5.

When these trends are considered together with the knowledge that a drop in pH is known to increase the solubility of metals, a slight drop in pH may cause some of the metals to be released into the water. This would effectively reduce the amount of metals held in the sediments. But because pH is within the TV values at site 1, pH is unlikely to be the main reason for the very high levels of metals in site 1 compared to sites 5 and 2. It may be that one or more of the following is influencing metal levels in sediments;

- rivers bring metals downstream and these accumulate in sediments, in particular where flow is restricted
- increases in the fine sediment particle fractions is often associated with increases in metal retention in sediments
- wetlands near heavily trafficked roads are more likely to have inflows of metals
- wetlands closer to the river contain more metals in the sediments
- older and/or denser urban areas have contributed to accumulation of metals with time
- metals and the geochemistry of the metals in specific soils influence the retention of metals in sediments
- rehabilitation of wetlands may restrict flow and therefore removal of metals from wetlands
- other works done to reduce metal inflow and retention in wetlands are associated with these trends and observations.

Plots of metals in sediments at sites 1, 5, and 2

There were also variations between sites in terms of the dominance of metals in the sediments. Overall, iron and aluminium were most abundant and tended to trend together. These two metals were more dominant in October 2015 and 2016 in site 1 (Figure 75) than at any other time in site 1 as well as overall in sites 2 (Figure 77) and 5 (Figure 76). Then zinc, lead, chromium, copper, nickel, arsenic, selenium, and mercury in that order. While there appeared to be some clustering of lead and zinc as well of chromium, nickel and copper, these associations are not clear. Additionally, lead, zinc, copper, and chromium tended to be higher and trending upwards in site 5 than in the other two sites. Most metals in site 1 tended to trend upwards between 2013 and 2011. after which they tend to trend downwards. There were less evidence of any trends in metals (other than iron and aluminium) in site 2. Again, the causes of these differences are as yet unclear.

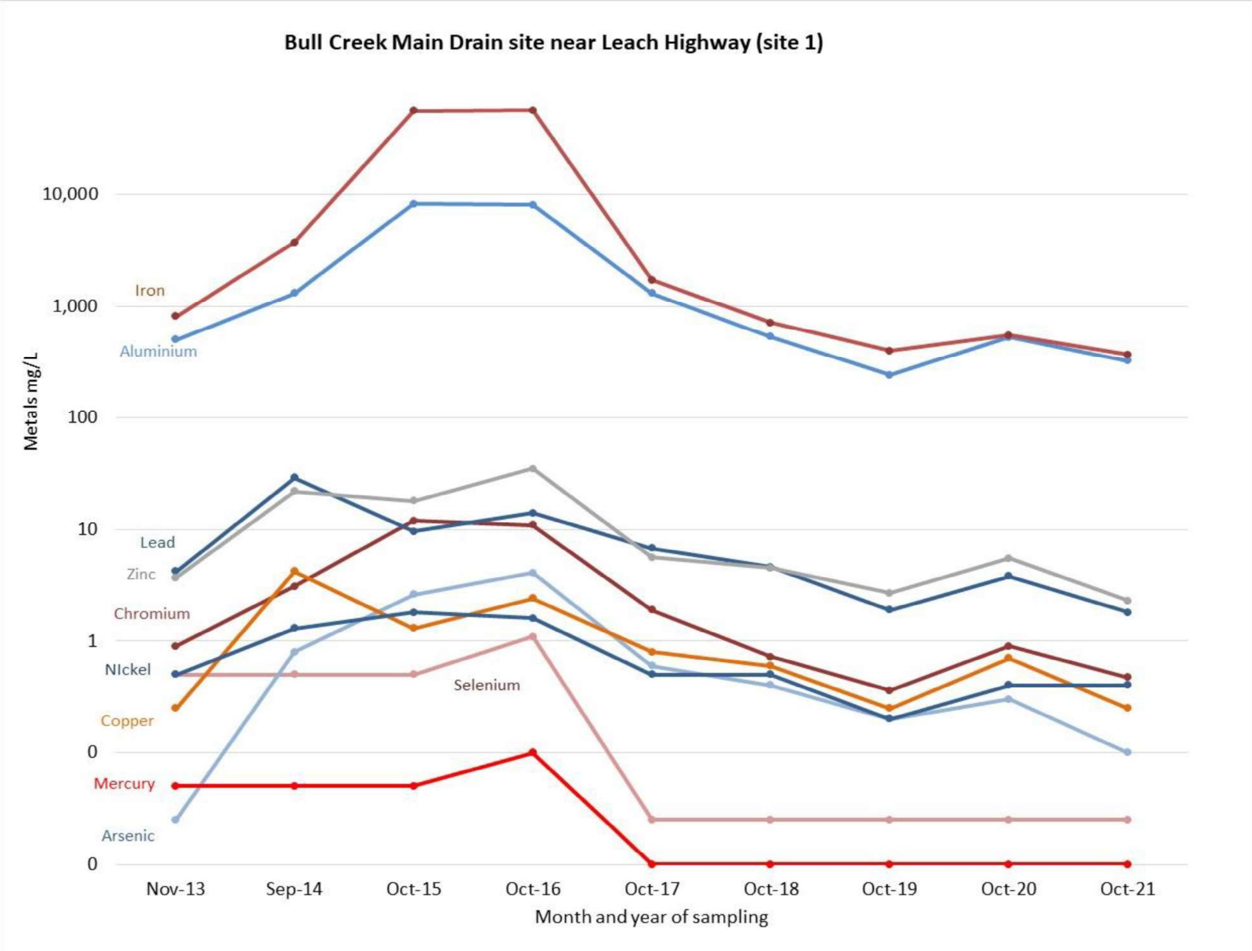


Figure 75. Logarithmic (log10) plot of metals in sediments at site 1.

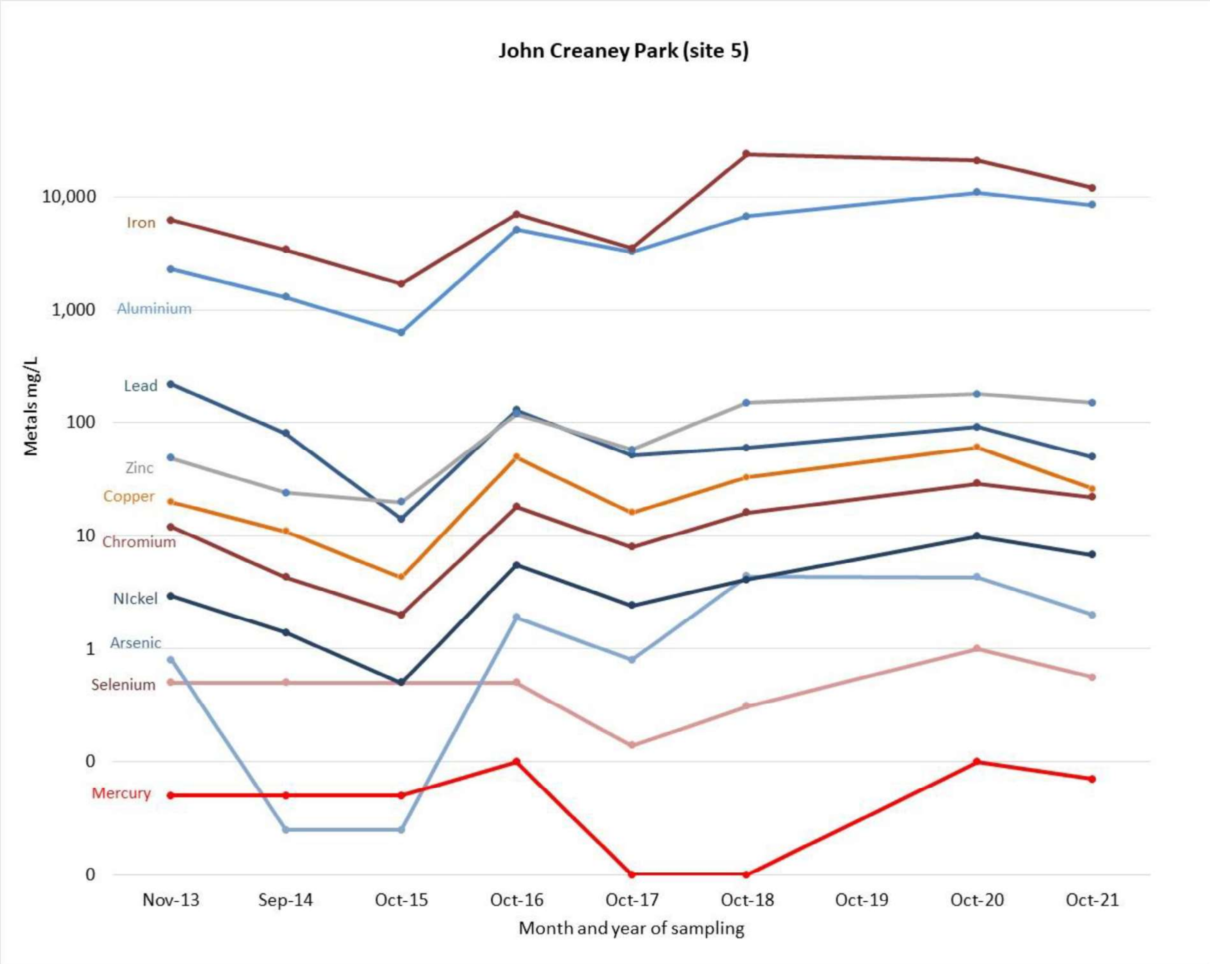


Figure 76. Logarithmic (log10) plot of metals in the sediment at site 5.

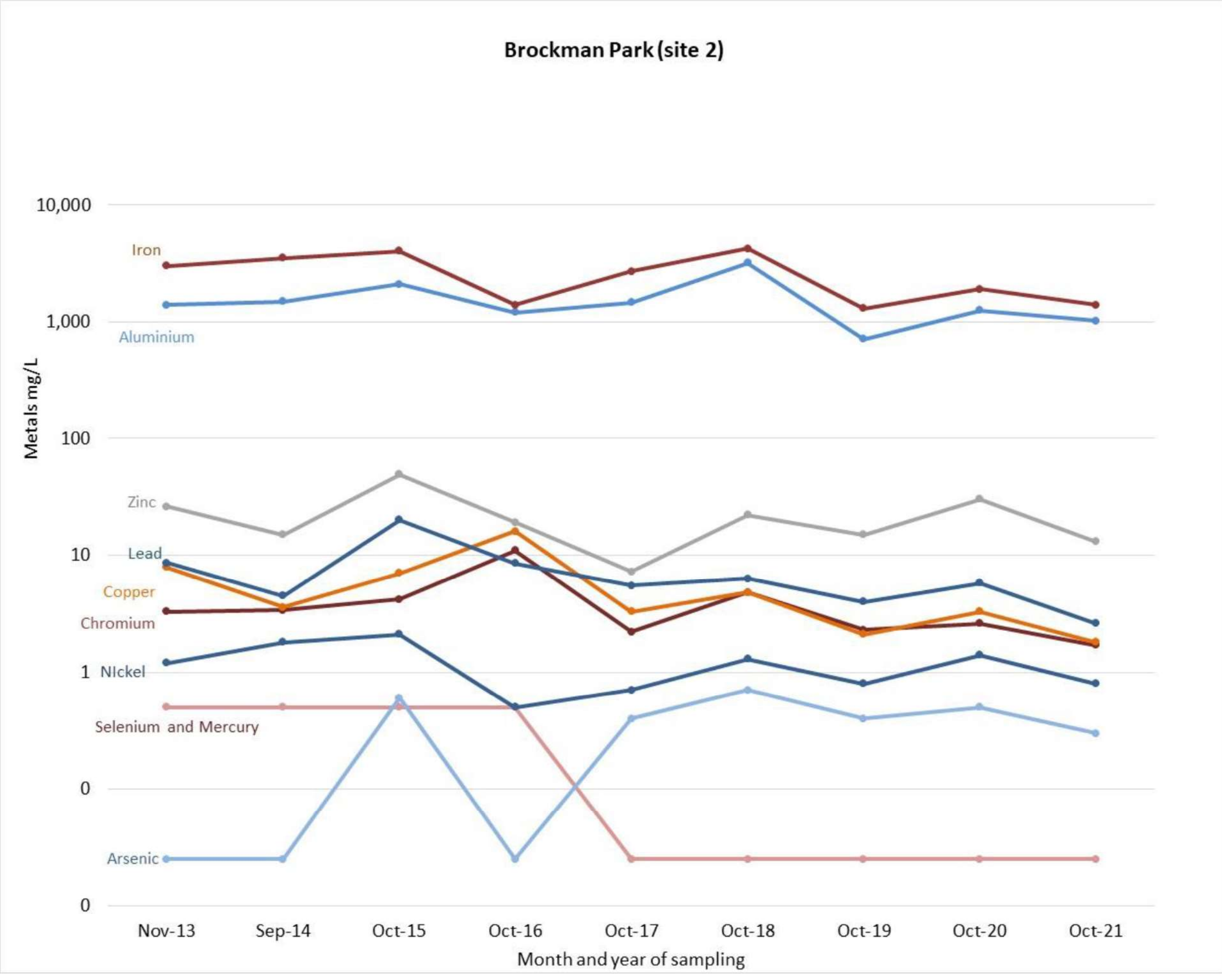


Figure 77. Logarithmic (log10) plot of metals in the sediments at site 2.

Brentwood Drain

This section covers the parameters measured for the Brentwood drain drainage line at Brentwood drain (site 13), RAAF Drain (site 14) and Bateman Park (site 6).

Physicochemical properties

pH

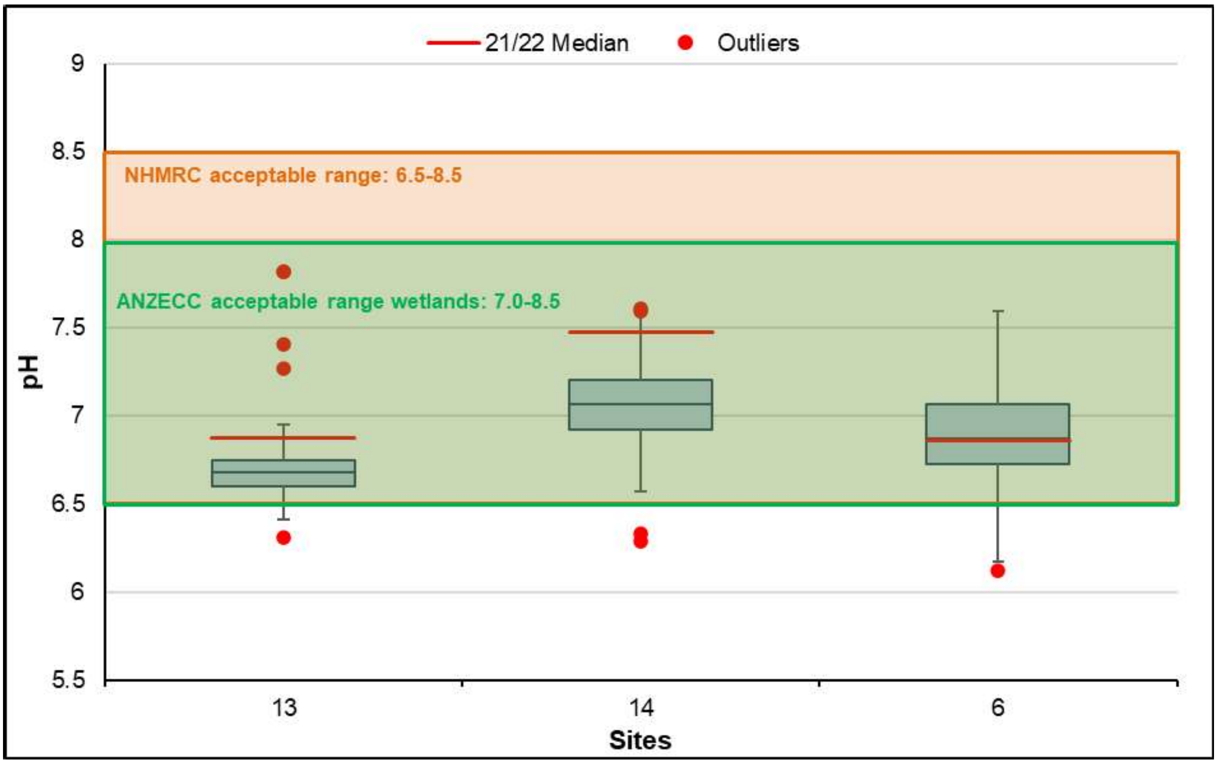


Figure 78. Box plot of pH 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

All three sites recorded pH values within the acceptable range in 2021 (6.87, 6.67 and 7.07, respectively, and below the NHMRC acceptable range (Figure 78). The pH across these sites appears to be relatively similar with long term medians ranging from 6.4-6.8 and 2021 medians ranging from 6.21-6.81.

Time series

Although median pH values recorded in 2021 were similar to their respective long-term medians, with the pH at the RAAF Drain (site 14) being higher and that at Brentwood Drain (site 13) being lower, there is a slight trend that pH is trending upwards at these sites, in particular site 13 and 14 (Figure 79). Bateman Park (site 1, closest to Canning River) was intermediate, but also more variable compared to the other two sites. The cause of variability as well as the possible upwards trend in the pH at these sites needs further study.

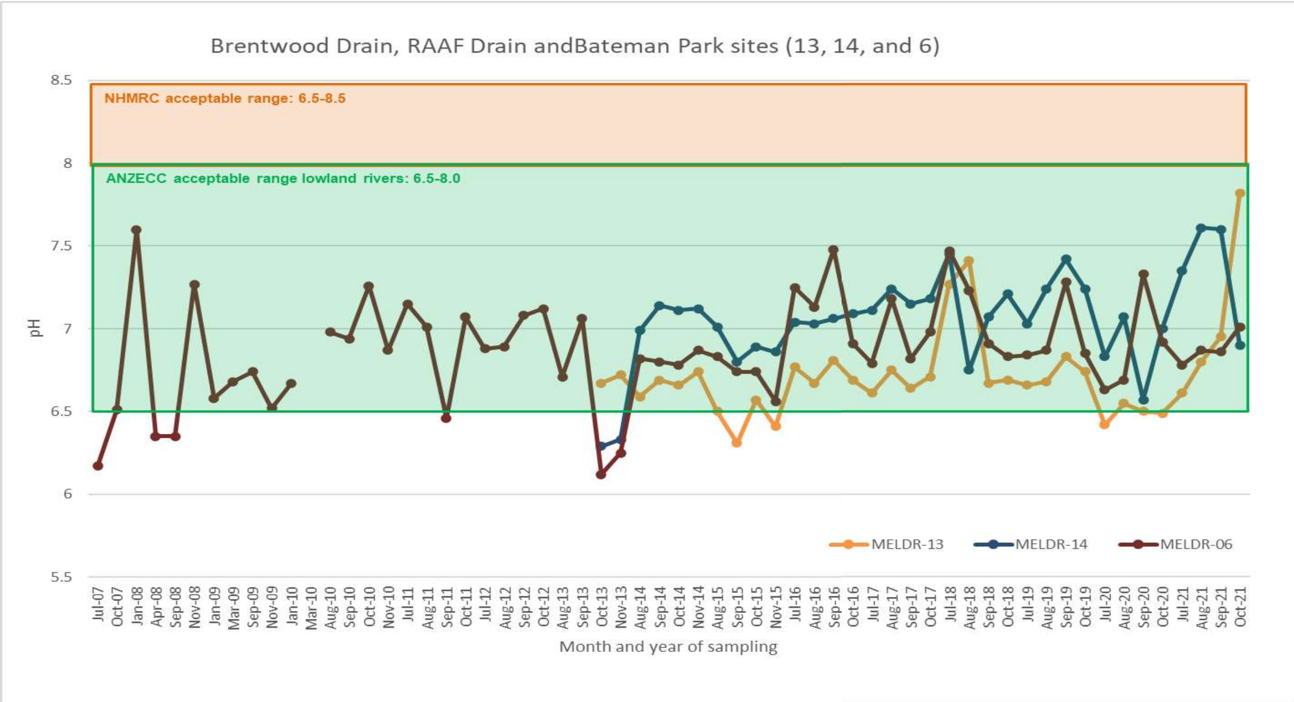


Figure 79. Historical data of the pH at Bateman Park as water flows along the Brentwood drain, RAAF drain and East into Canning River (MELDR-13, MELDR-14 and MELDR-06).

Table 26. Descriptive statistics of pH at the Brentwood Drain sites.

Site	Mean	SD	n
13	6.72	0.281	34
14	7.05	0.287	34
6	6.87	0.308	59

Oxygen saturation (%) and concentration (mg/L)

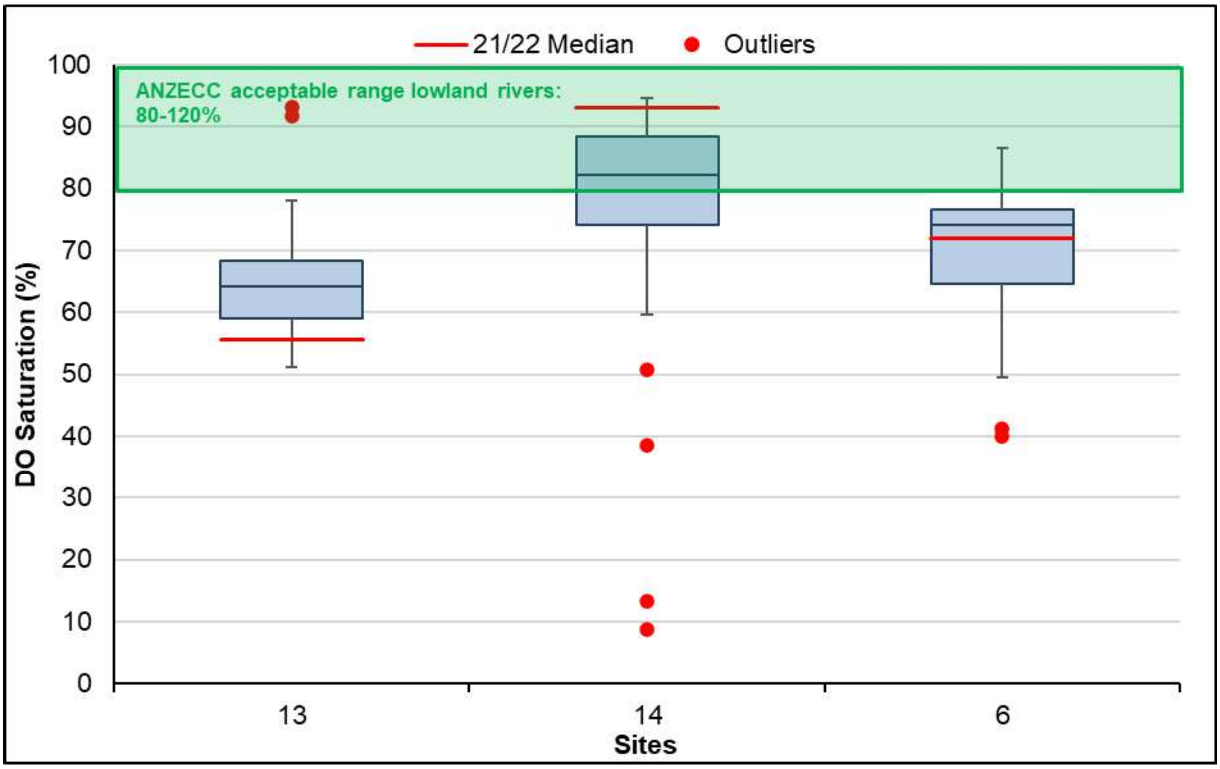


Figure 80. Box plot of DO% 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Nine of the twelve samples collected from the Brentwood drain line sites in 2021 recorded dissolved oxygen (DO) saturations below the ANZECC acceptable ranges (lowland rivers: 80-120%, wetlands: 90-120%) and the NHMRC recreational guidelines lower limit (80%) (Figure 80 and Table D-5 in Appendix D). Site 6 (Bateman Park) recorded saturations below the acceptable range on all occasions when sampled. One sample from site 13 (Brentwood Drain) recorded DO saturations greater than the acceptable range with readings of 91.6% in October. Three samples at site 14 (RAAF Drain) recorded a DO saturation greater than the acceptable range in July, August, and September 2021 with a reading of 94.6%, 93.1% and 92.9% respectively. Site 6 (Bateman Park) recorded the lowest saturation in the catchment of 70.5% in September, compared to 2020 sampling event where September saw the highest concentration of 81.8%, this appears to be an outlier. All 2021 medians at sites along Brentwood drain line recorded similar results to the long term 2007-2020 medians. Only site 13 (Brentwood Drain) recorded an outlier in October 2021 (8.98%).

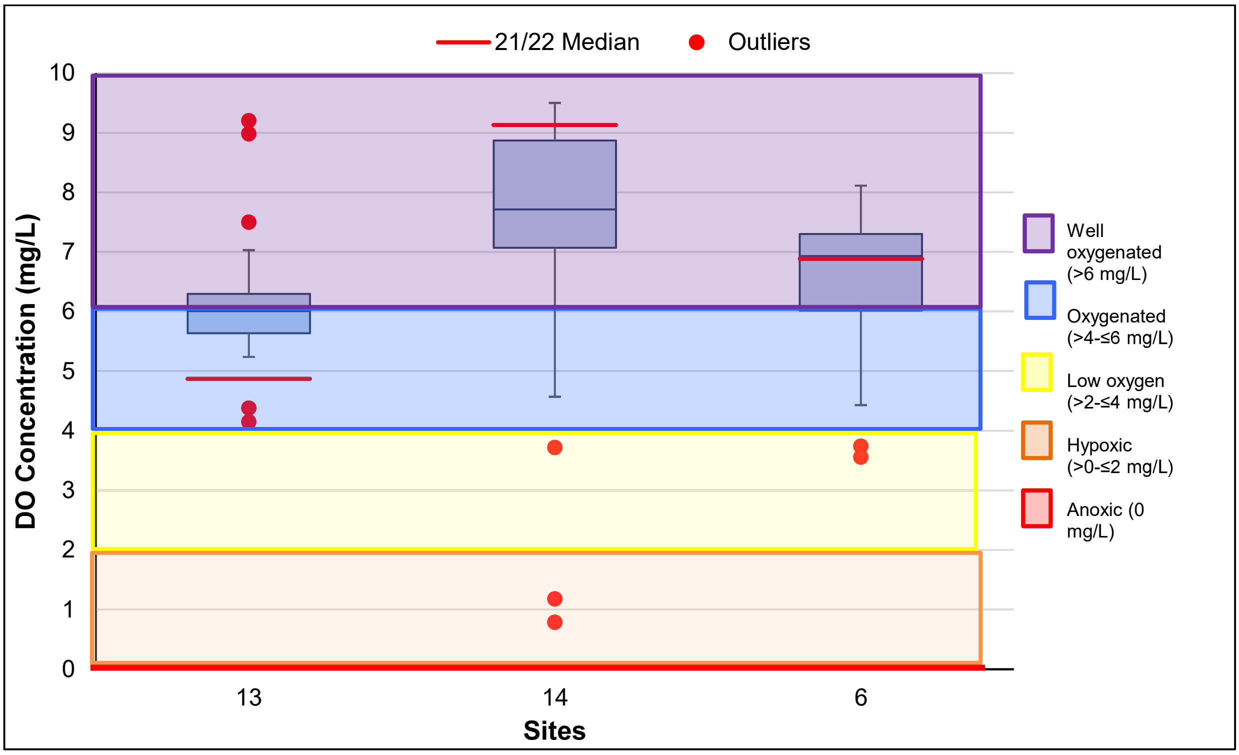


Figure 81. Box plots of DO mg/L 2007-2020 historical median values, with the red line indicating the median value in 2021.

Bateman Park (site 6), Brentwood Drain (site 13) and the RAAF Drain (site 14) samples taken in 2021 recorded a median DO concentration of 1.93mg/L, 1.005mg/L and 7.715mg/L deeming all sites to be generally well oxygenated (< 6mg/L) in accordance with DBCA standards (DPaW, 2015) (Figure 81 and Table D-6 in Appendix D).

Apart from some outliers at each site, in particular at Brentwood Drain (MELDR-14) and Bateman Park (MELDR-06) most data showed that oxygen saturation and concentration was sufficiently high to support most life in these wetlands (above 4 mg/L).

Time series

While the variation in % dissolved oxygen and oxygen concentration have tended to be highest and most variable in water flowing from the RAAF drain (site 14) compared to the other two sites (Table 27), the overall trend shows a reasonably steady levels of oxygen at this drain (Figures 82 and 83). Site 13, Brentwood Drain, has less of the forms of oxygen and shows low variability in oxygen levels as well.

Table 27. Descriptive statistics of the oxygen saturation and concentration at the Brentwood Drain sites.

	Dissolved oxygen %			Oxygen concentration mg/L		
Site	Mean	SD	n	Mean	SD	n
13	64.61	9.74	34.00	1.06	1.00	34.00
14	71.18	20.32	34.00	7.43	2.10	34.00
6	70.49	10.50	59.00	1.62	0.97	59.00

The low levels of dissolved and concentrations of oxygen in October and November 2013 can be due to Perth recording lower than average rainfall as well as higher than average temperatures. Without waterflow, and associated with higher temperatures and more sunlight, it is possible that conditions in these wetlands became less oxygenated due to growth of aquatic plants. Alternatively, it may be valuable to explore the cause of these abnormally low results. Overall, historical data of the DO and Oxygen concentration show that oxygen patterns are likely to be seasonal, oxygenated to well oxygenated, but that %oxygen is often below the ANZECC requirements for lowland rivers, particularly in sites 13 and 14.

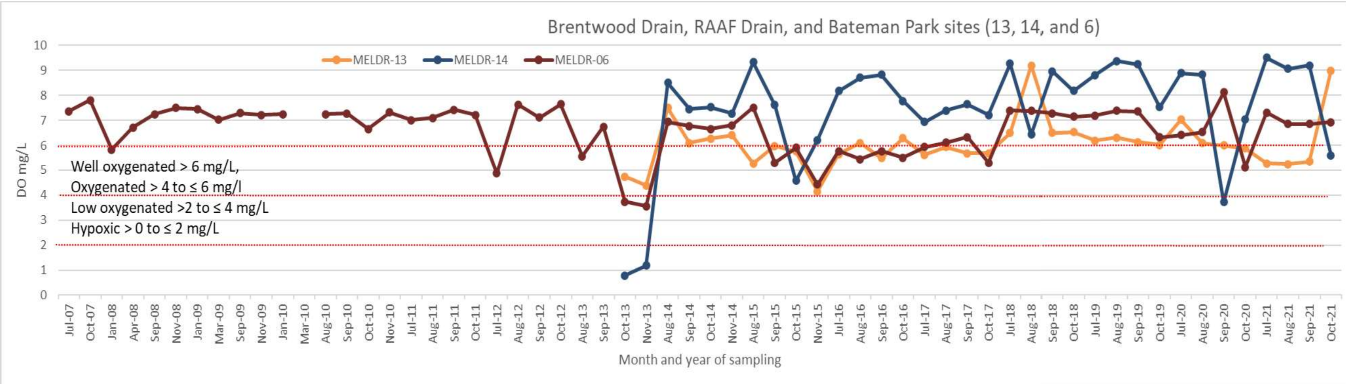


Figure 82. Historical data of dissolved oxygen concentration (mg/L, Appendix F. 7.4) at the Brentwood Drain sites

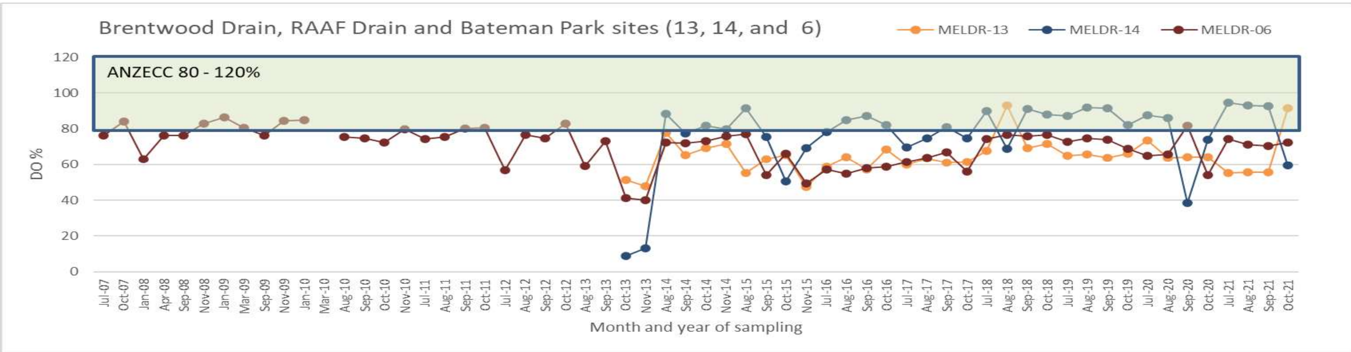


Figure 83. Historical data of dissolved oxygen saturation (%, Appendix F. 7.5) at the Brentwood Drain sites

Electrical conductivity (EC)

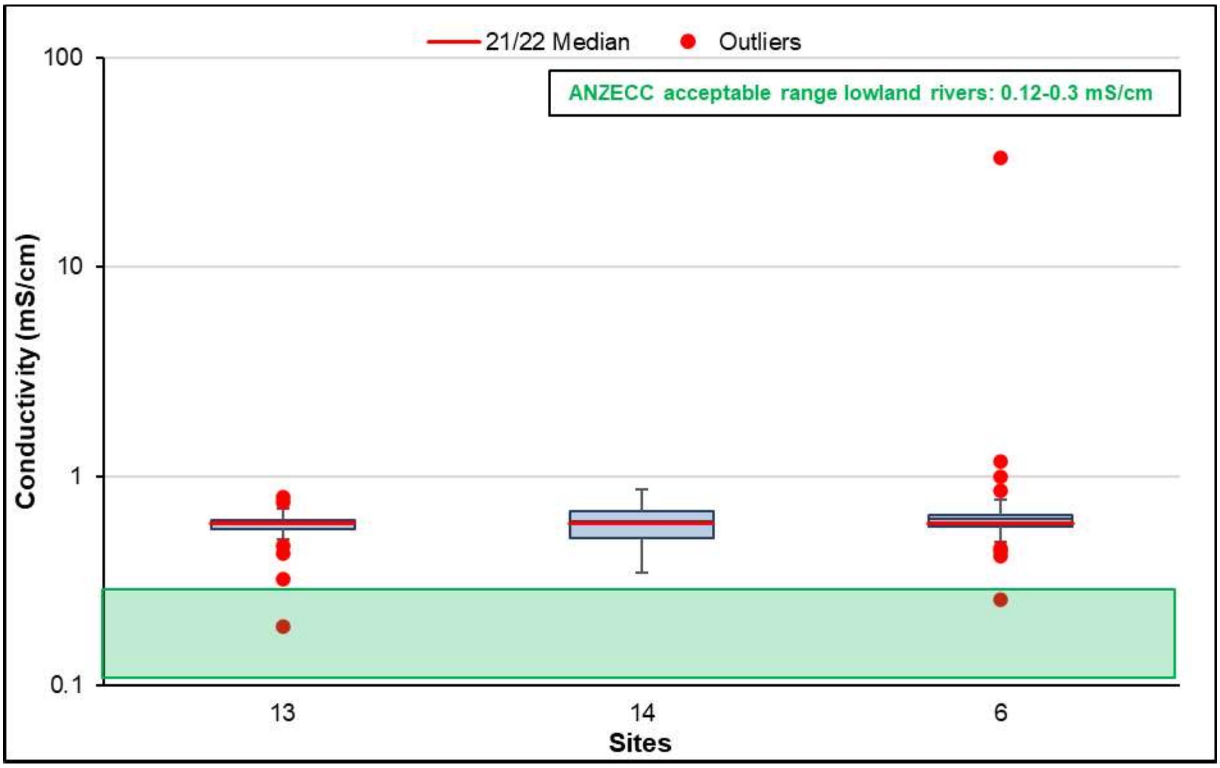


Figure 84. Box plot of conductivity 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

EC values recorded at Bateman Park (site 6), Brentwood Drain (site 13) and the RAAF Drain (site 14) were within the acceptable range for wetlands (0.3-1.5 mS/cm) (Figure 84 and Table D-7 in Appendix D). Median values observed in these sites were 0.634 mS/cm, 0.666 mS/cm, and 0.607 mS/cm respectively. All samples collected in the 2021 sampling event were above ANZECC acceptable ranges for lowland rivers (0.12-0.3 mS/cm) with the lowest concentration being 0.481 mS/cm, 0.499 mS/cm, and 0.49 mS/cm respectively. EC values recorded at these sites in 2021 are similar to those recorded in the preceding 14 years of sampling.

Time series

An unusually high outlier in July 2012 at Bateman Park (site 6, conductivity at 33.2 mS/cm) is more common in a wetland (ANZECC TV wetlands 0.3 – 1.5 mS/cm) than in a lowland river. Although not as high as the outlier in site 6 the conductivity at Bateman Park peaked in April 2008 and again in October 2013 (Figure 85). Overall, apart from August 2014, the conductivity at all three Brentwood Drain sites have consistently been above the ANZECC guideline for lowland rivers. The average of all sites seems quite consistent, though variation in values was slightly higher at Bateman Park than at the other two sites (even when the outlier was removed) (Table 28). Since 2014, however, the conductivity at site 6 has become less variable and slightly lower than it was prior to 2014. The other sites have tended to show a similar conductivity as site 6 (without the outlier), though they were not monitored prior to 2014.

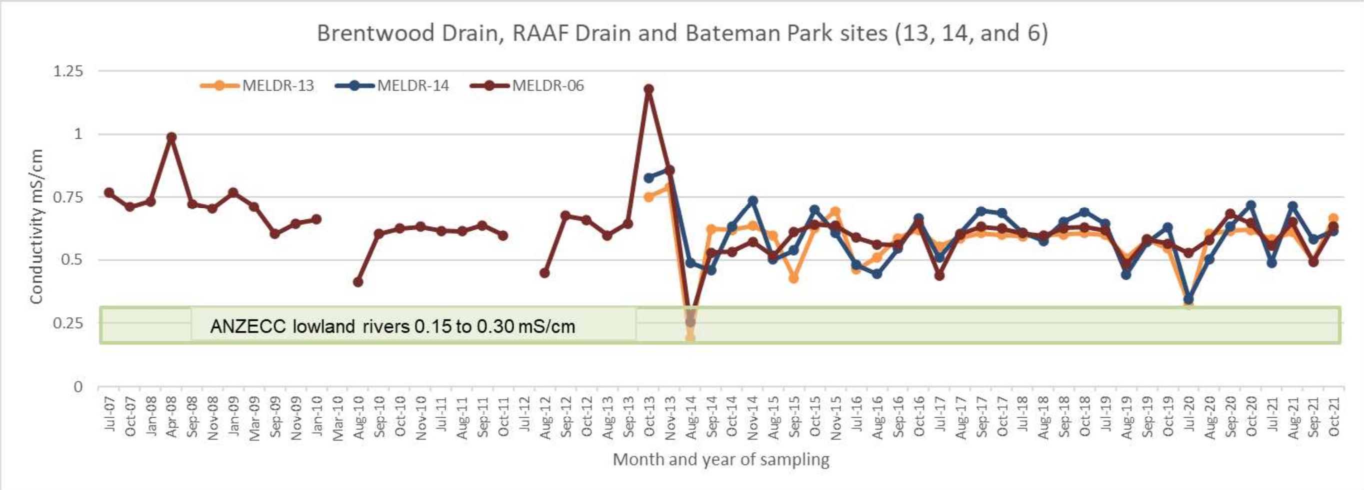


Figure 85 Historical data of electrical conductivity at the Brentwood Drain sites. Note – an outlier of 33.2 mS/cm in July 2012 was removed from this plot to highlight more common differences. Acceptable levels for wetlands 0.3 – 1.5 mS/cm.

Table 28. Descriptive statistics of electrical conductivity at the Brentwood Drain sites. Includes all data up to and including that of 2021.

Site	Mean	SD	n
13	0.58	0.11	34.00
14	0.60	0.11	34.00
6	1.18	4.21	59.00
6 without outlier	0.62	0.13	58.00

Total suspended solids (TSS)

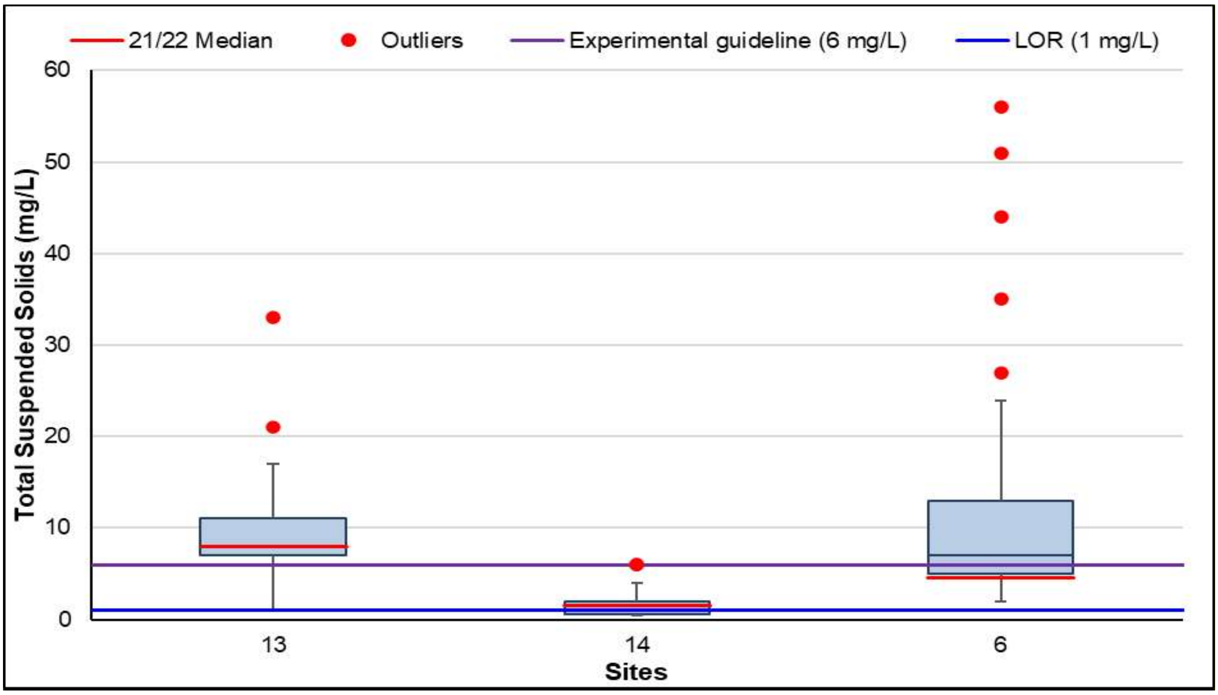


Figure 86. Box plot of TSS 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

TSS concentrations were notably lower across the Brentwood drain section than historically experienced, with 3 out of 12 samples collected at Bateman Park (site 6), Brentwood Drain (site 13) and the RAAF Drain (site 14) recording concentrations equal to or above the experimentally derived guideline of 6 mg/L, rather than 8 mg/L as recorded in the 2020 sampling event (Figure 86 and Table D-8 in Appendix D). All exceedances in 2021 were recorded at site 13 (Brentwood Drain) between August and October with the highest concentration of 13 mg/L recorded at this site in October. One sample at site 14 (RAAF Drain) in 2021 recorded a concentration below the LOR of 1.0 mg/L in August. Medians at Bateman Park (site 6) and the RAAF Drain (site 14) were both below the experimental guideline of 6mg/L, whereas the medians for Brentwood Drain (site 13) was above this guideline.

Time series

When comparing results between sites 13 and 14 (Brentwood Drain and RAAF Drain respectively), TSS concentrations have historically always been lower at site 14 than at site 13 (excluding one sampling occasion in October 2016) (Figure 87). To note, site 14 has recorded two values exceeding the trigger value for TSS in September and October 2020 (both 6 mg/L). This is the first exceedance recorded for this site since sampling began here in 2013. Site 13 records exceedances on approximately 81% of the time and site 14 recording exceedances on <1% of occasions. In 2021, TSS at site 6 was often somewhere in between the two sites.

Table 29. Descriptive statistics of the TSS at the Brentwood Drain. Includes all data up to and including that of 2021.

Site	Mean	SD	n
13	9.97	5.65	34
14	2.28	1.43	25
6	11.08	11.02	60
6 without outliers	9.02	1.42	57

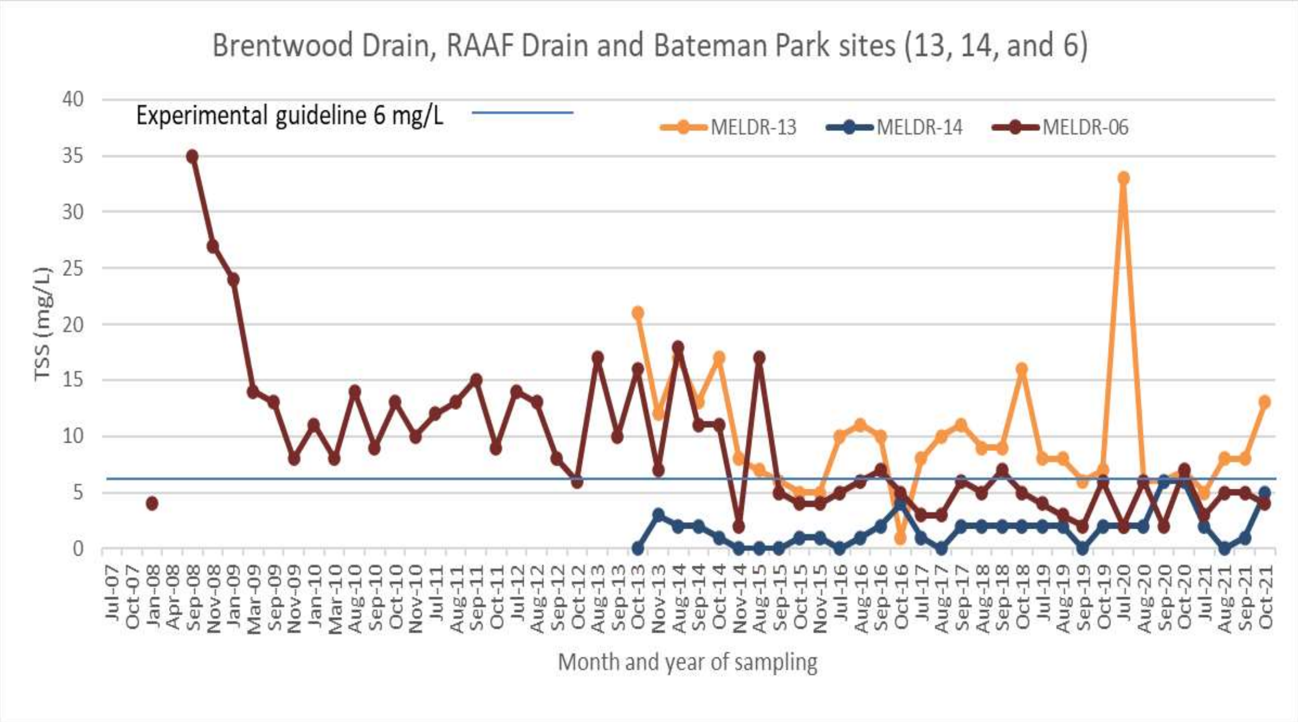


Figure 87. Historical TSS at the Brentwood Drain sites. Note; three outliers of 51 mg/L, 56 mg/L and 44 mg/L TSS in Bateman Park (site 1. MELDR-06) in July and October 2007, and April 2008 were removed from this plot and in calculations to assist interpretations of more common results.

There were several occasions when the TSS mg/L in site 14 in particular, but also in site 6 was below the experimental guideline of 6 mg/L, particularly since 2015. Overall, however, the TSS (prior to 2015) at site 6 and site 13 tended to exceed this guideline and be very variable. These results contrasted with the trend of low TSS observed at site 14. Although outliers in site 6 in 2007 and 2008 existed, there is an overall trend that the TSS is decreasing in site 6 and possibly stabilising since 2015. In contrast, the trend in site 13 suggest quite a large variability while that in site 14 is remaining quite low and steady.

Temperature

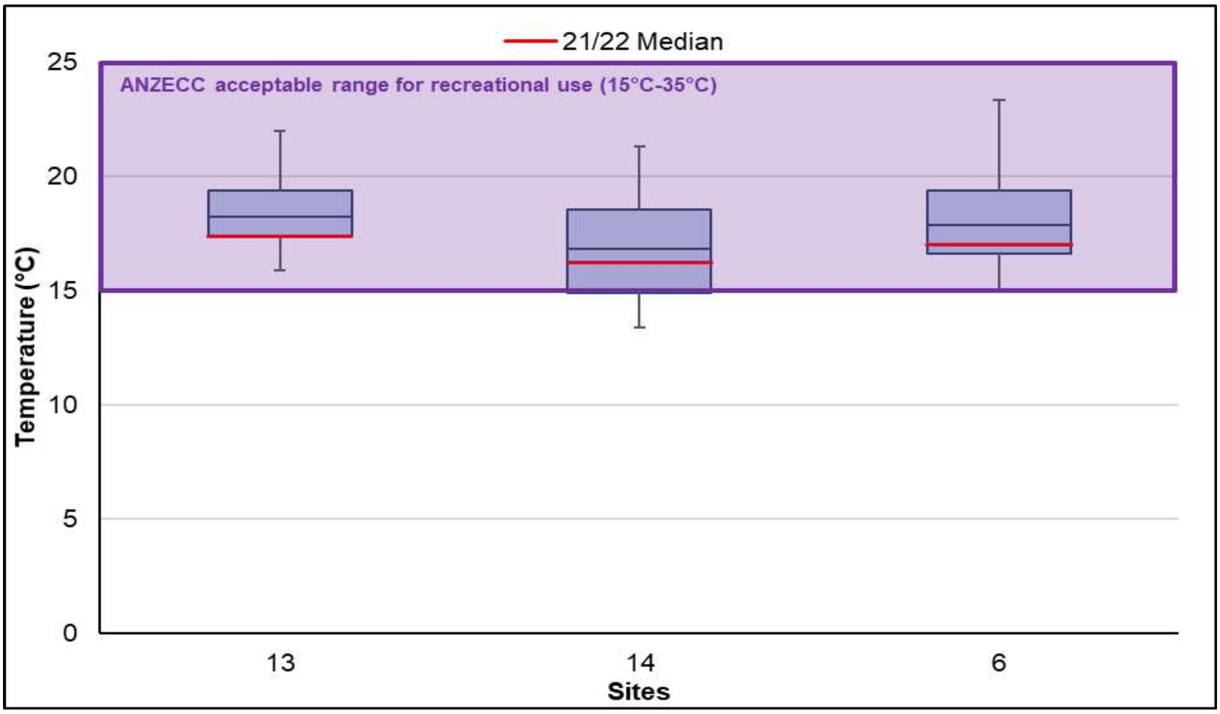


Figure 88. Box plot of temperature 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

No samples collected at Bateman Park (site 6), Brentwood Drain (site 13) and the RAAF Drain (site 14) recorded temperatures above or below the ANZECC acceptable range of 15°C to 35°C. Temperatures in the surface waters of the Melville Bull Creek catchments around the Brentwood drain ranged from 15.1°C in July at site 14, to 18.1°C in August at site 13 (Figure 88 and Table D-9 in Appendix D). Temperatures at all sites were considered to lie within a normal seasonal range and are comparable to those recorded in the previous 14 years of monitoring (Table G-48 in Appendix G).

Time series

Overall, the water temperatures at these sites remain similar since sampling began, within the acceptable range for recreational use, and in site 14 during winter, sometimes below this range (Figure 89). There is, however, possibly decreasing, and stabilising trends in the temperatures at the Brentwood Drain sites, in particular at Bateman Park. Seasonal patterns, such as maximum temperatures recorded were in summer and early autumn in 2009 (which was an unusually warm year) and in 2010 at Bateman Park and the minimum were at the RAAF Drain during winter since sampling began at this site.

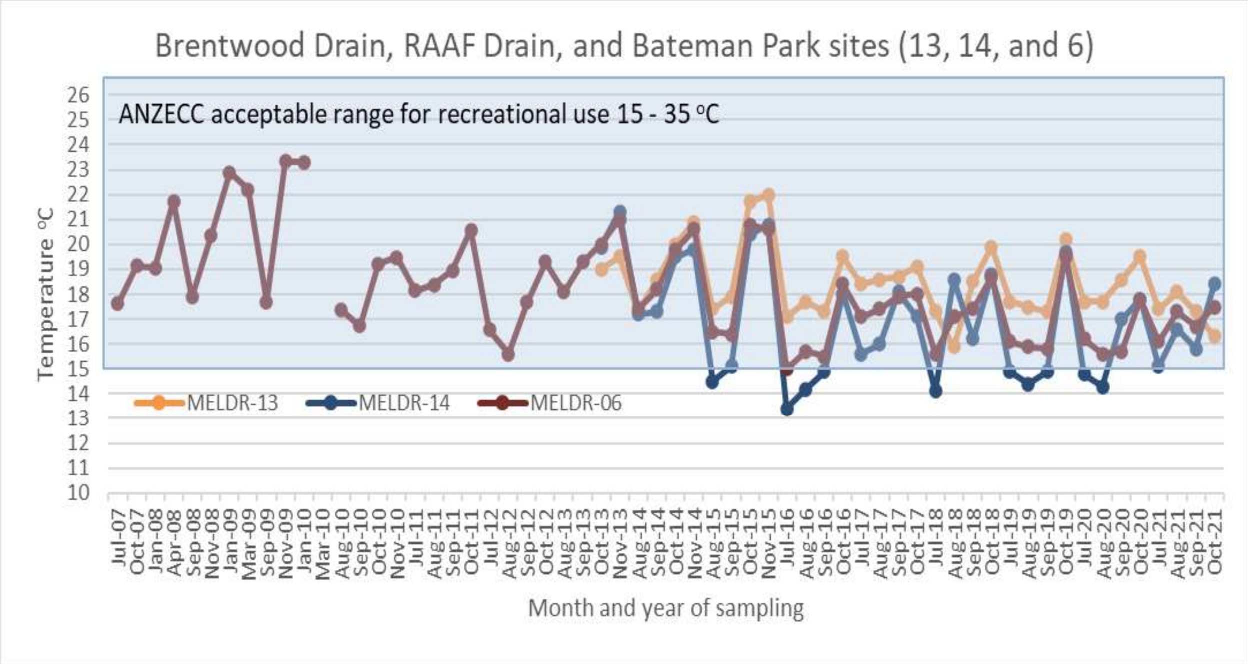


Figure 89. Historical data of water temperatures at the Brentwood Drain sites.

Nutrients

Nitrogen

A summary of the forms of nitrogen reveals that nitrogen occurs most often in both organic and oxidised forms (Table 30). The differences between sites in terms of nitrogen may indicate there are differences in the rates at which nitrogen, in particular in the ammonia/ammonium forms (site 14, RAAF Drain) is oxidised. The relationship between organic nitrogen and ammonia/ammonium, in particular at site 14 (RAAF Drain), may need further study.

Table 30. Average measures of the forms of nitrogen since sampling began at these sites.

	Total nitrogen mg/L			Total oxidised nitrogen mg/L			Nitrogen as ammonia/ammonium mg/L			Organic nitrogen (dissolved and total) mg/L		
Site	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
13	0.62	0.10	34	0.279	0.148	34	0.130	0.030	34	0.255	0.067	34
14	0.66	0.17	34	0.245	0.201	34	0.055	0.020	33	0.416	0.091	34
6	0.69	0.36	60	0.257	0.280	60	0.147	0.066	60	0.299	0.057	44

Note: site 6 was sampled from 2007 and sites 13 and 14 since 2011 for most parameters. The high variation in samples from site 6 is generally associated with sampling months. From 2007 to 2010, sampling occurred seasonally, four times each year, usually July, August, September and October or August, September, October, and November.

Total nitrogen

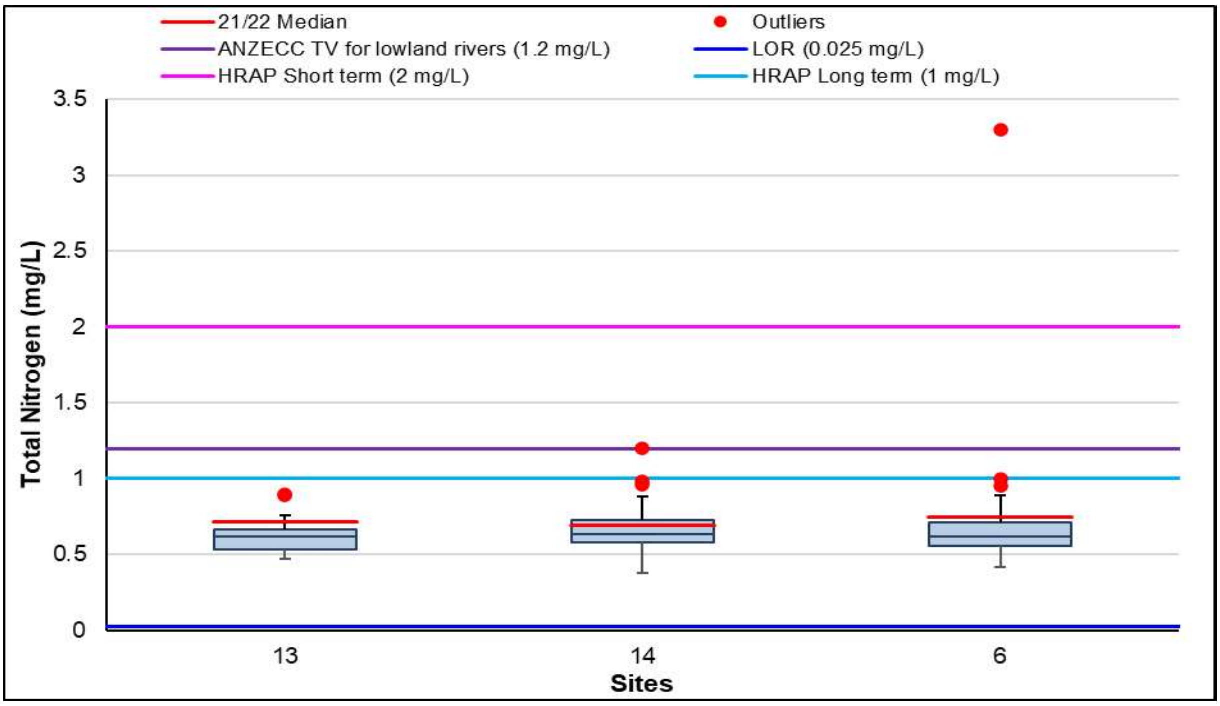


Figure 90. Box plot of total nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

TN concentrations exceeded ANZECC trigger values for lowland rivers (1.2 mg/L) or wetlands (1.5 mg/L) in 1 of 12 samples collected from Brentwood drain within the Melville Bull Creek catchment site (Figure 90 and Table D-10 in Appendix D). The highest concentration was recorded at site 13 with a reading of 0.89 mg/L in August 2021. There were no exceeding concentrations recorded on all sampling occasions at sites 6 and 14. The lowest concentration was recorded at site 14, 0.53 mg/L in October of 2021. None of the 12 samples exceeded the HRAP short term target (2 mg/L) or long-term target (1 mg/L) from sites 6, 13 and 14 in the 2021 sampling event.

Time series

Since sampling began in site 6 in 2007 (if the January 2007 high value of 3.3 mg/L is excluded) and sites 13 and 14 in 2013, the total nitrogen has remained below acceptable levels without any discernible trend (Figure 91). Site 14 has been most variable and site 13 least variable. Variations in total nitrogen seem to be associated with rainfall, in particular in August and September for most years of sampling at all three sites. Since there was only one sample collected in summer (January 2007) it is not possible to infer the total nitrogen levels during December through to February at these sites.

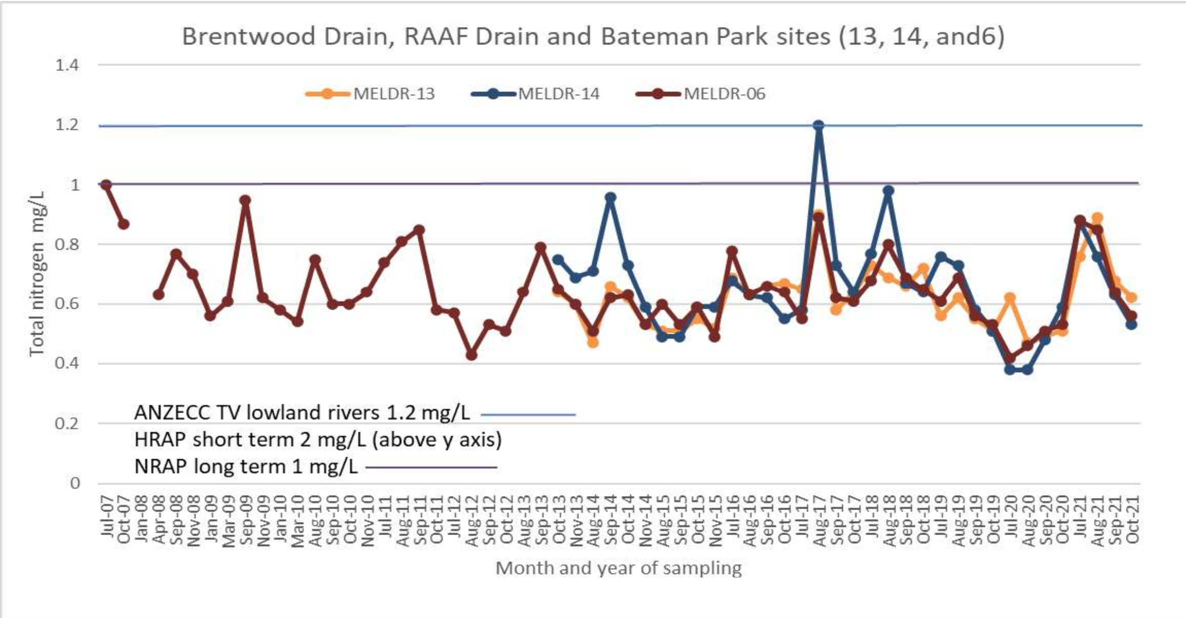


Figure 91. Historical data of total nitrogen at the Brentwood Drain sites.

Total oxidised nitrogen

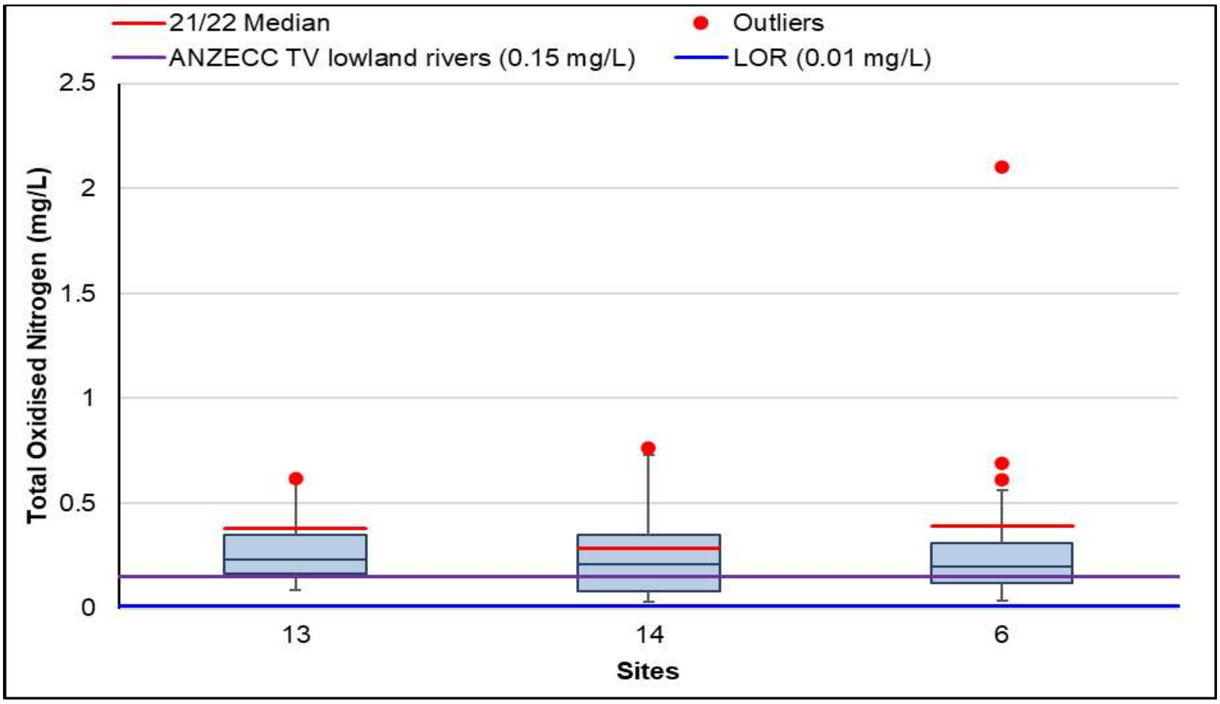


Figure 92. Box plot of total oxidised nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

NOx-N concentrations across these three sites were above relevant ANZECC trigger values lowland rivers of 0.15 mg/L, and wetlands: 0.1 mg/L. In the 2021 sampling event, the sample collected in October at site 14 (RAAF Drain) was an exception, with the lowest concentration on 0.088 mg/L (Figure 92 and Table D-11 in Appendix D). The highest concentration in the catchment was recorded at site 13 (Brentwood Drain) being 0.600mg/L in August. The 12 collected samples all recorded concentrations above the LOR of 0.01 mg/L.

Time series

The results in 2021 display some similar patterns that can be associated with weather at sites around the Brentwood drain. There were, however, notable deviations that can be linked to rainfall events in particular. The sampling event in January 2008 in site 6 recorded the highest NOx value of 2.3 mg/L recorded at any time in all sites, yet in January 2009 and 2010, this was not repeated (Figure 93). Another interesting observation is the levels of NOx in 2019 that may have been associated with rainfall events. The August 2019 sampling even occurred soon after rainfall in that month. The lower rainfall in September and October that year, may have reduced the opportunity for water to flow downriver, causing NOx levels to remain quite high throughout that winter.

In spite of winter peaks in NOx, the NOx in site 14 is on average lower and often below the ANCECC trigger value of 0.15 mg/L on several occasions, in particular in October of most years. If the outlier in January 2007 is excluded, there are trends in all sites that NOx was increasing between 2013 to 2019.

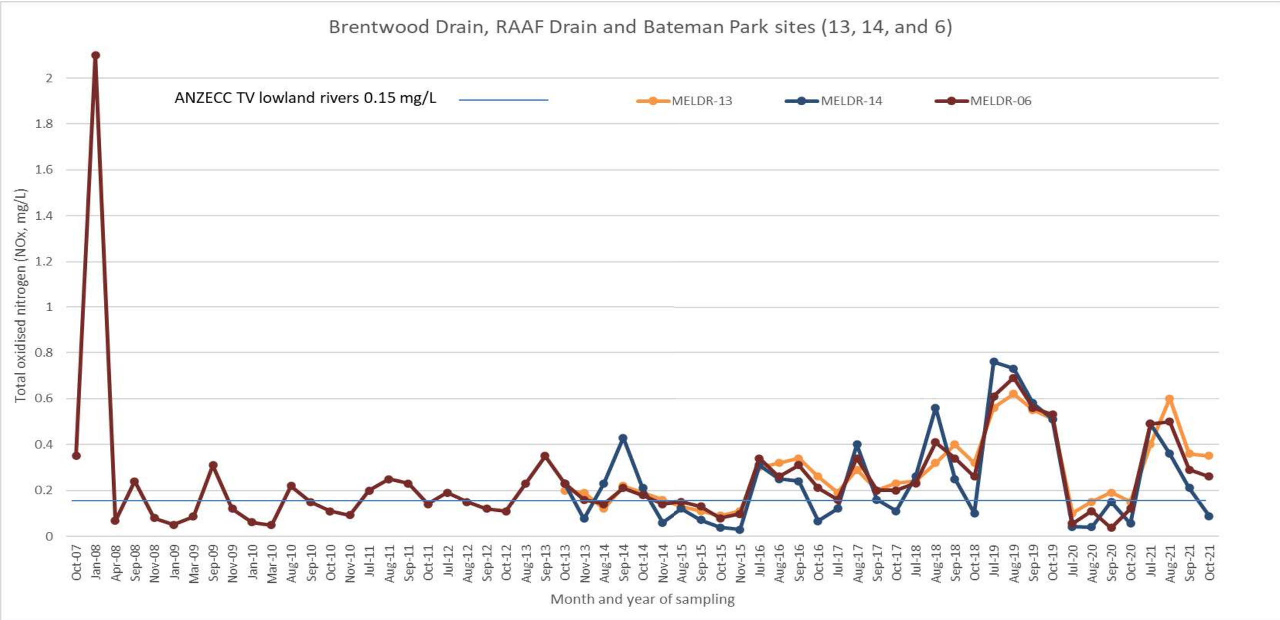


Figure 93. Historical data of total oxidised nitrogen at the Brentwood Drain sites.

Nitrogen as ammonia/ammonium

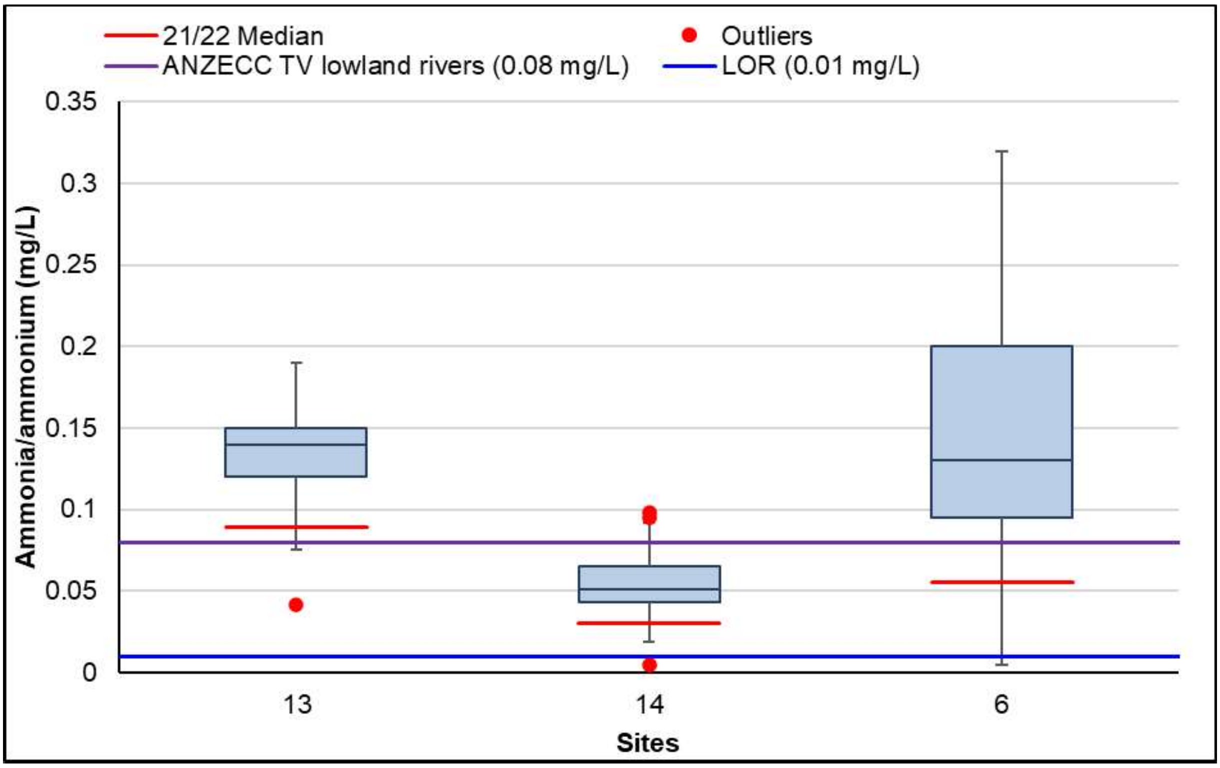


Figure 94. Box plot of nitrogen as ammonium/ammonia 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Three out of 12 samples in 2021 exploring nitrogen as ammonium/ammonia (NH4+/NH3-N) at Brentwood Drain sites were outliers (deviations from ANZECC TV lowland rivers: 0.08 mg/L, wetlands: 0.04 mg/L, Figure 94, and Table D-12 in Appendix D). It is important to mention that the trigger value for 95% level of protection is only applicable at pH 8 and 20°C as per table 8.3.7 in the ANZECC guidelines (ANZECC and ARMCANZ 2000, page 8.3-161). The trigger value decreases with increasing pH and increases with decreasing pH. Site 13 in Brentwood Drain recorded NH4+/NH3-N concentrations exceeding the trigger value for lowland rivers and wetlands on 3 of the 4 sampling occasions, except during the September 2021 sampling event. All other samples were below the ANZECC trigger values (lowland rivers: 0.08 mg/L, wetlands: 0.04 mg/L) as well as NHMRC (2008) recreational trigger value of 0.5 mg/L. One sample recorded a concentration below the LOR of 0.01 mg/L in September 2021 at site 14 (RAAF Drain).

Time series

When all the data from sampling events are examined, and disregarding seasonal differences, there is a possibility that nitrogen as ammonia/ammonium is trending down in site 6 (in particular between 2007 and 2013) as well as in site 13 since sampling began in this site in 2013 (Figure 95). But this trend is not evident in site 14, the RAAF Drain. Additionally, the downwards trends in sites 13 and 6 tend to even out after 2013.

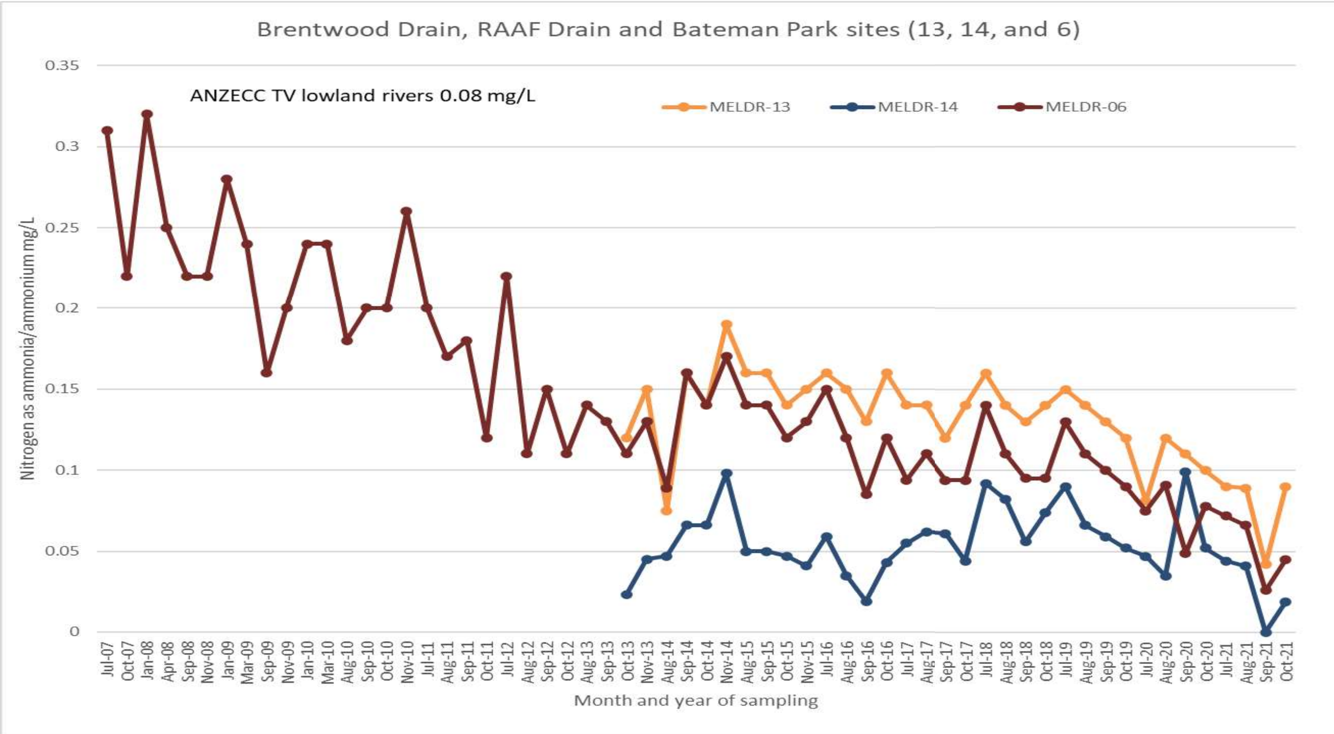


Figure 95. Historical data of nitrogen as ammonia/ammonium at the Brentwood Drain sites.

Organic nitrogen (total and dissolved)

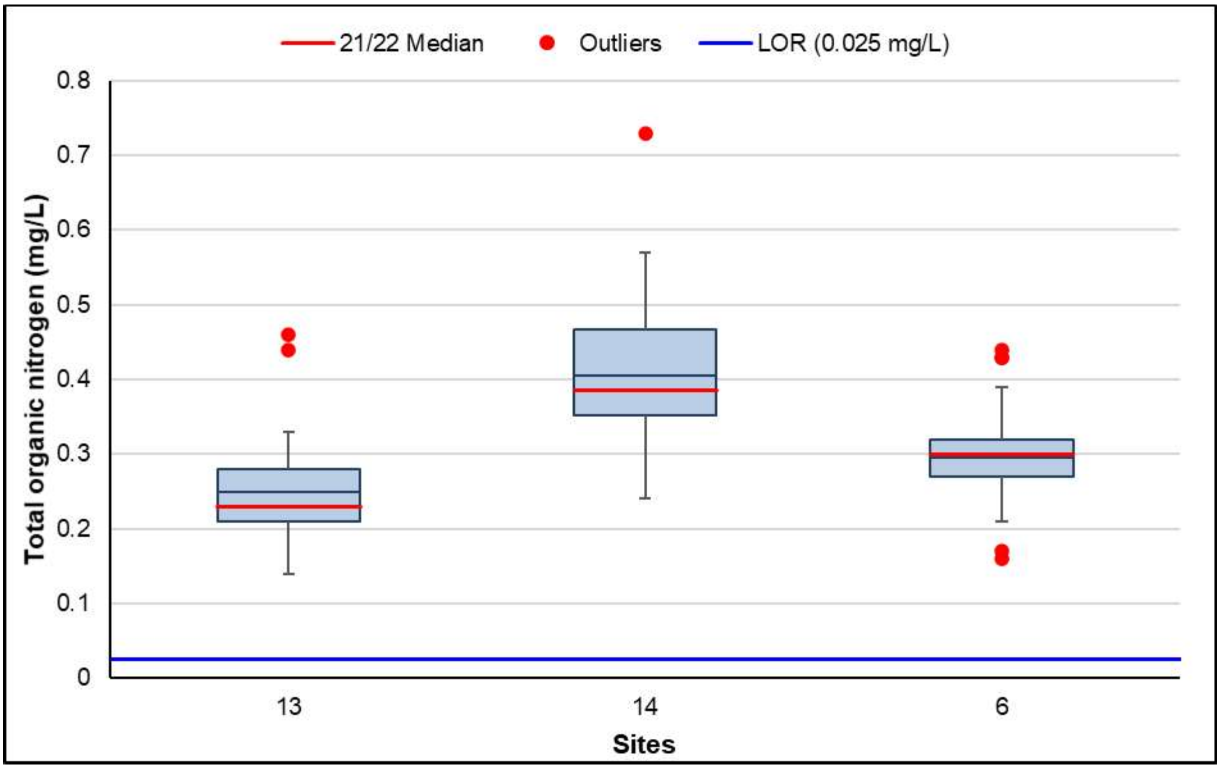


Figure 96. Box plot of total organic nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

As no guideline currently exists for TON and DON it is difficult to assess the results for these parameters in terms of threats to ecosystem and/or human health. The LOR is low, <0.025 mg/L and all values exceeded this. The origins of DON in wetlands and the relationship of DON with metals and other chemicals in in the water or sediments in complex and needs further study. There is, however, some evidence that organic nitrogen compounds are taken up by phytoplankton and bacteria and may therefore influence the composition and densities of these communities.

Site 14 (RAAF Drain) recorded the highest median concentration of TON of 0.405 mg/L, with concentrations between 0.35mg/L, and 0.42 mg/L. Site 13 (Brentwood Drain) recorded the lowest TON concentrations in the range of 0.2 to 0.28 mg/L, with a median of 0.25 mg/L (Figure 96).

Time series

Since sampling began in these sites, the levels of dissolved organic nitrogen has varied seasonally, but without any indication of a change in the trend with time (hence no plot of these). The dissolved organic nitrogen was highest in site 14 94% of the time and lowest in site 13, 87% of the time (Figure 97) The values at site 6 remained intermediate. There is a slight trend that the dissolved organic nitrogen is decreasing in site 14 (RAAF Drain), but this needs verification.

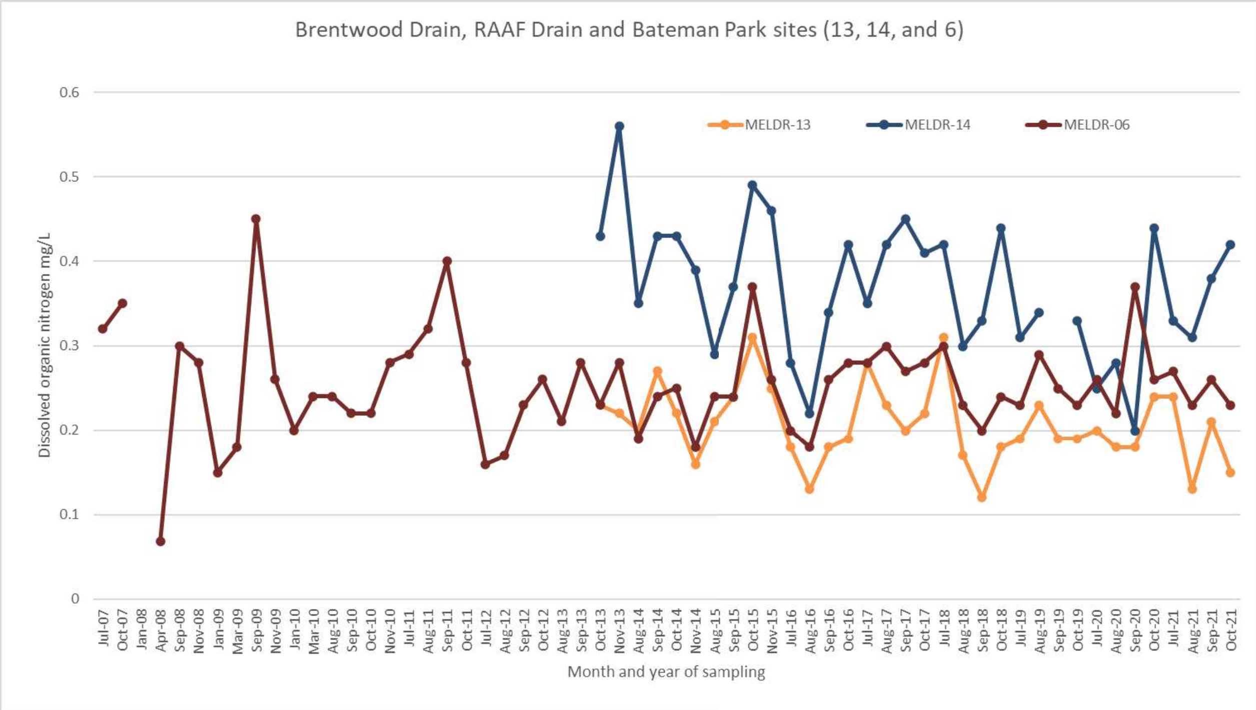


Figure 97. Historical data of dissolved organic nitrogen at the Brentwood Drain sites. Note: outliers that were removed from this plot include a January 2008 value of 2.1 mg/L and a September 2019 value of below 0.025 mg/L which is also the LOR value.

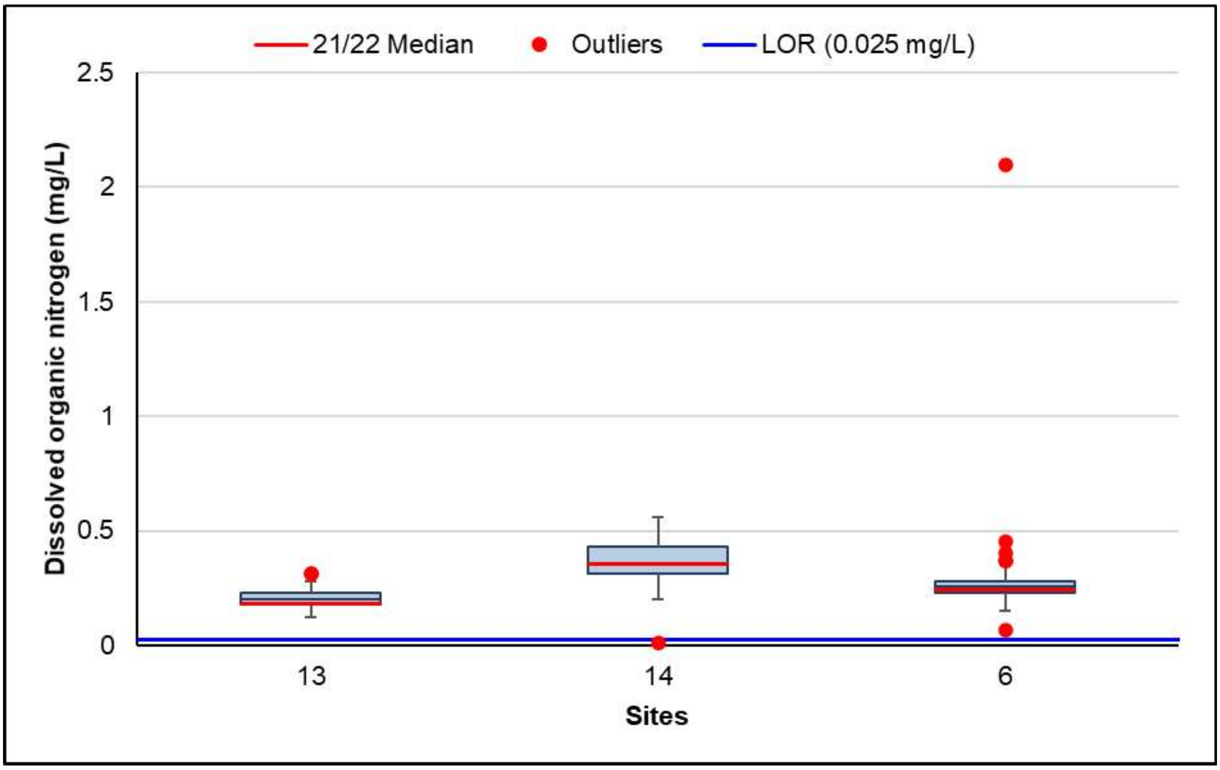


Figure 98. Box plot of dissolved organic nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

DON concentrations (Figure 98) were similar to TON concentrations. Site 14 (RAAF Drain) had the highest median of 0.36 mg/L, site 6 (Bateman Park) at 0.255 mg/L and site 13 (Brentwood Drain) with 0.2 mg/L. The lowest DON concentration was seen in site 13 at 0.13mg/L and the highest was seen in site 14 at 0.42 mg/L. DON concentrations seen in 2021 continue the pattern observed in previous years of sampling, with higher values recorded during winter sampling events (Figure 99). The total organic nitrogen in site 14 was highest in 94% of the samples and lowest in site 13 in 84% of the time since 2013. The values observed in site 6 has remained intermediate between these sites.

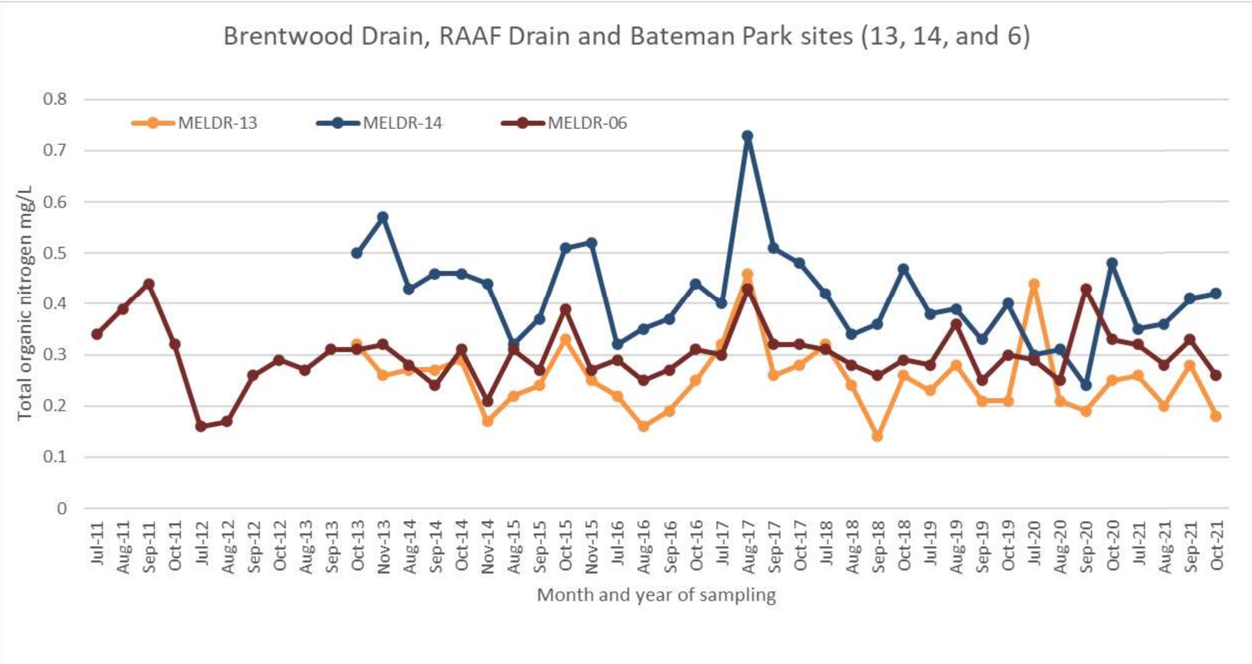


Figure 99. Historical data of the total organic nitrogen at the Brentwood Drain sites.

Phosphorus

In all sites the soluble reactive phosphorus levels were just over 50% of that of the total phosphorus (Table 31). Research suggests (M. Berthold et al, 2018) that the there is an inverse relationship with the % oxygen and filterable phosphorus in cold temperate coastal wetlands, and that macrophytes are able to buffer this relationship. It is therefore important to understand the relationships between TP, FRP, oxygen and well as nitrogen and metals is necessary and the role of macrophytes in maintaining liveable conditions for organisms in the systems.

Table 31. Descriptive statistics of the total and filterable reactive phosphorus at the Brentwood Drain sites. (note; the majority of samples were below the LOR for FRP of 0.005 mg/L and therefore not included in calculations here)

	Total phosphorous mg/L			Filterable reactive phosphorous mg/L			% FRP of TP (approximate %DO)
Site	Mean	SD	n	Mean	SD	n	
13	0.01143	0.00846	28	0.00633	0.00137	6	55 (65)
14	0.01221	0.00446	33	0.00617	0.00134	6	51 (82)
6	0.01226	0.00497	54	0.00664	0.00123	11	54 (75)

Total phosphorus

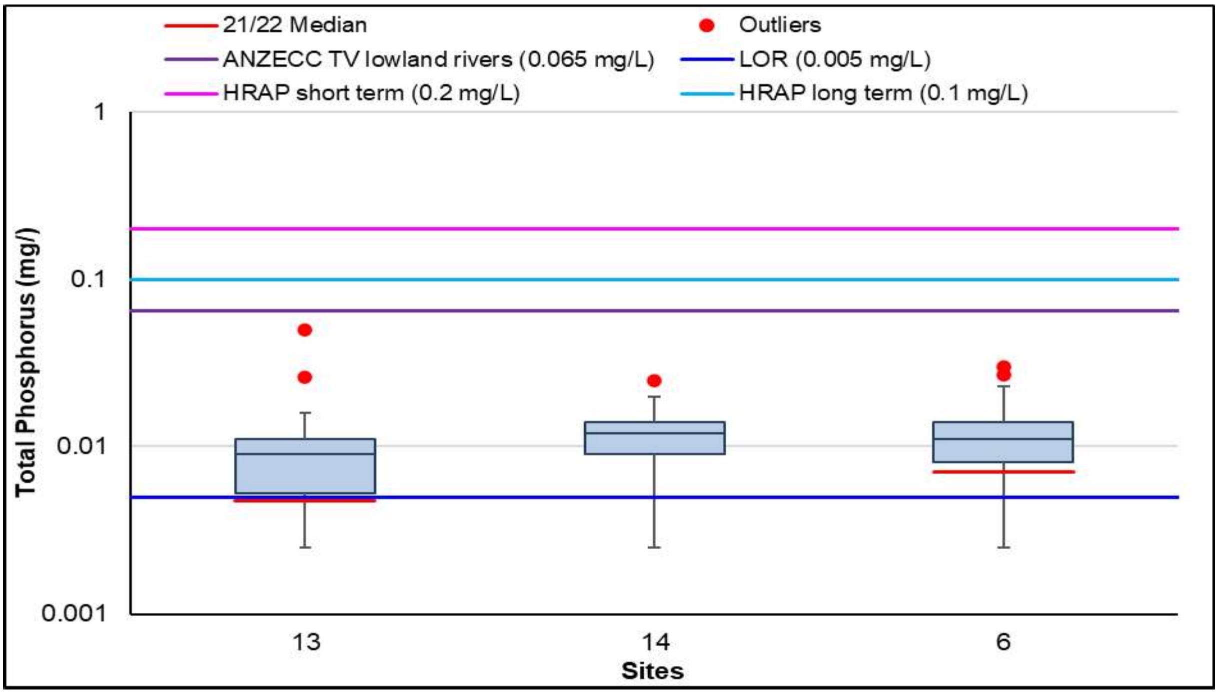


Figure 100. Box plot of total phosphorus 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

TP is a measure of all phosphorus in the water encompassing both soluble and particulate forms. None of the TP concentrations recorded in Melville Bull Creek catchment sites in 2021 exceeded relevant ANZECC trigger values (lowland rivers: 0.065 mg/L, wetlands: 0.06 mg/L) (Table 31). None of the 12 samples from the Brentwood drain had exceedances when compared against assessment criteria (Figure 100 and Table D-15 in Appendix D). TP concentrations were the highest in site 6 (Bateman Park) with a value between <0.005 and 0.014mg/L and a median of 0.012mg/L. The lowest TP concentration were seen in site 13 (Brentwood Drain) with a value between <0.005mg/L and 0.011mg/L and a median of 0.01mg/L. Three samples recorded concentrations below the LOR (0.005 mg/L). These were at site 6 in

October and site 13 in the August and October 2021 sampling events. None of the samples collected within Brentwood drain section exceeded the HRAP short term target of 0.2 mg/L.

Time series

There is a slight trend that total phosphorous is decreasing at site 6 (Bateman Park) since sampling began. Since 2013, when sampling began at sites 13 and 14, the total phosphorous has been highest 14 times at site 14 (RAAF Drain), 6 times at site 6 (Bateman Park) and 4 times at site 13 (Brentwood Drain) (Figure 101). The cause of this may need further examination.

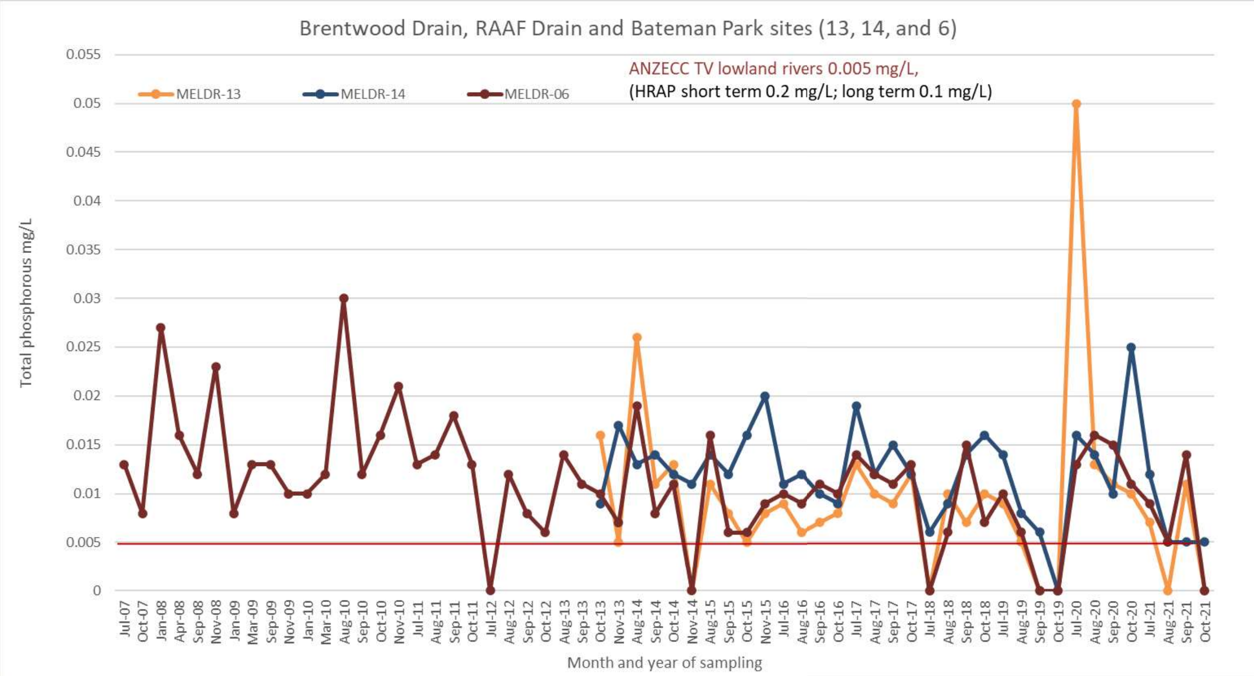


Figure 101. Historical data of the total phosphorus at Brentwood Drain sites.

Filterable reactive phosphorus

Box whisker

Testing of the samples collected from the sites within the Brentwood drain section did not detect many FRP concentrations (LOR at 0.005 mg/L). Thus, no exceedances relevant to ANZECC trigger values were reported (lowland rivers: 0.04 mg/L, wetlands: 0.03 mg/L) (Figure 102 and Table D-16 in Appendix D). Although some samples indicated values close to 0.01 mg/L these low values were potentially unreliable due to likely interactions of phosphorus with other compounds in the water. All concentrations were therefore recorded as below the LOR (0.005 mg/L)

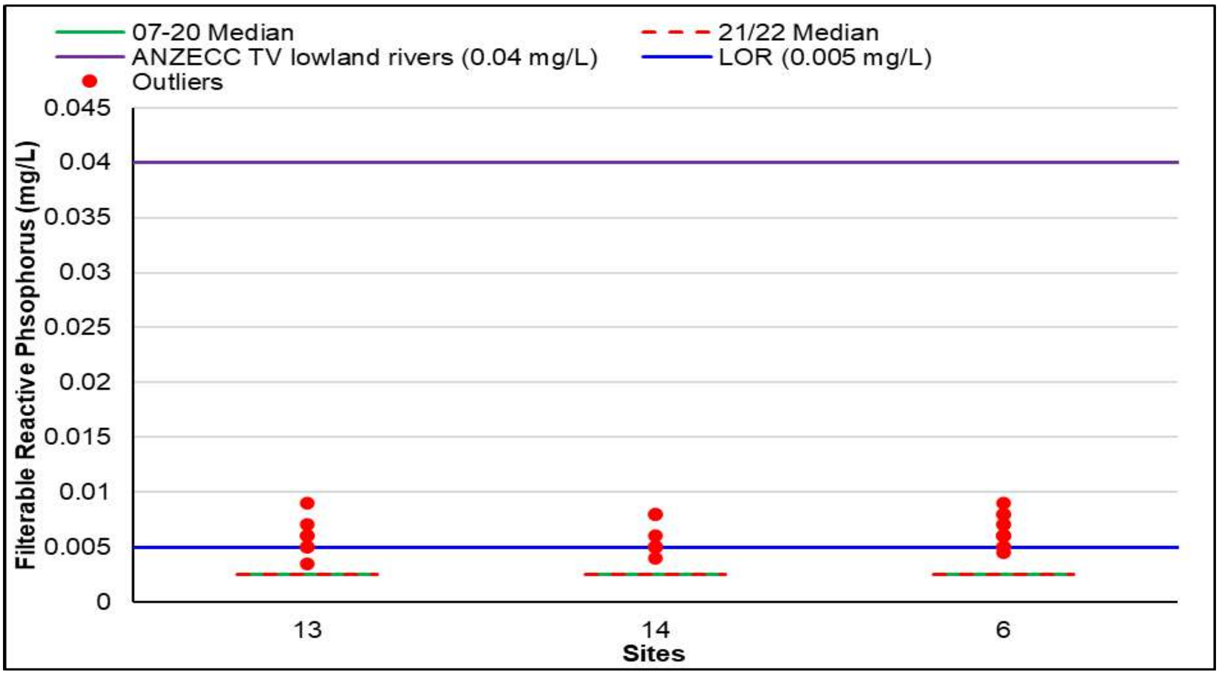


Figure 102. Box plot of FRP 2007-2020 historical median values, with a red line indicating the median value in 2021.

Time series

The low values of filterable reactive phosphorous for most of the sampling period since 2007, makes it difficult to infer any changes associated with the times or season of sampling. Hence no plot of this is supplied. The average filterable reactive phosphorous however, suggest that, overall, the levels in site 14 (6 readings above LOR) remains lowest and that in site 6 (11 readings above LOR) highest (Table 31).

Metals

Metals in water

Hardness

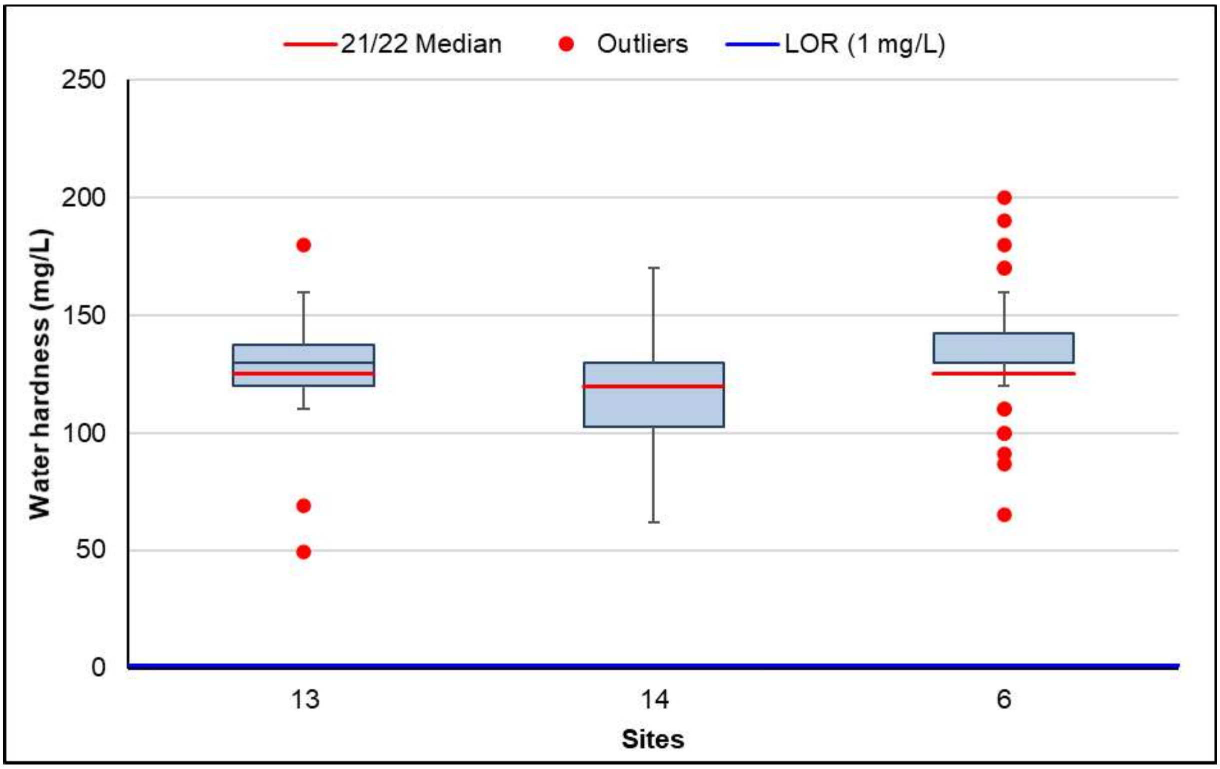


Figure 103. Box plots of hardness refer to the 2007-2020 historical median values, with the red line indicating the median value in 2021

Box whisker

In 2021 water hardness in the surface water of the Brentwood drains section of the Melville Bull Creek catchment varied from a minimum of 99 mg/L in July recorded at site 14 (RAAF Drain) to a maximum of 140 mg/L recorded at sites 6 (Bateman Park) and 14 in October (Figure 103 and Table D-17 in Appendix D). Based on the ANZECC guidelines classification of water hardness as Soft (0 to 59 mg/L), Moderate (60 to 119 mg/L), and Hard (120 to 179 mg/L), all samples collected in September are seen to be Moderate, whereas all samples collected in August and October are Hard ranging from 120-140.

Time series

Overall, the total water hardness levels seen in the 2021 sampling event followed the patterns of that seen in previous years and tended to trend downwards in all sites (Figure 104). Hardness was hard just over 81% of the time in sites 6 and 13, and 41% of the time in site 14 since these sites were sampled. It was only soft once, in August 2014 in site 13, since sampling began in that site in 2014. Additionally, TSS exceeded the maximum hard level of 179 mg/L three times in site 6 (April and November 2008, and October 2014). At all other times (approximately 23% of the times) the water hardness was Moderate.

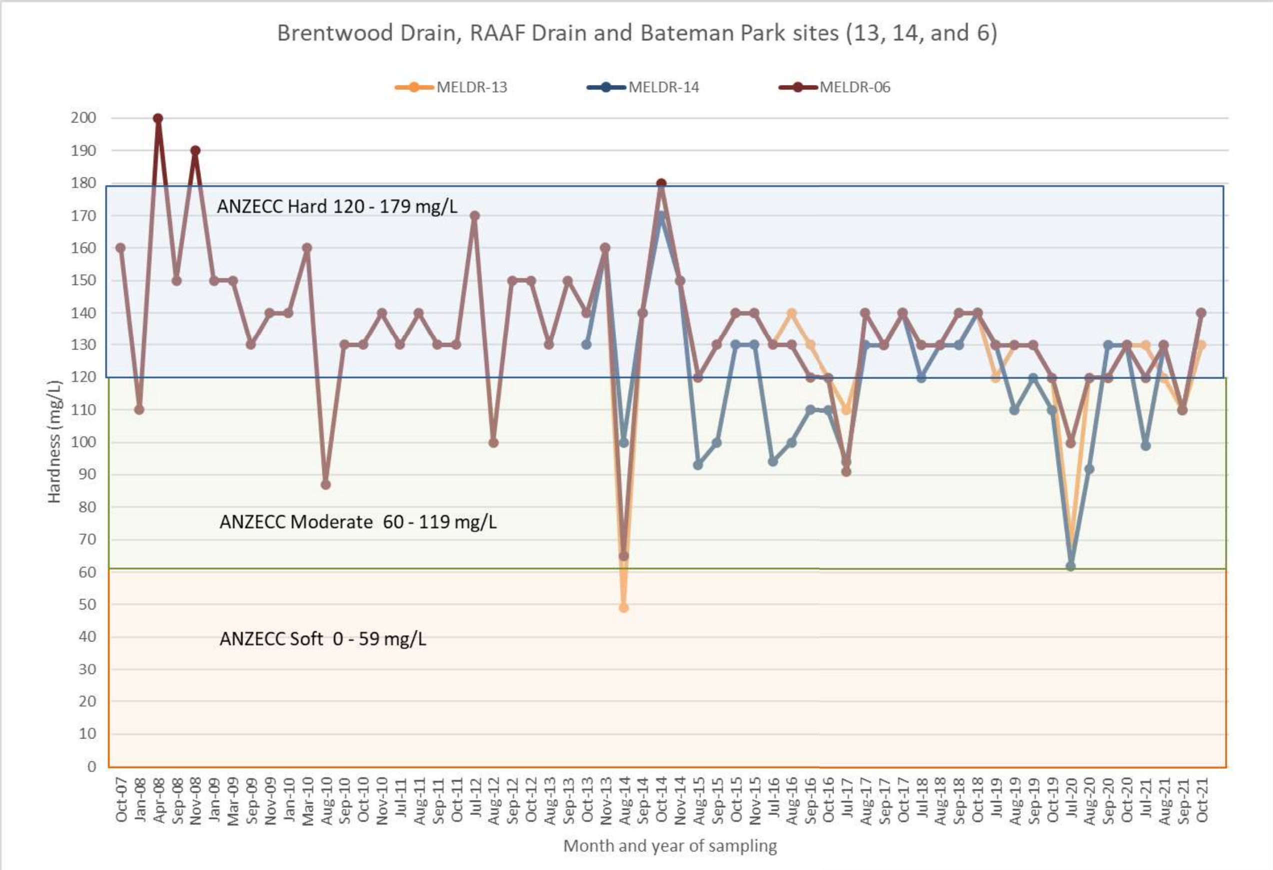


Figure 104. Historical data of hardness at the Brentwood Drain sites.

Aluminium

Box whisker

Concentrations of total aluminium across the Brentwood drain section of the catchment exceeded the ANZECC trigger value for 95% level of protection of 0.055 mg/L or the NHMRC guideline value for aesthetics of 0.2 mg/L (Figure 105 and Table D-18 in Appendix D). Samples were only tested for total aluminium in July, the lowest concertation observed at site 14 (RAAF Drain) at 0.16 mg/L and the highest at site 13 (Brentwood Drain) with a concentration of 0.32 mg/L.

All 12 samples recorded soluble aluminium concentrations exceeding the ANZECC trigger value for 95% level of protection where samples with pH <1.5, being at the low reliability interim value for freshwater protection (Figure 106 and Table D-19 in Appendix D). The highest concentration of soluble aluminium was seen at a total of 0.12 mg/L at site 13 (Brentwood Drain) in July and the lowest was seen to be 0.073 mg/L at the same site in October 2021. None of the 12 samples collected in 2021 exceeded the NHMRC guideline value for aesthetics (0.2 mg/L) of soluble aluminium (outliers occurred in 2010,2015, 2017, and 2019)

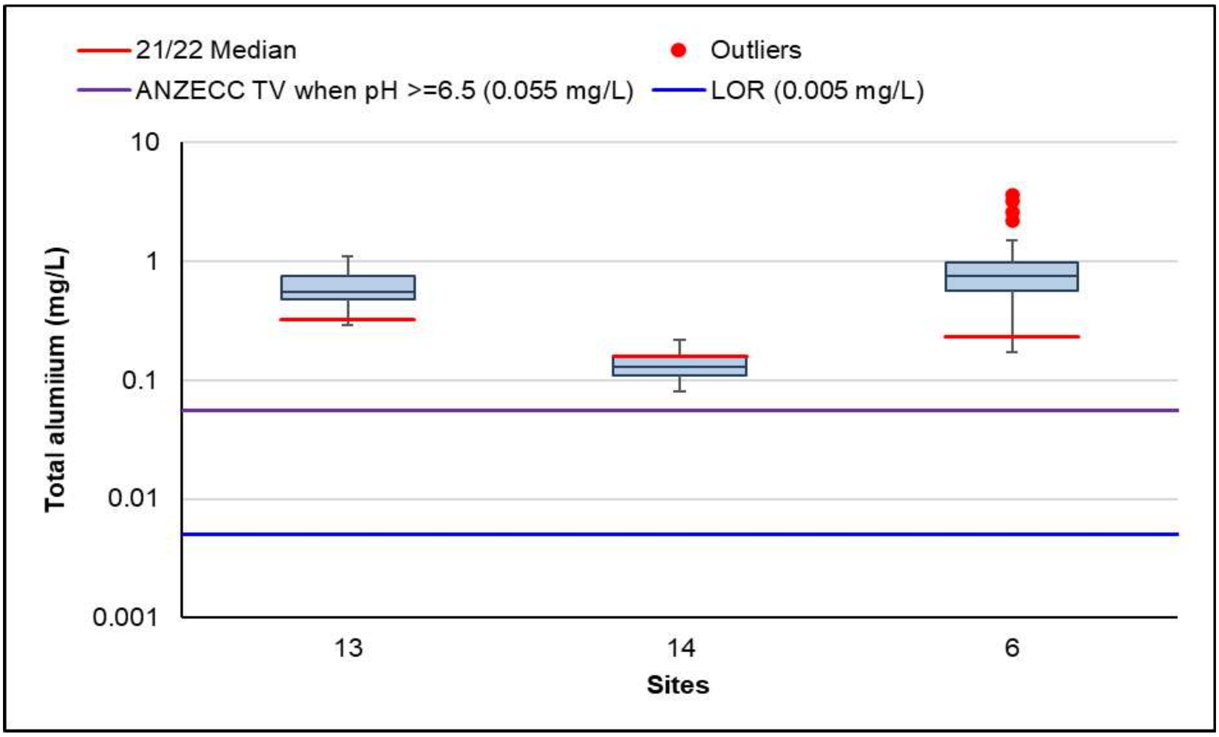


Figure 105. Box plots of total aluminium refer to the 2007-2020 historical median values with the red line indicating the median value in 2021.

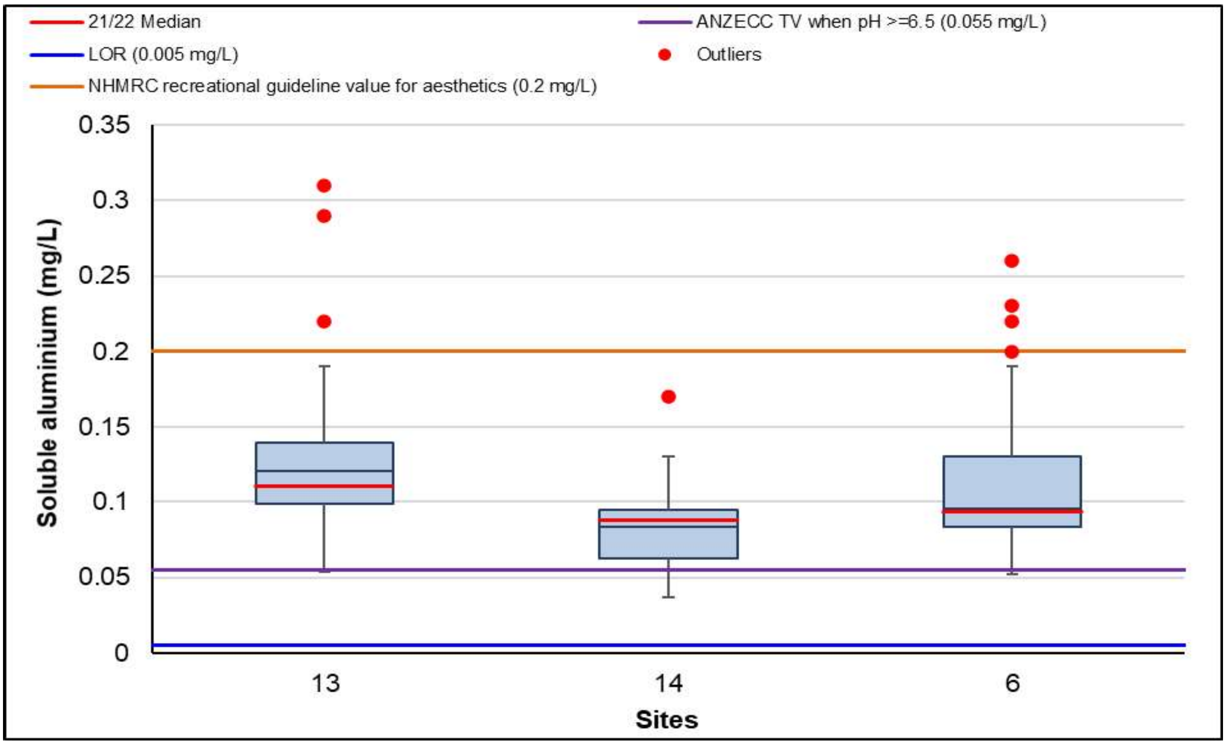


Figure 106. Box plots of soluble aluminium 2007-2020 historical median values, with the red line indicating the median value in 2021.

Time series

The total (Figure 107) and soluble (Figure 108) aluminium (not adjusted for hardness) showed different trends. At site 6, both forms of aluminium have trended downwards from high values in July and October 2007 and September and November 2008 up to 2012, after which there have been fewer large deviations. Overall, since 2013, the lowest total aluminium was consistently recorded in site 14, and the highest in site 13 (also Table 32). Further examination of the data of soluble aluminium, reveals that this has remained very variable at site 6 since sampling at this site began in 2007, and while some peaks can be associated with rainfall, there is no consistent pattern linking peaks or troughs in the data with weather. The data from the other two sites was equally variable. Further work needs to examine the relationship of pH and other factors influencing solubility of aluminium to identify the sources and understand how aluminium varies in these ecosystems.

Table 32. Descriptive statistics of total and soluble aluminium at the Brentwood Drain sites.

	Total aluminium mg/L			Soluble aluminium mg/L		
Site	Mean	SD	n	Mean	SD	n
13	0.605	0.218	13	0.1291	0.0554	34
14	0.140	0.039	13	0.0828	0.0269	34
6	0.951	0.745	39	0.1101	0.0464	52

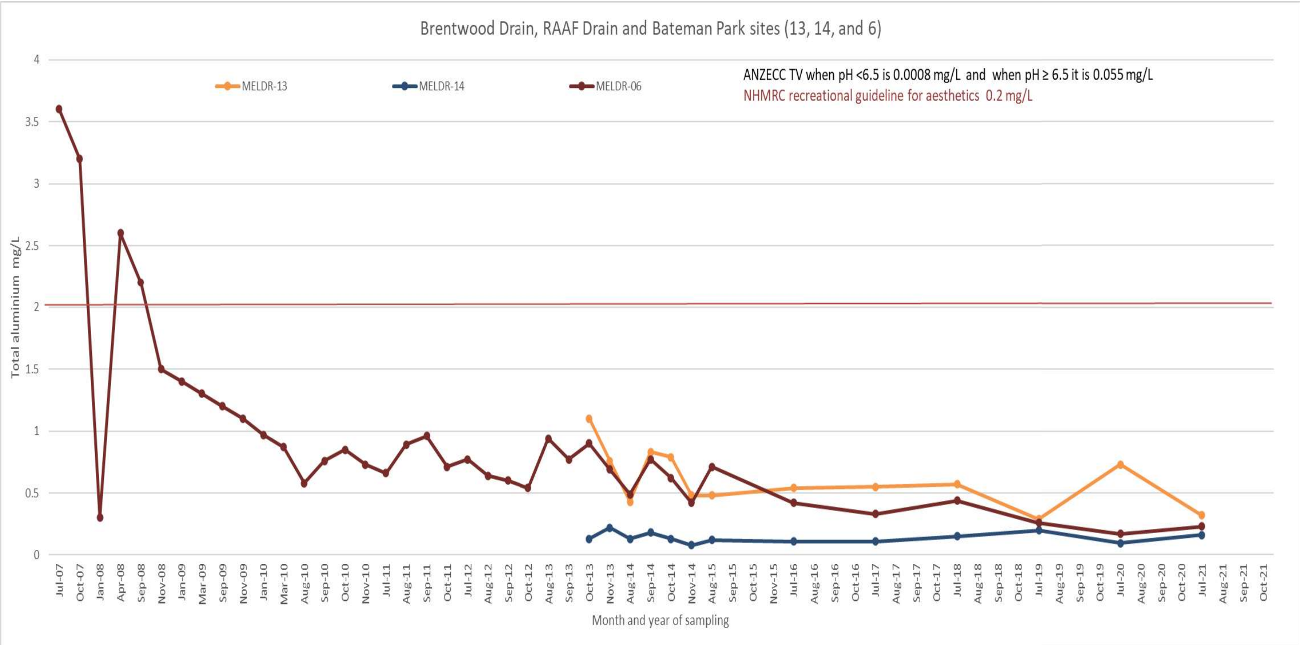


Figure 107. Historical data of total aluminium at Brentwood Drain sites.

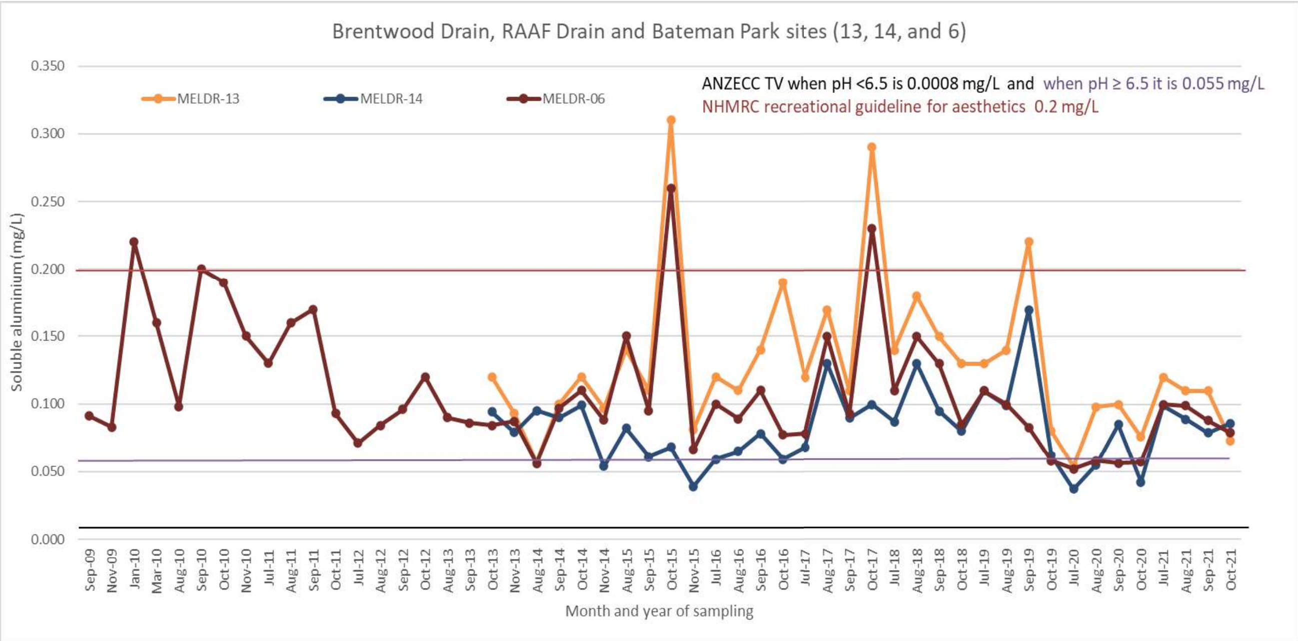


Figure 108. Historical data of soluble aluminium at Brentwood Drain sites.

Chromium

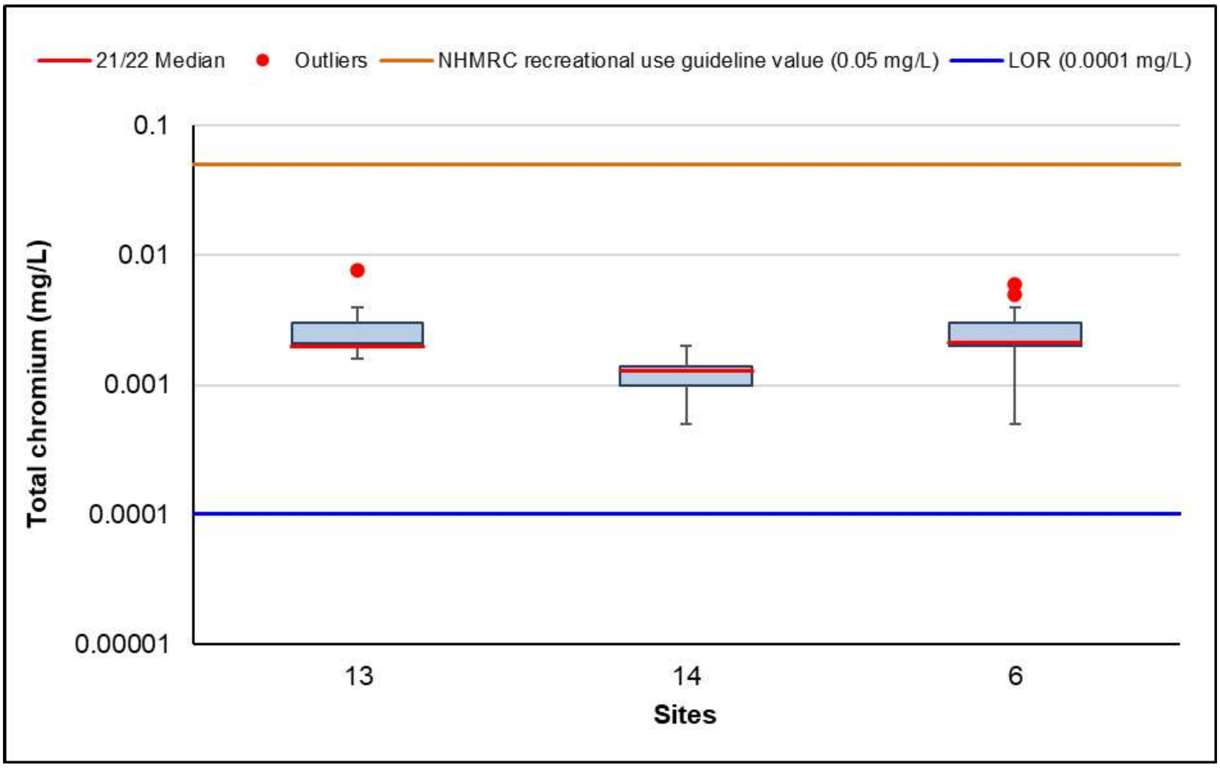


Figure 109. Box plot of total chromium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total and soluble chromium (where both include Cr3+ and Cr6+ chromium fractions) concentrations recorded at all Brentwood drain line sites were below ANZECC hardness adjusted trigger values for 95% protection of biota (unmodified trigger value for chromium: 0.0033 mg/L) in 2021 (Figures 109 and 110, Table D-20, and Table D-21 in Appendix D). The trigger value for Cr3+ was selected for discussion (and not Cr6+), as Cr3+ is the predominant species present in natural water due to a range of factors. As the trigger value for chromium is affected by water hardness, and this varied at different sites, the trigger values were modified to consider this in development of the Figures (see Table D-21 in Appendix D).

The highest total chromium concentration recorded within the Brentwood drain section was 0.0021 mg/L at site 6 (Bateman Park) in July; the highest soluble chromium concentration of 0.0015 mg/L was recorded at site 13 (Brentwood Drain) twice, in July and October and in site 6 (Bateman Park) in October. The lowest total chromium concentration of 0.0013 mg/L was recorded at sites 14 (RAAF Drain) in July. The lowest soluble chromium concentration of 0.0010 was recorded once in September at site 14. No sites recorded values equal to or below the LOR nor did total or soluble chromium concentration exceed the NHMRC recreational guideline value for health (0.05 mg/L).

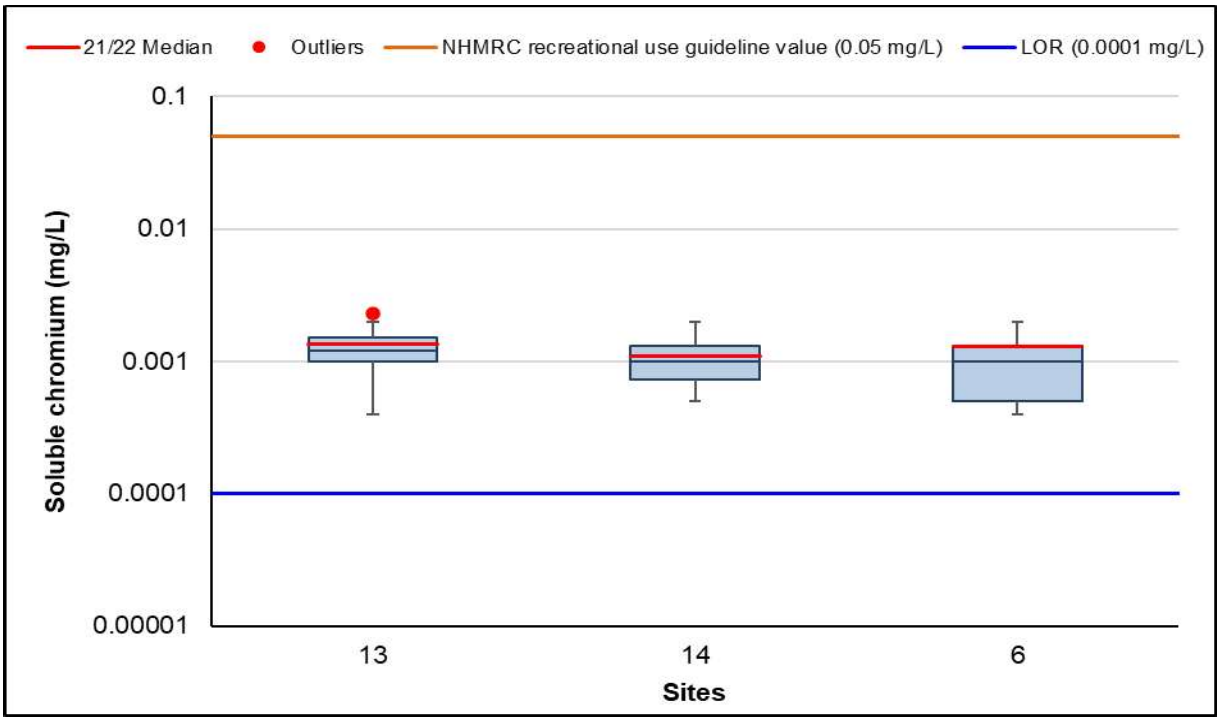


Figure 110. Box plot of soluble chromium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Time series

Soluble chromium concentration has always been below adjusted ANZECC trigger values (adjusted to include the impacts of water hardness) since sampling of this parameter began in 2009 (Figure 111). Total chromium concentrations have however exceeded the adjusted ANZECC trigger values in 2007 twice at site 6 (Bateman Park) in 2020 (Table G-51 in Appendix G).

One notable observation of soluble chromium levels at these sites was that they seem to have increased since 2017, particularly in site 13. But the reason for this is not understood. Is the presence of soluble chromium in these wetlands an indication of improved chromium cycling, increased release of chromium from sediments or an increase in chromium pollution?

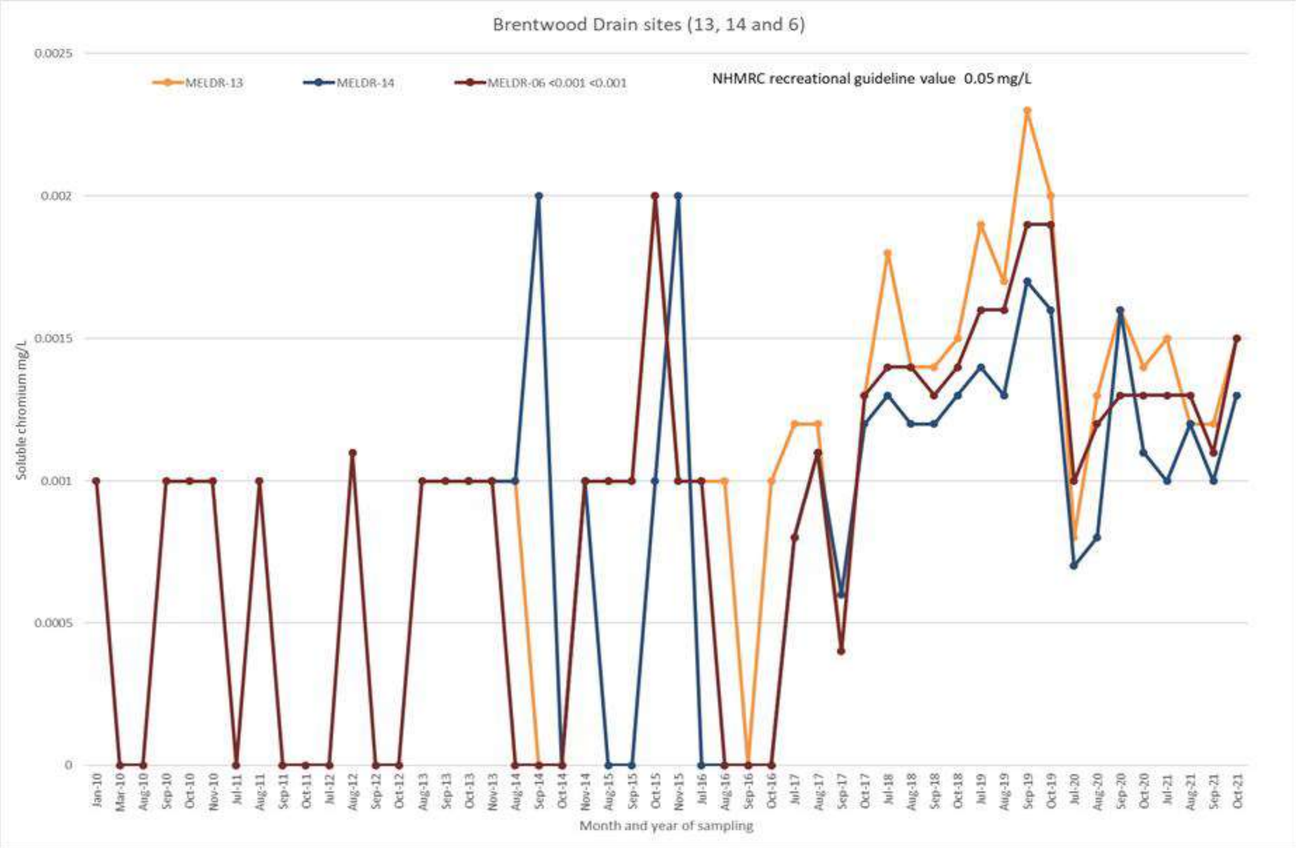


Figure 111. Historical data of soluble chromium at the Brentwood Drain sites.

Copper

Box whisker

The ANZECC guidelines unmodified trigger value for copper in water for a 95% level of protection is 0.0014 mg/L. The 95% protection trigger value for copper is however, affected by water hardness. Therefore, the modified trigger values shown on the graph vary, as they are dependent on the water hardness concentration recorded at each site. For the details and calculations see Table D-22 and Table D-23 in Appendix D.

Concentrations of total (Figure 112) and soluble (Figure 113) copper had higher than usual exceedances of the hardness adjusted ANZECC trigger values for 95% protection of biota in 2021, particularly in July. Total copper exceeded the hardness adjusted ANZECC trigger value at 2 out of 3 sites within the Brentwood drain section, with the highest value (0.0038 mg/L) recorded at site 13 (Brentwood Drain) and the lowest value (0.0017 mg/L) recorded at site 6 (Bateman Park) (Tables D-22 and D-23).

Soluble copper exceeded the hardness adjusted ANZECC trigger value at 2 out of 3 sites (sites 13, Brentwood Drain and 14, RAAF Drain) in the July and September monitoring events, and once at site 13 in August. The highest value recorded was 0.0068 mg/L at site 13 and 14 in September and July 2021 respectively, and the lowest value recorded was 0.0019 mg/L at site 6 (Bateman Park) in July (Table D-23 in Appendix D). No total or soluble copper concentration exceeded the NHMRC recreational guideline for aesthetic value (1 mg/L) or health value (2 mg/L) (Figures 112, 113 and Table D-23 in Appendix D).

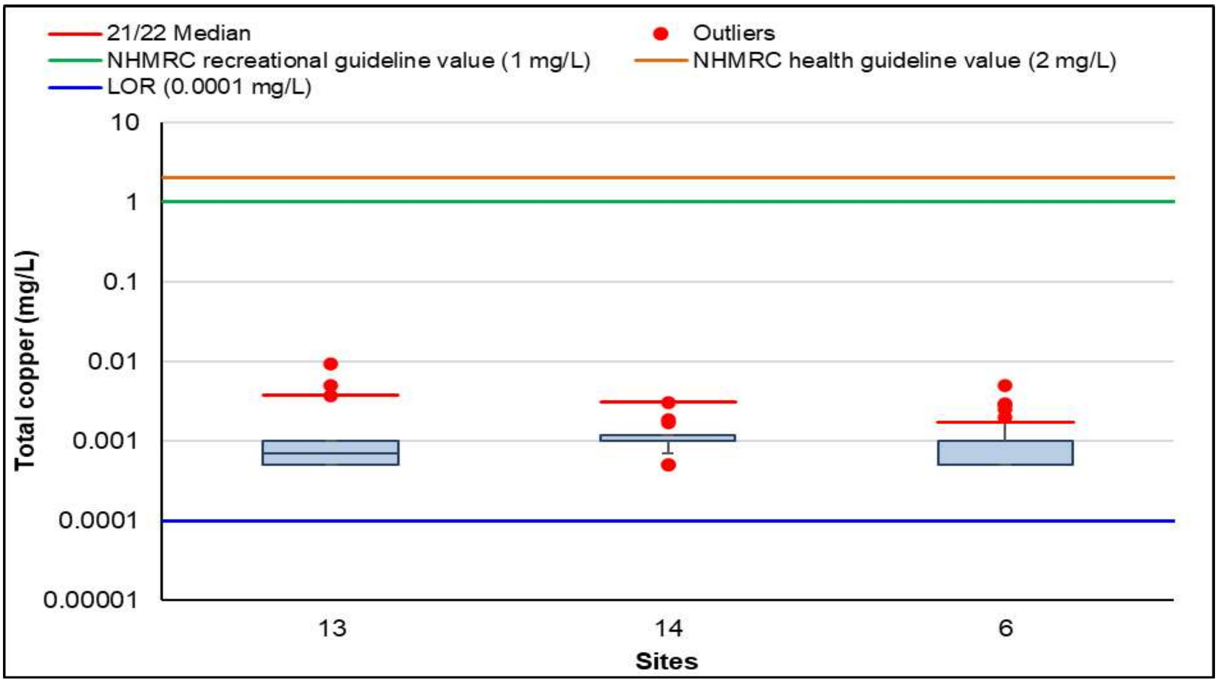


Figure 112. Box plot of total copper refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

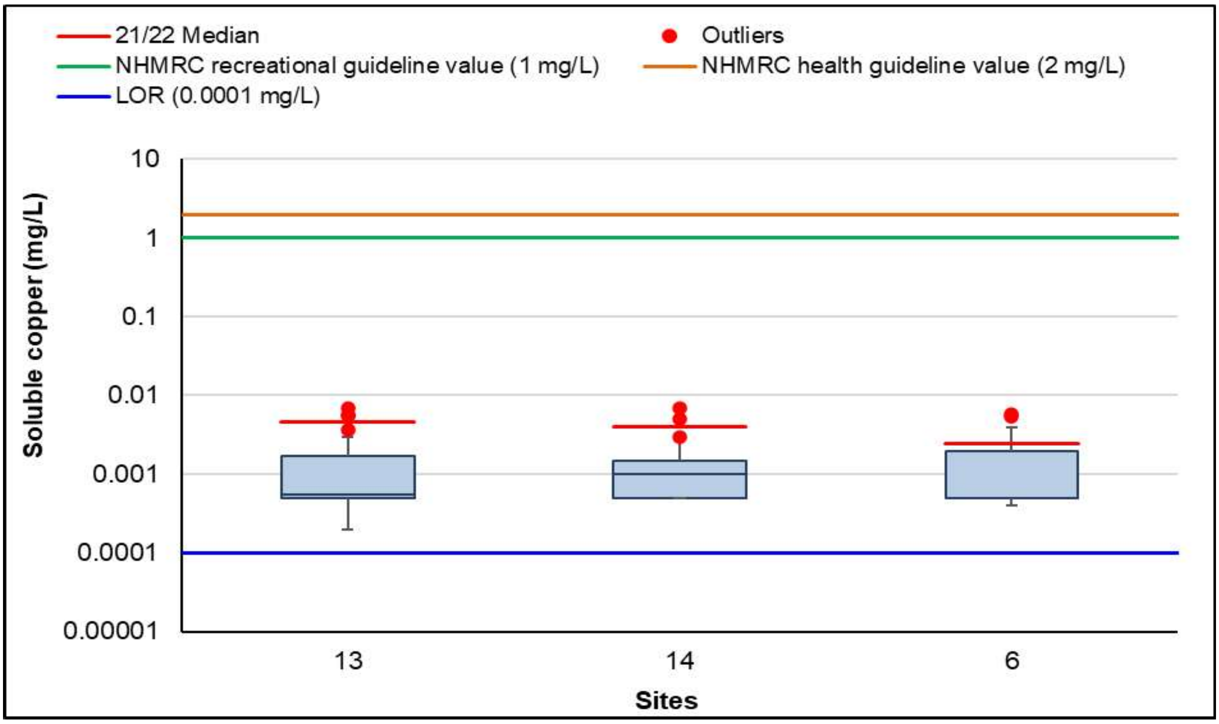


Figure 113. Box plot of soluble copper 2007-2020 historical median values, with a red line indicating the median value in 2021.

Time series

When the historical data of soluble copper is examined, it become apparent that soluble copper has been and may be increasing since 2017 at the three Brentwood Drain sites (Figure 114). While these levels still remain below guideline values, further study is needed to understand the dynamics of copper in these wetlands.

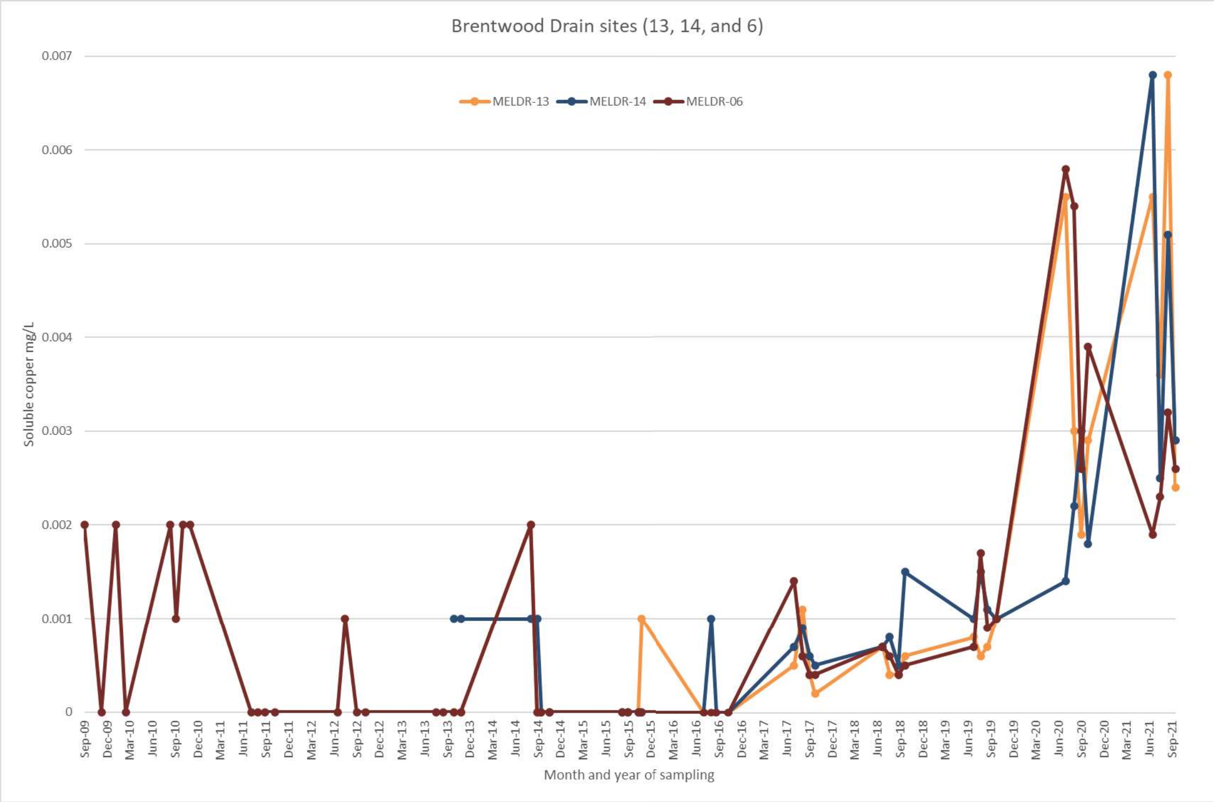


Figure 114. Historical data of soluble copper at the Brentwood Drain sites.

Iron

Box whisker

ANZECC & ARMCANZ advises that there continues to be insufficient data at this stage to determine a reliable trigger value for iron in freshwater ecosystems. The current Canadian guideline level of 0.3 mg/L could be used if required and seen to be an issue. Due to this, it is difficult to gauge the severity of any potential impact arising from the concentrations recorded in the water collected from Melville Bull Creek catchment sites. Total iron concentrations recorded in 2021 are within the range of those collected in the preceding 14 years of monitoring, although concentrations have varied somewhat between years (Figures 115 and 116, Table H-56 in Appendix H). Out of the three sites, site 13 has generally recorded the highest total iron concentrations and site 14 has always recorded the lowest. Concentrations seen in the 2021 sampling events were highest at site 13 at 1.7mg/L, second highest was site 6 with a concentration of 1.1mg/L, followed by site 14 at 0.37mg/L. Site 6 had the highest median of 4.0mg/L followed by site 13 at 3.2mg/L and the lowest was site 14 a 0.6mg/L.

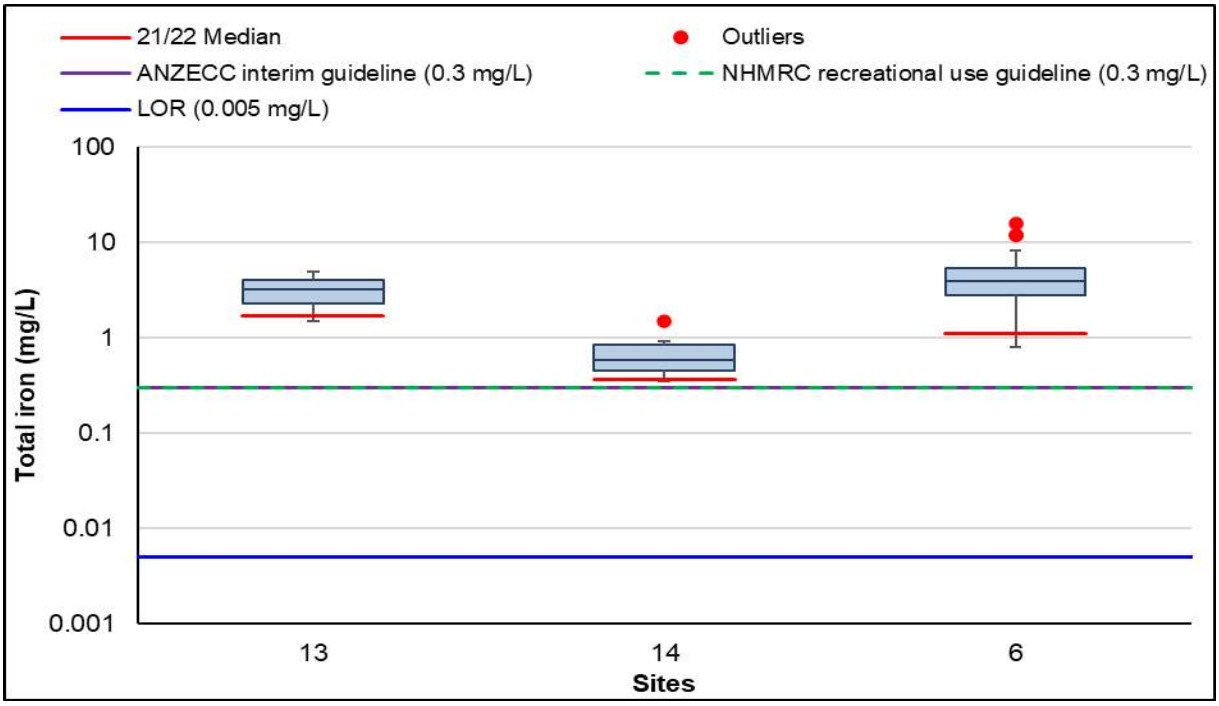


Figure 115. Box plots of total iron refer to the 2007-2020 historical median values with a red line indicating the median value in 2021.

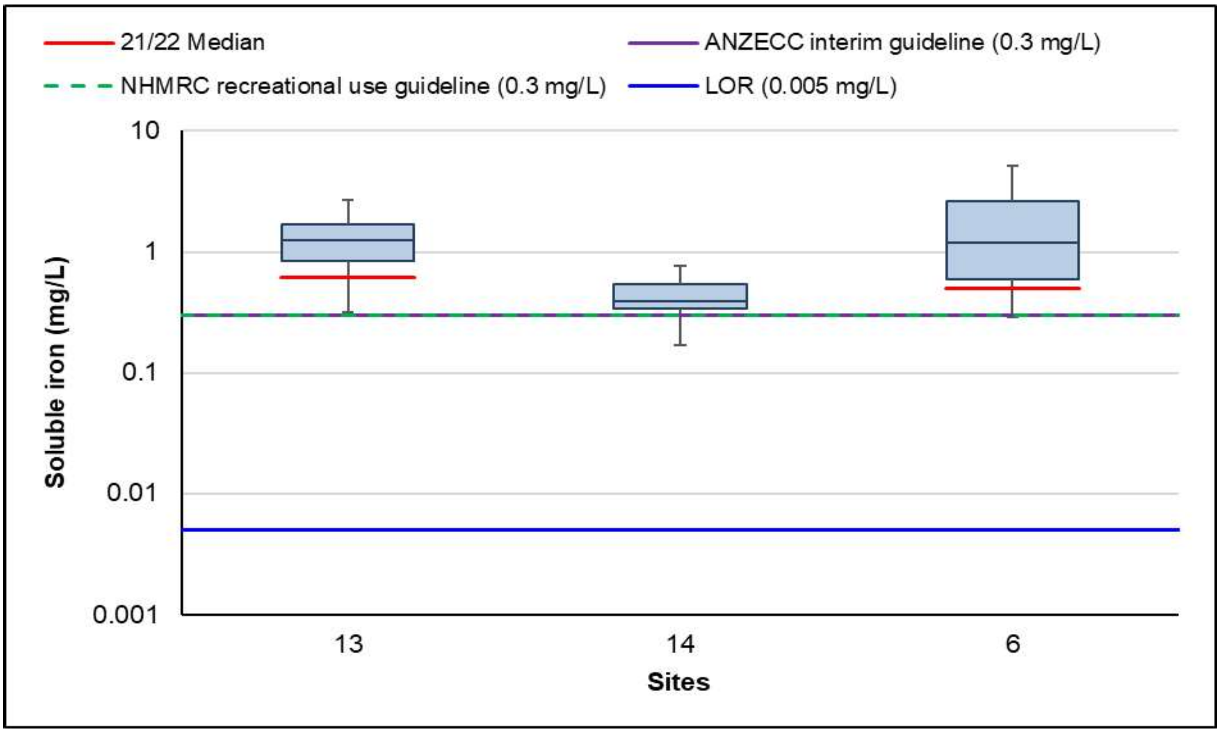


Figure 116. Box plots of soluble iron refer to the 2007-2020 historical median values with the red line indicating the median value in 2021.

The 2021 sampling event showed that soluble iron concentrations have exceeded the interim trigger value at all sites except site 14 in July. Total and soluble iron concentrations are generally highest at site 13. In the Brentwood drain, total and soluble iron concentrations coming from the Brentwood drain site before the living stream (site 13) are generally greater than those coming from site 14 (the Mandala Crescent branch/RAAF drain), with total and soluble iron concentrations at site 6 (Bateman Park) fluctuating between sites 13 and 14 concentration.

Time series

Throughout the 14-year monitoring period, total iron concentrations have almost always exceeded the interim trigger value at all Melville Bull Creek catchment sites 13, 14, and 6 (Figure 117). The decrease in total iron over time at Brentwood Drain site 6 in particular, was opposite to the observed increasing concentration of other metals in solution. This raises the question as to the role of iron in the dynamics of metals in solution. What role does rehabilitation play in the dynamics of iron and other metals in these wetlands? And what are the sources of these metals?

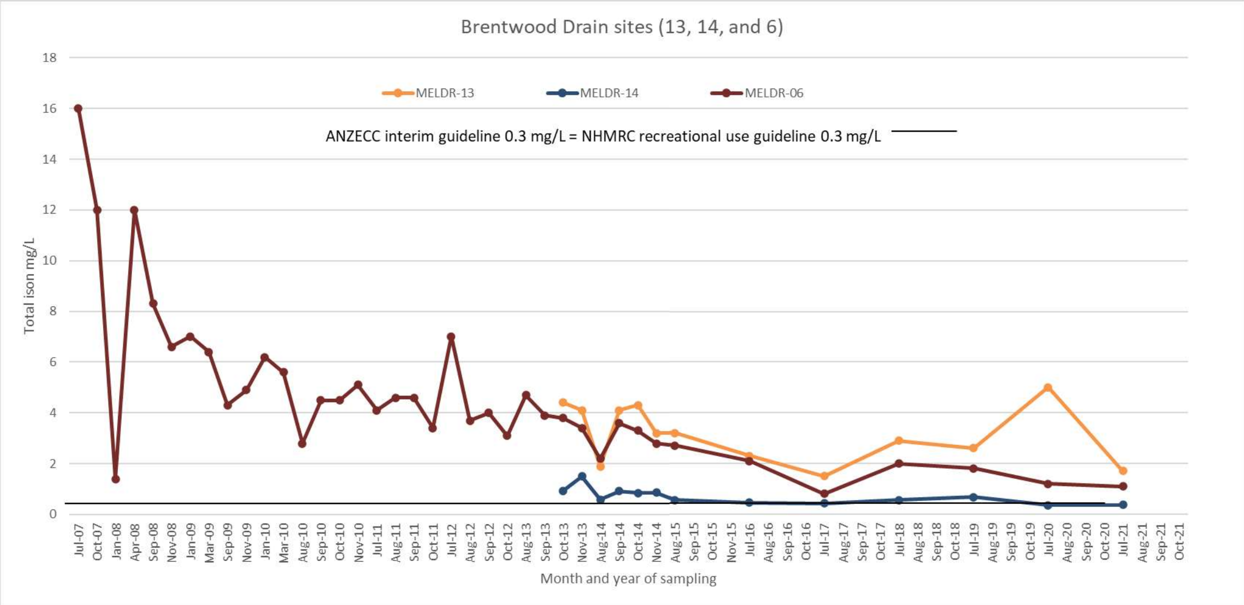


Figure 117. Historical data of total iron at Brentwood Drain sites.

Lead

Box whisker

None of the samples collected from the Brentwood Drain section of the Melville Bull Creek catchment sites in 2021 recorded total lead concentrations above adjusted ANZECC trigger values for 95% protection of biota (unadjusted trigger value: 0.0034 mg/L) (Figure 118, Tables D-26, D-27 in Appendix D). All samples collected from the Brentwood drain sites in 2021 recorded soluble lead concentrations below the adjusted ANZECC trigger values for 95% protection of biota (unadjusted trigger value: 0.0034 mg/L). The highest total lead concentration (0.0009 mg/L) was recorded at site 6 in July and the highest soluble lead concentration (0.0004 mg/L) was recorded at site 14 in July and August. The lowest total lead concentration of 0.0007mg/L was recorded at site 13 July. All sites recorded soluble lead concentrations equal or less than the LOR (0.0001 mg/L), site 13 (Brentwood drain; July, August, and September), site 14 (RAAF drain; October) and site 6 in October. All recorded total and soluble lead concentrations were below the NHMRC recreational guideline for health value (0.01mg/L). As a result of these low values, no box whisker plot was made of soluble lead for these sites. Total and soluble lead concentrations recorded in the Brentwood drain sites in 2021 are similar to that recorded since 2017, but not in site 6 prior to this time (Table G-53 in Appendix G).

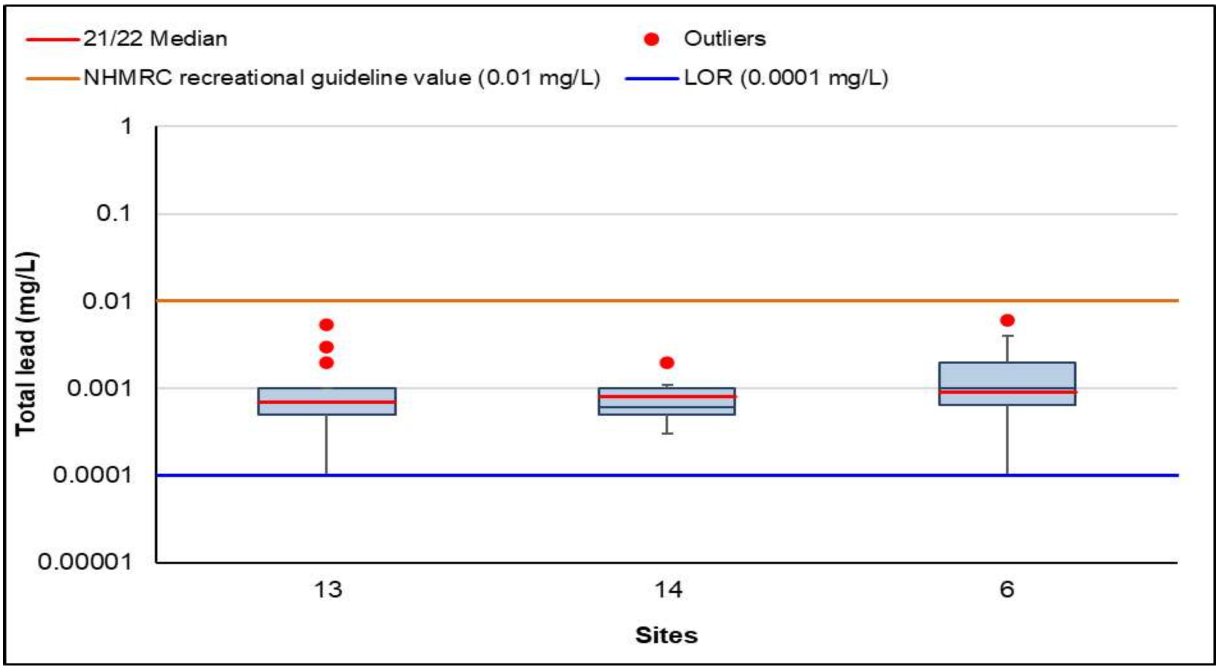


Figure 118. Box plot of total lead 2007-2020 historical median values, with a red line indicating the median value in 2021.

Time series

Exploring the historical data of total and soluble lead revealed that soluble lead remained similar through the years of sampling (no plot for soluble lead as values were very low), but total lead differed (Figure 119). Total lead decreased with time in site 6 and perhaps also in site 14 but showed variability in site 13 with a high value recorded in July 2020. The cause of these results are yet to be examined.

Concentrations of total lead exceeding the hardness modified trigger values have only been recorded 3 times throughout the 14-year sampling period other than the year sampling began in 2008, 2013, 2014 and 2020.

Concentrations of soluble lead exceeding the hardness modified trigger values have been recorded once at site 14 in 2013 and 2014 throughout the 14-year sampling period with the highest total and soluble lead concentrations generally recorded at site 13.

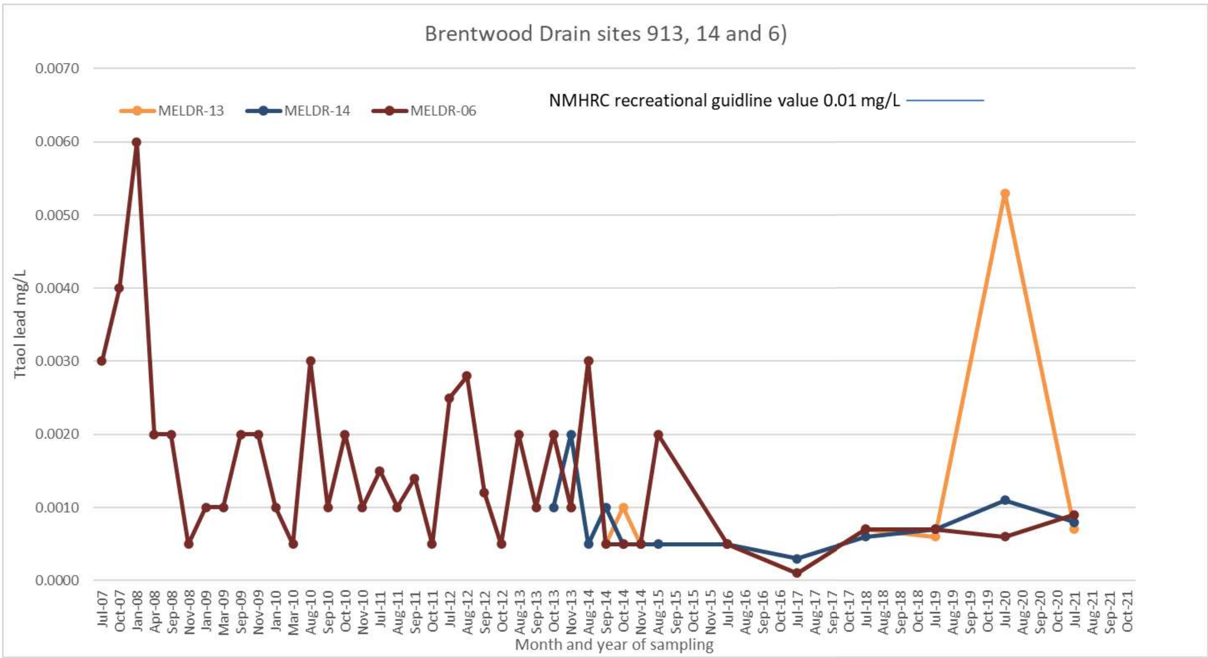


Figure 119. Historical data of total lead at Brentwood Drain sites.

Mercury

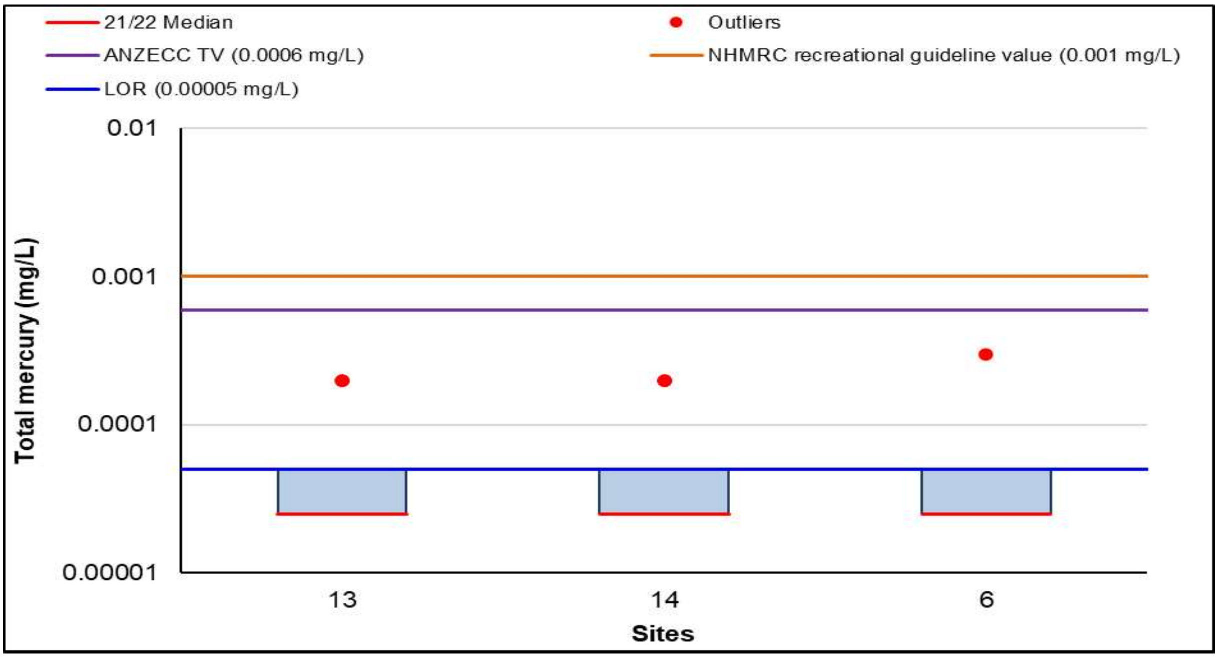


Figure 120. Box plot of total mercury 2007-2020 historical median values, with a red line indicating the median value in 2021.

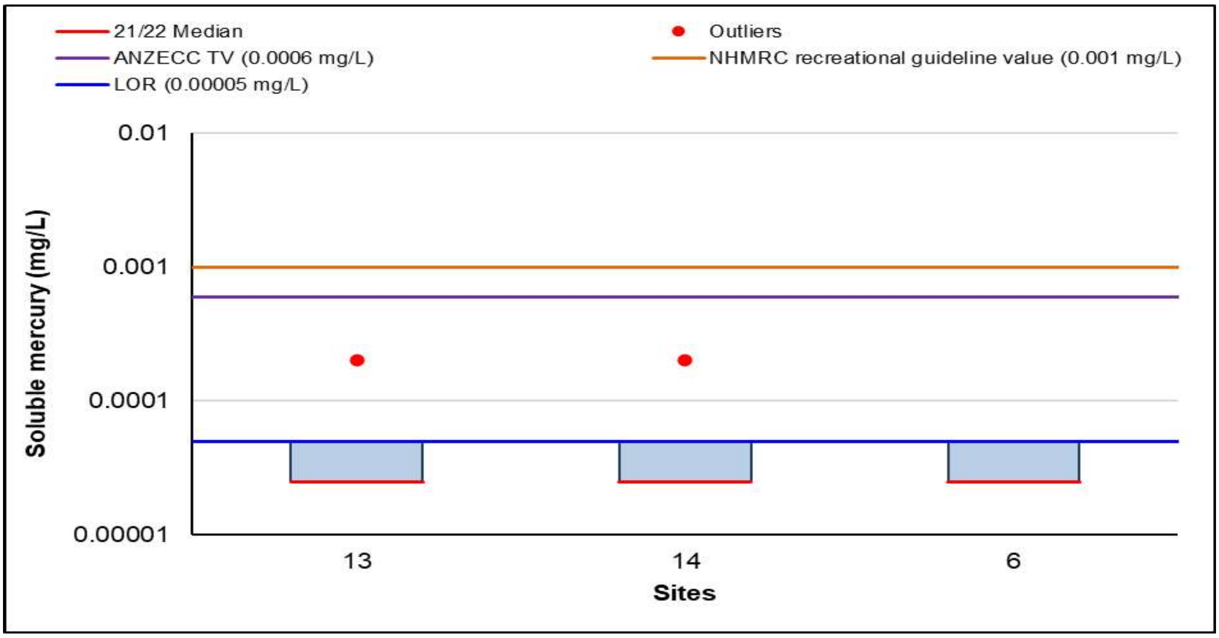


Figure 121. Box plot of soluble mercury 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

There were no detections of total (Figure 120) and soluble (Figure 121) mercury above the LOR of <0.00005 mg/L during the 2021 sampling events. Previous years has similar results with a concentration of <0.0001 mg/L. the highest concentration of mercury seen in 2017 in sites 13 and 14 with a concentration of 0.0002 mg/L exceeding the NHMRC recreational guideline value of 0.001 mg/L. The medians seen in the total Mercury for sites 13 and 14 were 0.0002 mg/L and 0.0003 mg/L in site 1. Medians for soluble mercury 0.0002 mg/L for sites 13 and 14 and site 6 had no determined median.

Time series

No historical plots of total or soluble mercury are displayed as the levels of mercury in the water were either very low or below LOR values of 0.0001 mg/L prior to 2018 and below 0.0005 mg/L since then at most sampling occasions. Any trends with time are therefore difficult to comment on or verify.

Zinc

Box whisker

Total zinc sampled in July 2021 did not exceed the adjusted ANZECC TV for 95% protection or the NHMRC recreational value of 3 mg/L (Figure 122 and Table D-30 in Appendix D). Soluble zinc concentrations however, exceeded the above ANZECC TV on one occasion; in July 2021 (Figure 123 and Table D-31 in Appendix D).

Time series

There are indications that total zinc is trending upwards in all three sites. A spike in total zinc occurred in all three sites in July 2014 and again in July at site 6 in 2020. The 2014 event may be linked to the strong front bringing rainfall across Perth in July 2014, but such conditions did not recur in July 2020, suggesting that the high levels of zinc at site 6 could be a site-specific event.

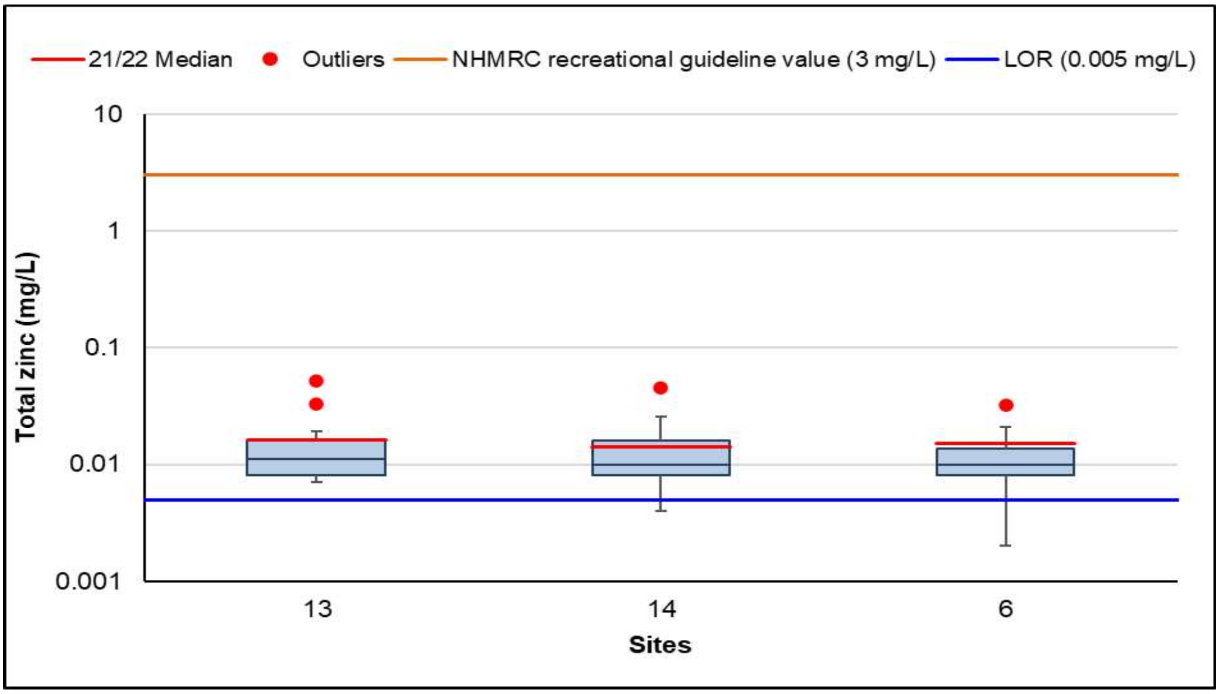


Figure 122. Box plot of total zinc refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

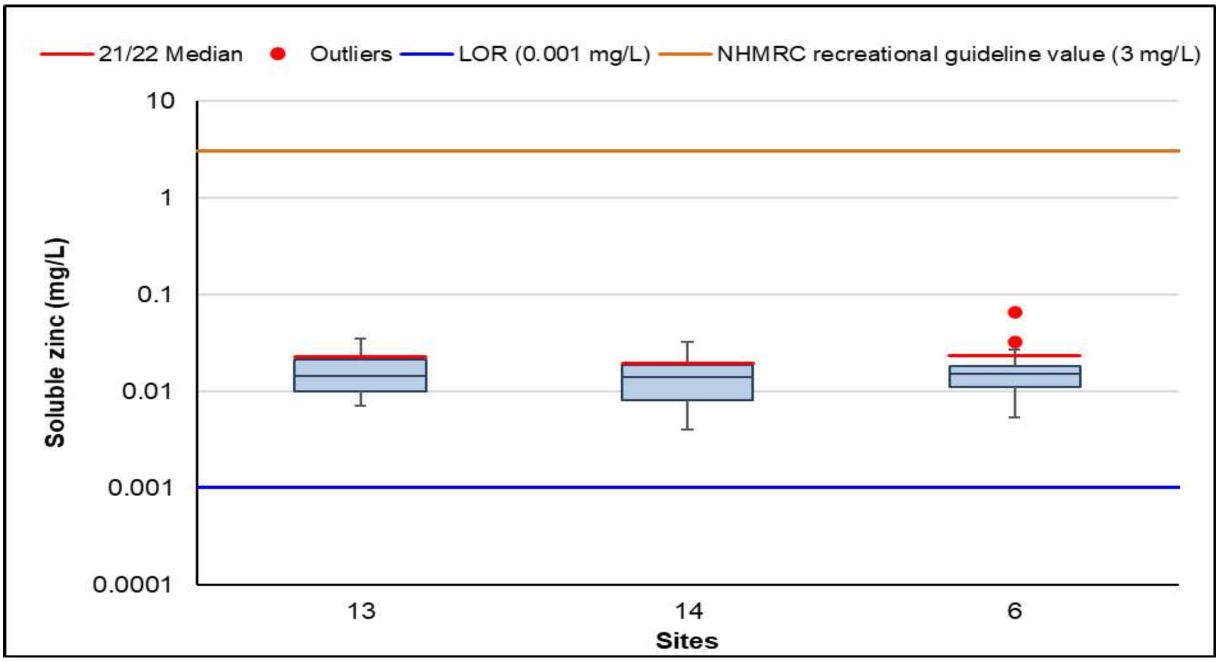


Figure 123. Box plot of soluble zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

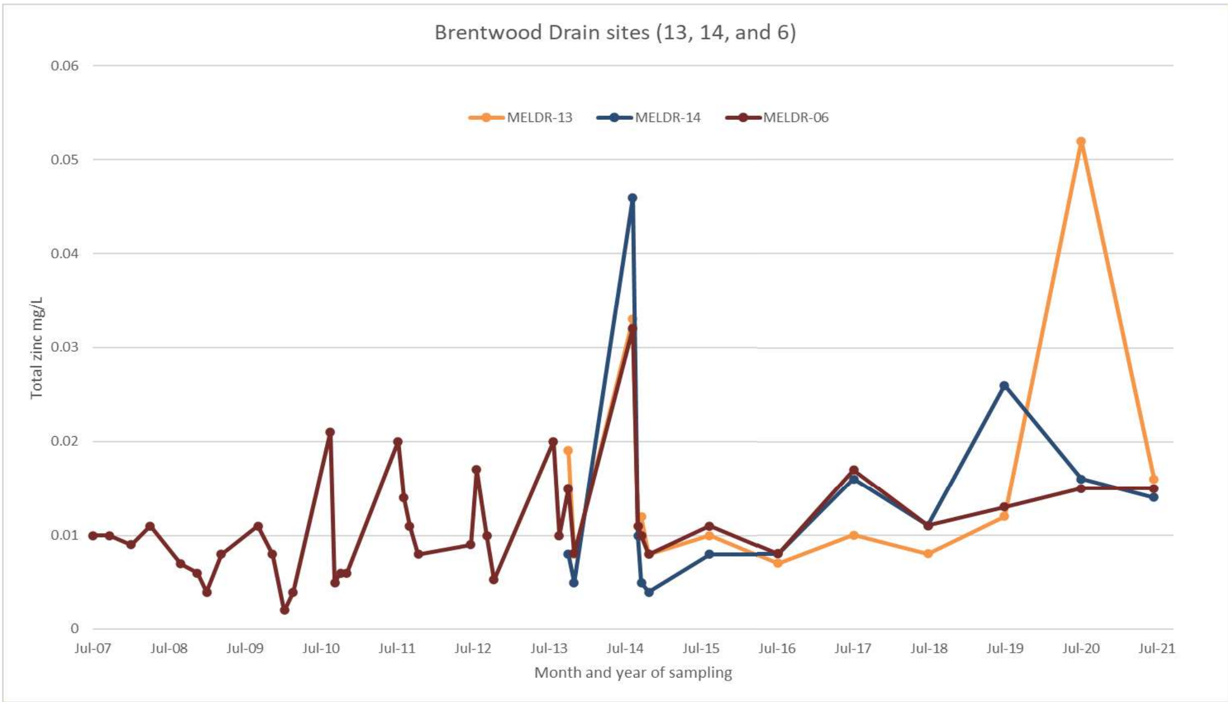


Figure 124. Historical data of total zinc at Brentwood Drain sites.

Arsenic

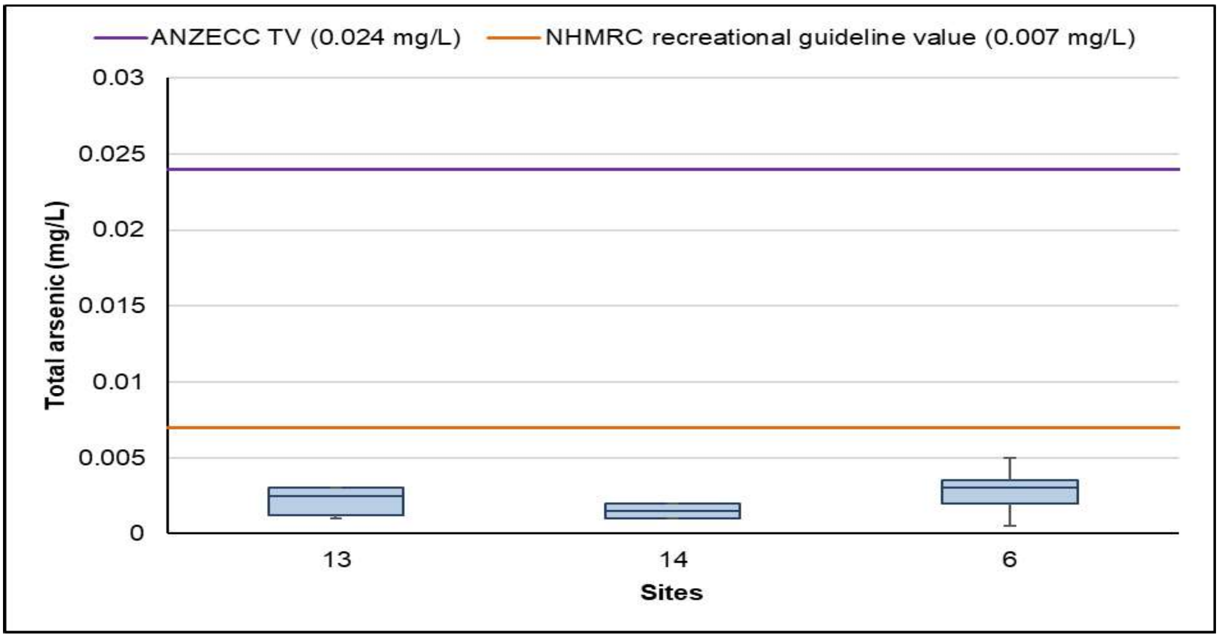


Figure 125. Median total arsenic (mg/L) recorded in 2021 at sites in the Brentwood drainage line. Black line in the boxes refer to the 2007-2020 median values.

Box whisker and Time series

Water samples from site 6 were analysed for arsenic between 2007 and 2014 (n = 31) and the other two sites during 2013 and 2014 (n = 6 each). Both total and soluble arsenic of these samples were below ANZECC TV for lowland rivers as well as NHMRC recreational guideline values. Values of total arsenic at site 6 varied between 0.0005 to 0.005 mg/L and at the other two sites between 0.001 and 0.003 mg/L.

While there is a possible trend that arsenic was higher as well as decreasing with time at site 6 in comparison with the other two sites, the values are very variable and there is insufficient data to comment further (for site 6, mean = 0.00273 mg/L, SD = 0.00111, n = 31). Because of the lack of more recent results as well as scarcity of data, no box whisker plots for soluble arsenic or time series plot for total and soluble arsenic were therefore included in this report.

Metals in sediment

Metals in sediments will first be displayed in box whisker plots to compare results from 2021 with the average values since sampling of sediments began in 2013 (sections 1.4.1 to 1.4.10). And second with by an overall summary plots of all metals per site (section 1.4.11) to display trends and site differences.

Aluminium

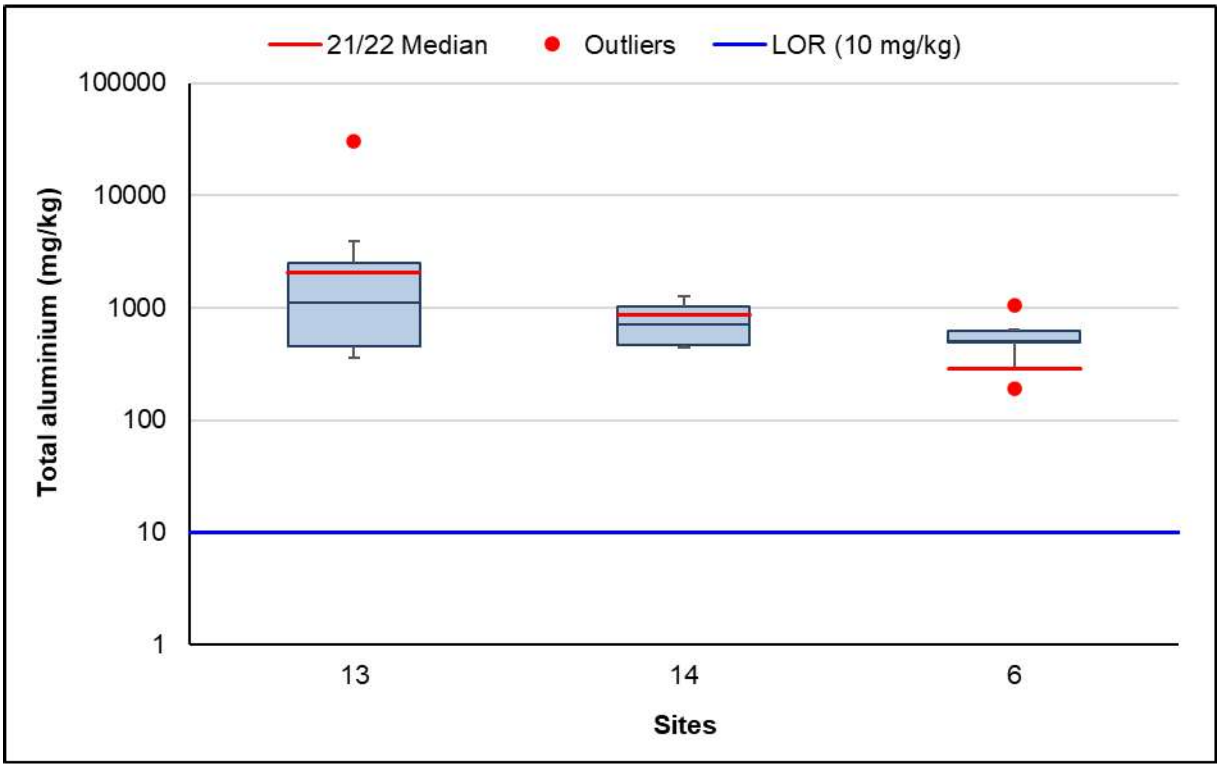


Figure 126. Box plot of sediment total aluminium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Sediment total aluminium concentrations in 2021 varied across the catchment, with the highest concentration of 2080 mg/kg recorded at site 13 and the lowest concentration of 285mg/kg recorded at site 6 (Figure 126 and Table D-36 in Appendix D).

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Total aluminium concentrations have varied greatly in sediment of Melville Bull Creek catchment sites with the data available in Table H-55 in Appendix H. It is notable that the very high result (30,000 mg/kg) recorded at site 13 (Brentwood Drain) in 2016 was significantly higher than all recorded concentrations elsewhere, including those recorded in other years at site 13 (ranging from 360 mg/kg in 2013 to 3880 mg/kg in 2018). Additionally, site 13 tends to show the highest concentrations of aluminium within the Brentwood Drain section sampled through all years sampled whereas that at sites 14 and 6 has remained lower and similar to each other (ranging from 438 to 1260 mg/L and 192 to 1050 mg/L respectively). As aluminium is retained in organic matter and common in Bassendean sands, high levels of these in sediments can indicate a significant organic matter load in the sediments.

Arsenic

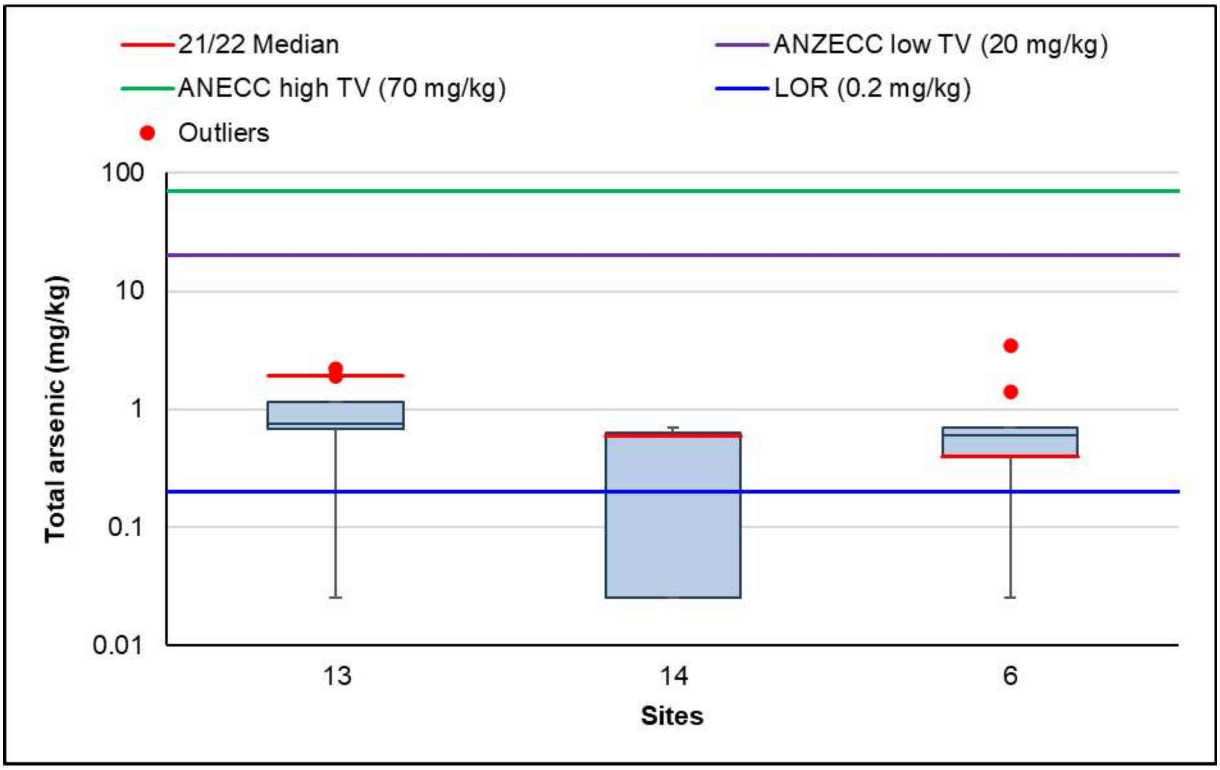


Figure 127. Box plot of sediment total arsenic 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total arsenic concentrations in sediments in 2021 were all below the ANZECC low (20 mg/kg) and high (70 mg/kg) trigger values (Figure 127 and Table D-37 in Appendix D). The highest concentration of 1.9 mg/kg was recorded at site 13 in October 2021, followed by 0.6 mg/kg at site 14 and site 6 the lowest with a concentration of 0.4.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Total arsenic concentrations in sediment at Melville Bull Creek catchment sites have generally been low throughout the ten years of monitoring (Table H-55 in Appendix H) which makes it difficult to assess any longer terms trends.

Chromium

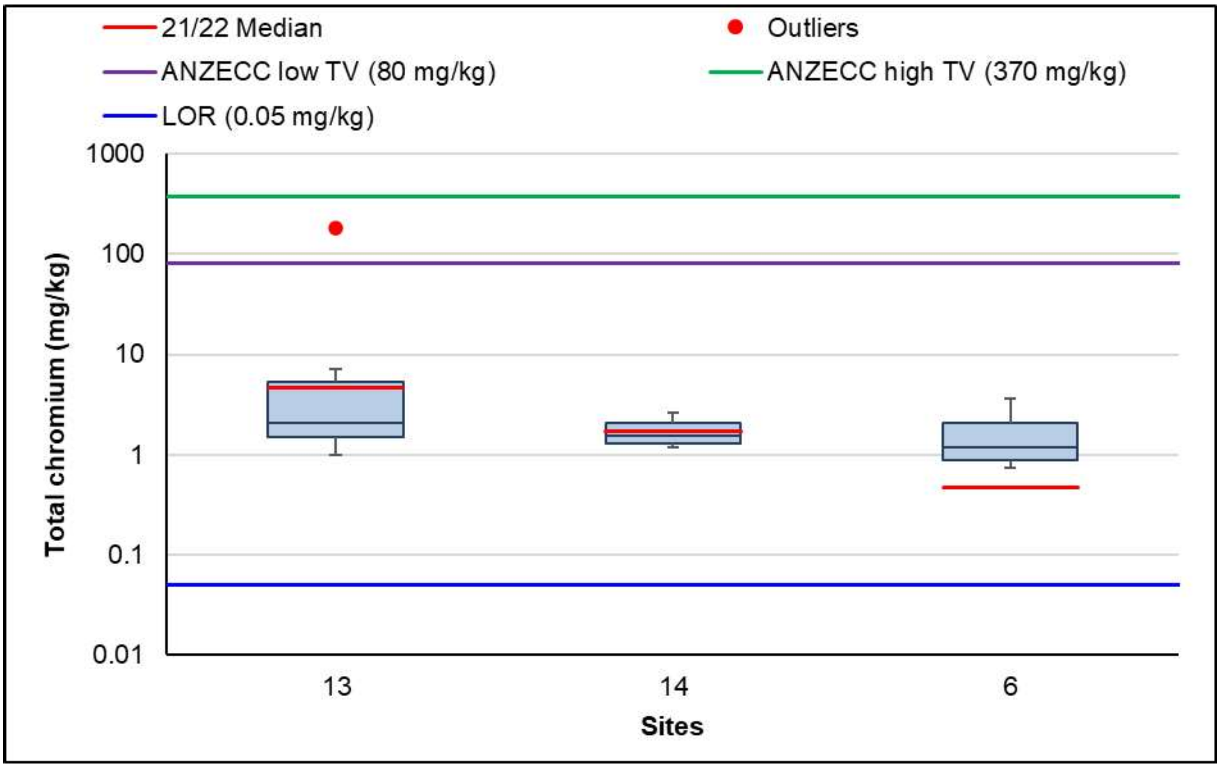


Figure 128. Box plot of sediment total chromium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total chromium (including Cr3+ and Cr6+) concentrations in sediment at all Brentwood drain sites within the Melville Bull Creek catchment were below ANZECC low (80 mg/kg) and high (370 mg/kg) trigger values in 2021 (Figure 128 and Table D-38 in Appendix D). The highest concentration in the Brentwood drain section was 4.6mg/kg was recorded at site 13 and the lowest concentration of 0.75mg/kg was recorded at site 6. Site 14 consecutively records the lowest concentrations within Brentwood drain.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Total chromium concentrations in sediment at Melville Bull Creek catchment sites have been generally low throughout the ten years of monitoring (Table H-55 in Appendix H). In spite of this, there is an indication that the levels of chromium at site 6 has remained lower than that of the other sites and that in site 13 the highest. A concentration of 180 mg/kg recorded at site 13 within the Brentwood drain catchment in 2016 is by far the highest concentration recorded over the monitoring period and has been the only sample to exceed the low trigger value.

Copper

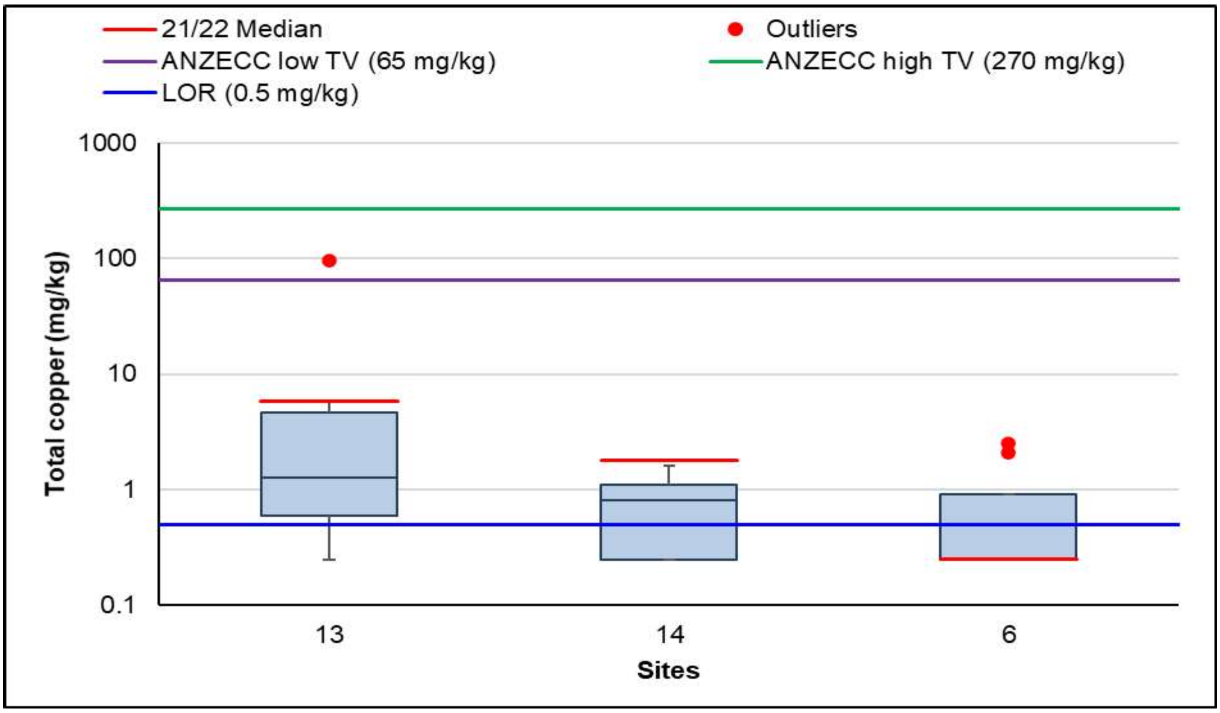


Figure 129. Box plot of sediment total copper 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total copper concentrations in sediment collected from all the samples collected from Brentwood drain sites in 2021 were below ANZECC low (65 mg/kg) and high (270 mg/kg) trigger values (Figure 129 and Table D-39 in Appendix D). The highest concentration was 5.8 mg/kg recorded at site 13. Site 6 has consecutively recorded the lowest concentrations within the Brentwood drain section.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Total copper concentrations in sediment at Brentwood drain sites have been generally low and very variable in the previous ten years of monitoring (Table H-55 in Appendix H). In spite of this, the copper in sediments at site 6 and 14 have tended to be lowest and that of site 13 highest. Only one sample, site 13 in 2011 has recorded exceedances of the low trigger value in the monitoring period. Concentrations at site 13 were significantly higher than other concentrations recorded at the other sites over the years.

Iron

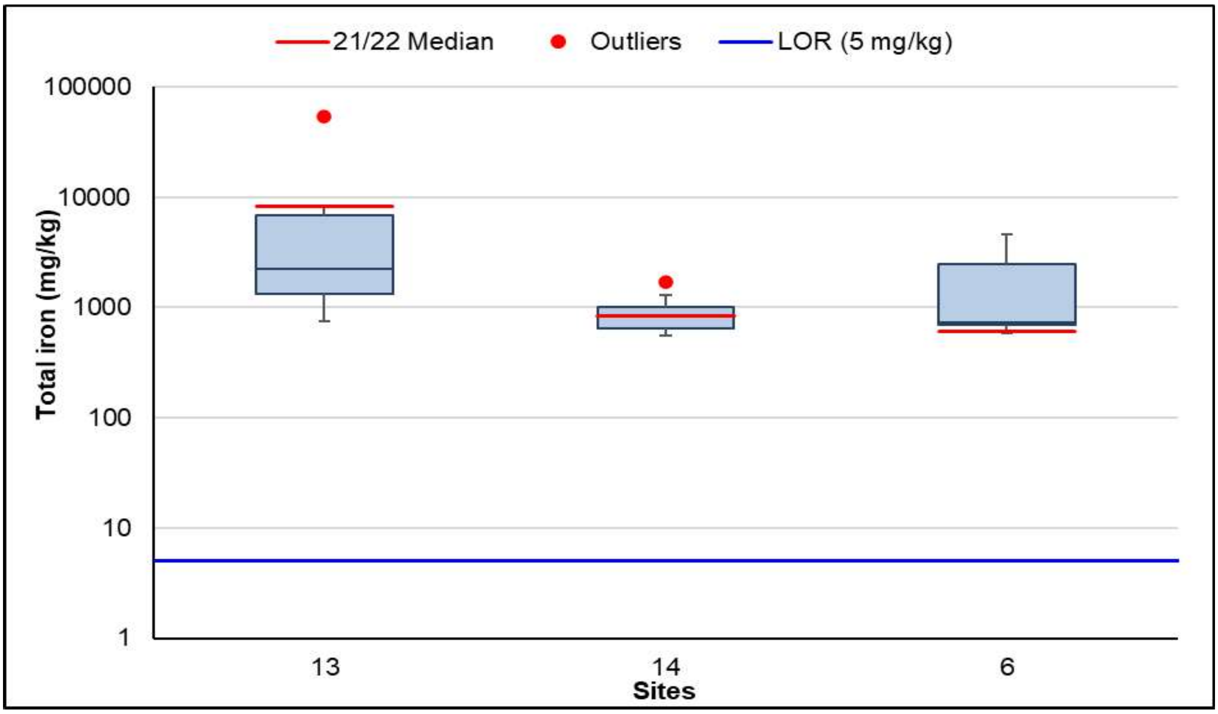


Figure 130. Box plot of sediment total iron 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

No guideline currently exists for iron concentrations in sediment; therefore, it is difficult to gauge the severity of any potential impact arising from the concentrations recorded in the sediment collected from Melville Bull Creek catchment sites. In 2021 total iron concentrations in sediment were varied (Figure 130 and Table D-40 in Appendix D). The highest concentration seen in the Brentwood drain sites was 8,200 mg/kg recorded at site 13 and the lowest concentration of 610 mg/kg was recorded at site 6.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Since sampling began, the iron levels at site 6 have tended to be lowest and that at site 13 the highest.

Lead

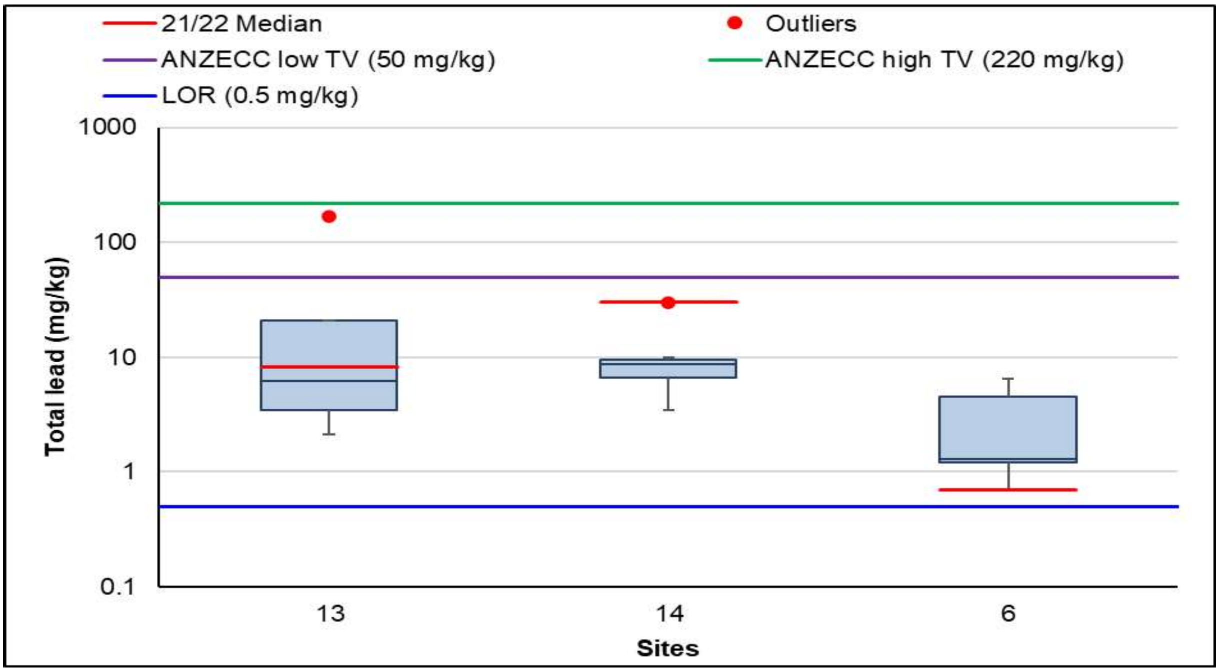


Figure 131. Box plots of sediment total lead 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

All three sites within the Brentwood drain section recorded lead concentrations in sediments below the ANZECC low trigger value (50 mg/kg) in the sampling event of 2021. Site 14 recorded the highest concentration of 30 mg/kg, the second highest concentration was seen in site 13 at 8.2mg/L (Figure 131 and Table D-41 in Appendix D). No samples collected recorded an exceedance of the high trigger value (220 mg/kg). The lowest concentration of 0.7 mg/kg was recorded at site 6.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Total lead concentrations in sediment collected in 2021 are similar to those collected in the preceding nine years of monitoring (Table H-56 in Appendix H). Concentrations exceeding the low trigger value have been recorded at site 13 in Brentwood drain on at least one sampling occasion throughout the nine-year monitoring period. All other concentrations across the Brentwood drain sites have been within acceptable limits.

Mercury

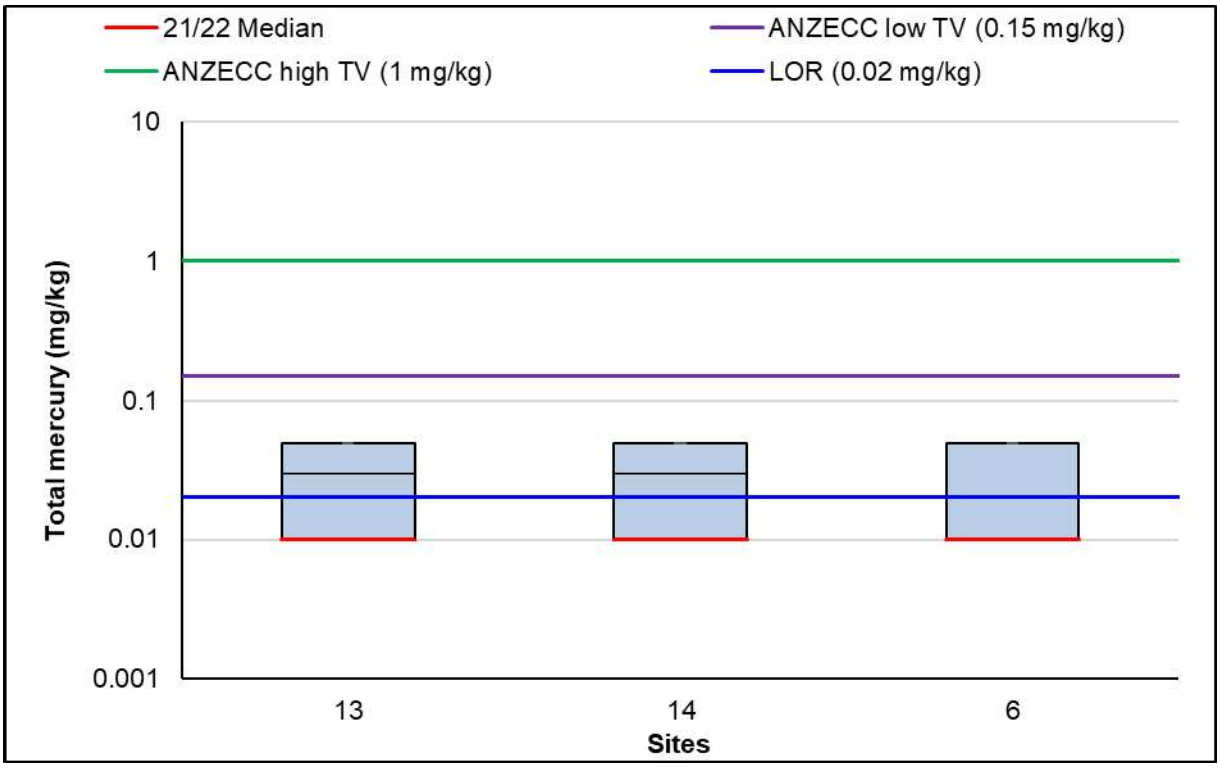


Figure 132. Box plots of sediment total mercury 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total mercury concentrations in sediment were all below the ANZECC low (0.15 mg/kg) and high (1.0 mg/kg) trigger values at all Brentwood drain sites in 2021 (Figure 132 and Table D-42 in Appendix D). There were no concentrations seen across the sampling events for site 6, 13 and 14 that were greater than the LOR (0.02 mg/kg).

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Concentrations of total mercury in sediment of the Melville Bull Creek catchment throughout the nine years of monitoring have generally been low and below the LORs (Table H-56 in Appendix H). During the 2013 to 2016 sampling seasons mercury at all sites was recorded at 0.050 mg/Kg while in 2017 through to 2021, it was below LOR of 0.02 mg/Kg. With such low values, it is difficult to differentiate the sites.

Nickel

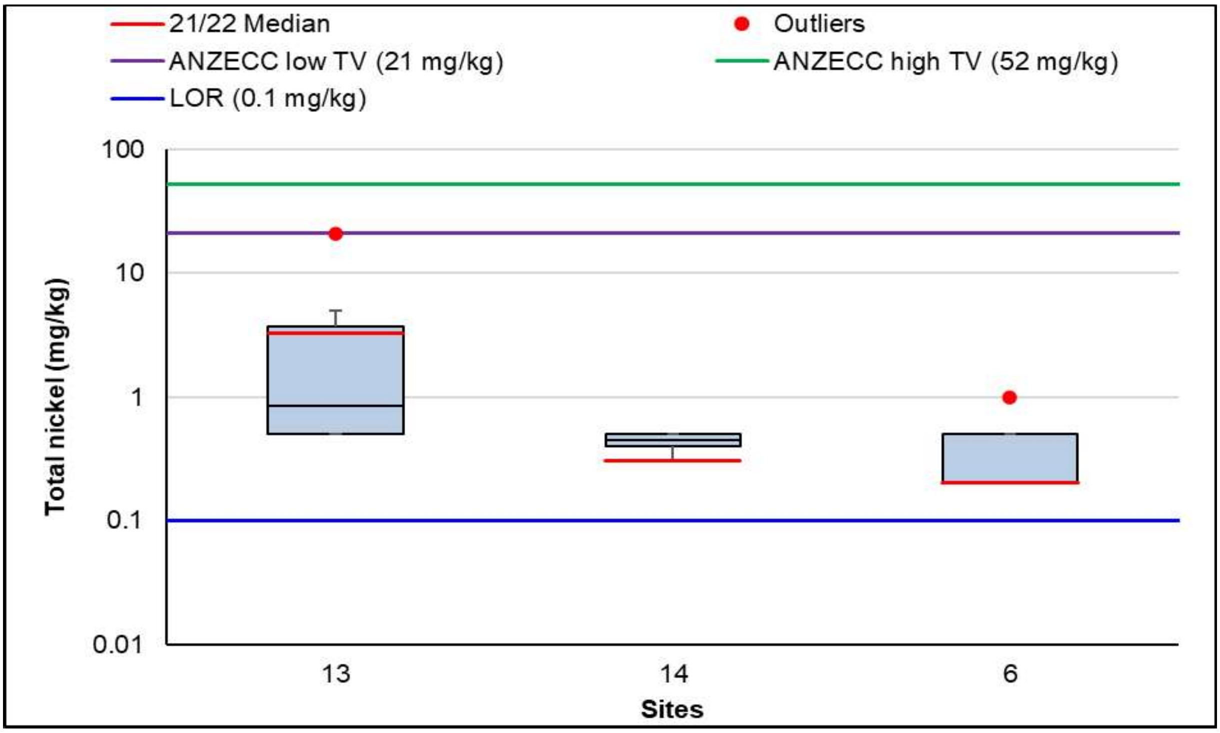


Figure 133. Box plot of sediment total nickel 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total nickel concentrations in sediment were all below the ANZECC low (21 mg/kg) and high (52 mg/kg) trigger values at Brentwood drain sites in 2021 (Figure 133 and Table D-43 in Appendix D). The highest total nickel concentration of 3.3 mg/kg was recorded at site 13, site 14 had a nickel concentration of 0.3mg/L and site 6 recorded the lowest concentration 0.2 mg/kg.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Concentrations of total nickel in sediment of the Melville Bull Creek catchment over the past eight years of monitoring have generally been low (Table H-56 in Appendix H). The only exceedances of the ANZECC low trigger value recorded during this time have been at site 13 (Brentwood drain) in 2011. Since sampling began, the nickel in sediments at site 6 has tended to be lowest and that at site 13 the highest and most variable. It is possible that the nickel in site 14 is decreasing with time, but this needs further examination.

Selenium

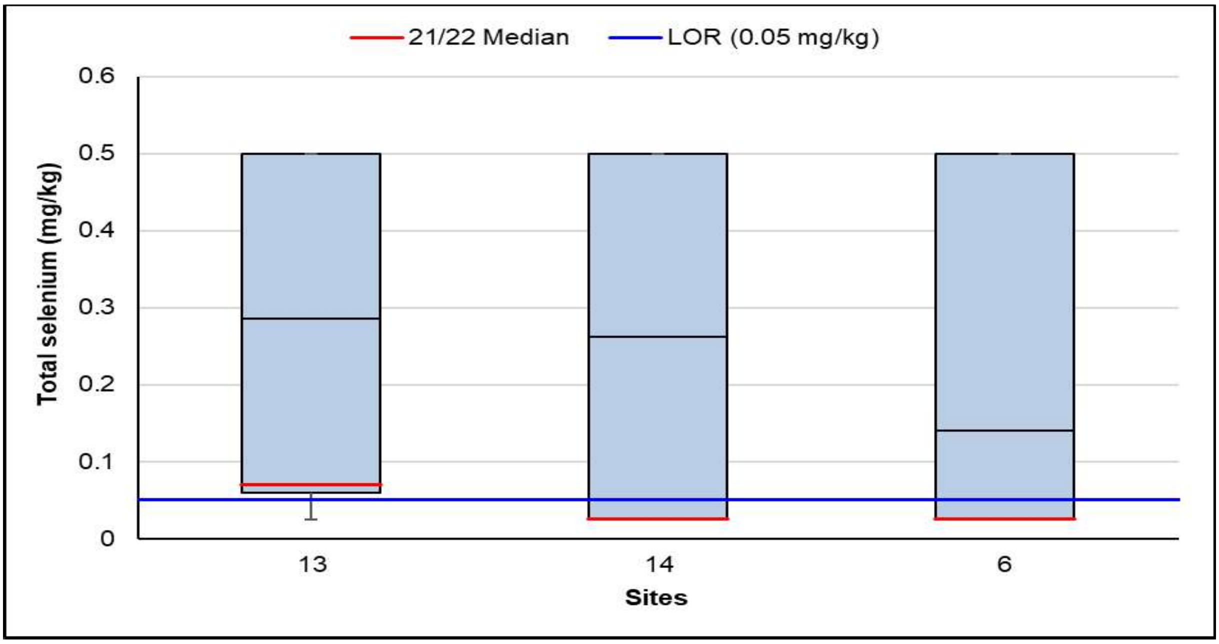


Figure 134. Box plots refer to the sediment total selenium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Sediments can be a significant source of selenium in fish and invertebrates. Toxic effect threshold levels for selenium in freshwater sediment, for food chain organisms according to ANZECC & ARMCANZ 2000 criteria is 3 mg/kg and 4 mg/kg, respectively (Lemly 1993). The highest selenium concentration (0.070 mg/kg) was recorded at site 13, sites 6 and 14 both recorded concentrations below the LOR (0.05 mg/kg) with concentrations of selenium seen to be at 0.025mg/L (Figure 134 and Table D-44 in Appendix D).

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Total selenium concentrations recorded in 2021 show some decrease with time, but because of the low values recorded, this cannot be quantified (Table H-57 in Appendix H). Site 13 has always recorded the highest concentration in the catchment, excluding the 2020 sampling event where only site 6 was sampled, sites 6 and 13 have always had the same concentrations of selenium in sediment.

Zinc

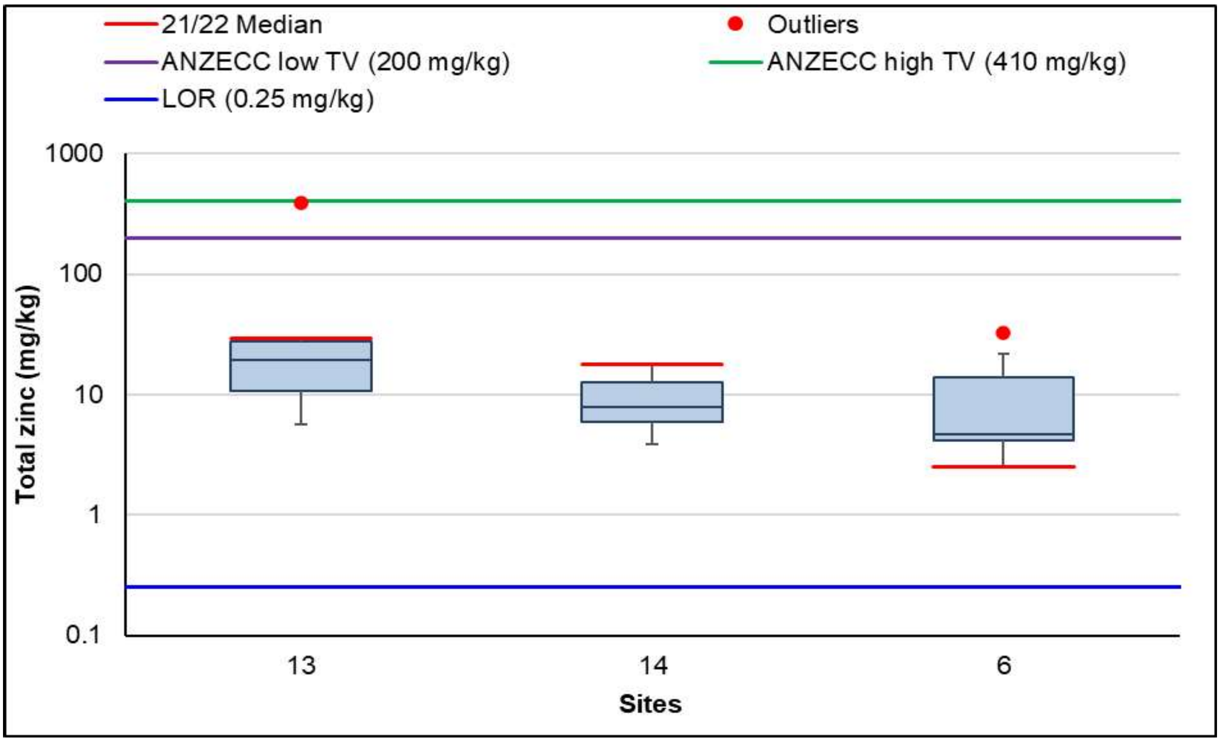


Figure 135. Box plot of sediment total zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Concentrations of total zinc in sediment throughout the Melville Bull Creek catchment sites in 2021 were low, with all concentrations below ANZECC low (200 mg/kg) and high (410 mg/kg) trigger values (Figure 135 and Table D-45 in Appendix D). The highest concentration 29 mg/kg was recorded at site 13, followed by 18mg/L at site 14 and the lowest 2.5 mg/kg at site 6.

Time series

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

Concentrations of total zinc in sediment recorded in 2021 show some slight differences between sites since sampling began (Table H-57 in Appendix H). Site 13 has on most years, recorded the highest zinc concentrations. One of these, in October 2011, exceeded the low trigger value, with a concentration of 390 mg/kg (all other values at all sites ranged between 2 and 30 mg/Kg). Additionally, zinc at site 6 was generally lower than that at the other two sites.

Logarithmic plots of all metals in sediments

Below are logarithmic plots of total metals at each of the Brentwood Drain sites. The logarithmic plots allow for visual observations of all metal data at one time. The total metals without adjustment for hardness were used to explore variations between metal concentrations of the sites.

Refer all time series discussions to the relevant summary plots; For site 13 – Figure 136, For site 14, Figure 137 and for site 6 Figure 138.

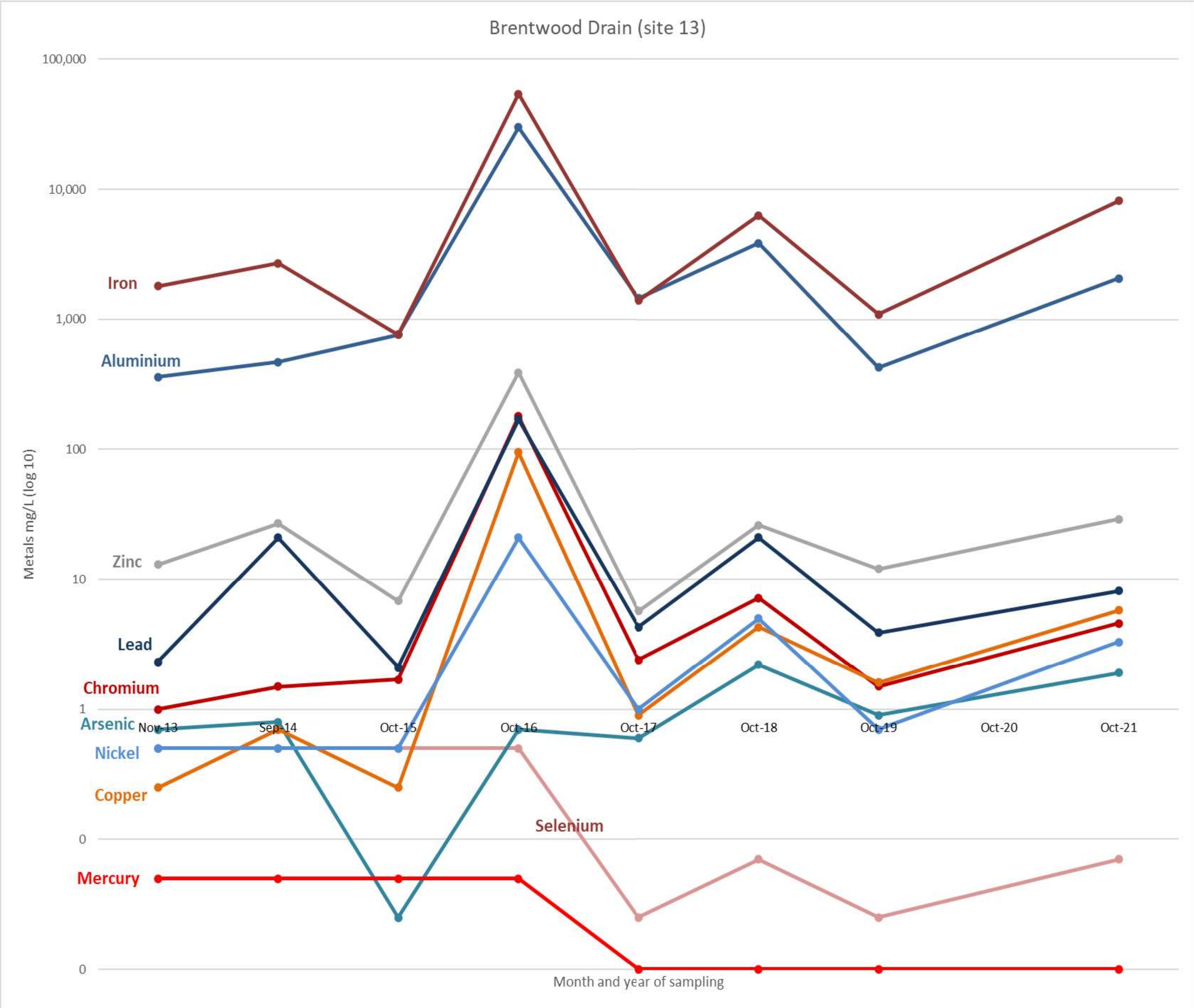


Figure 136. Historical logarithmic plot of the total metals in sediments at the Brentwood Drain site 13.

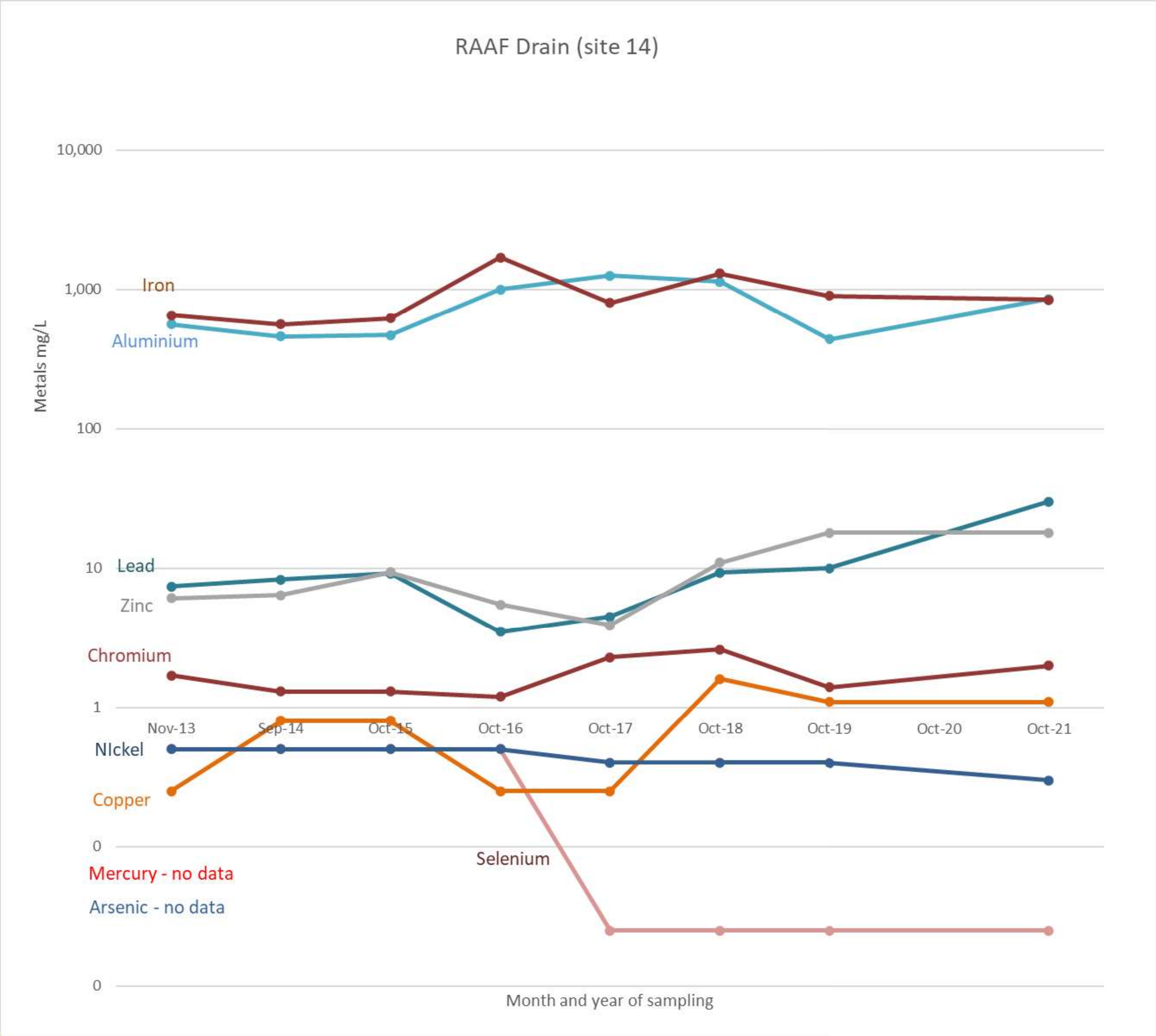


Figure 137. Historical logarithmic plot of the total metals in sediments at the Brentwood Drain site 14.

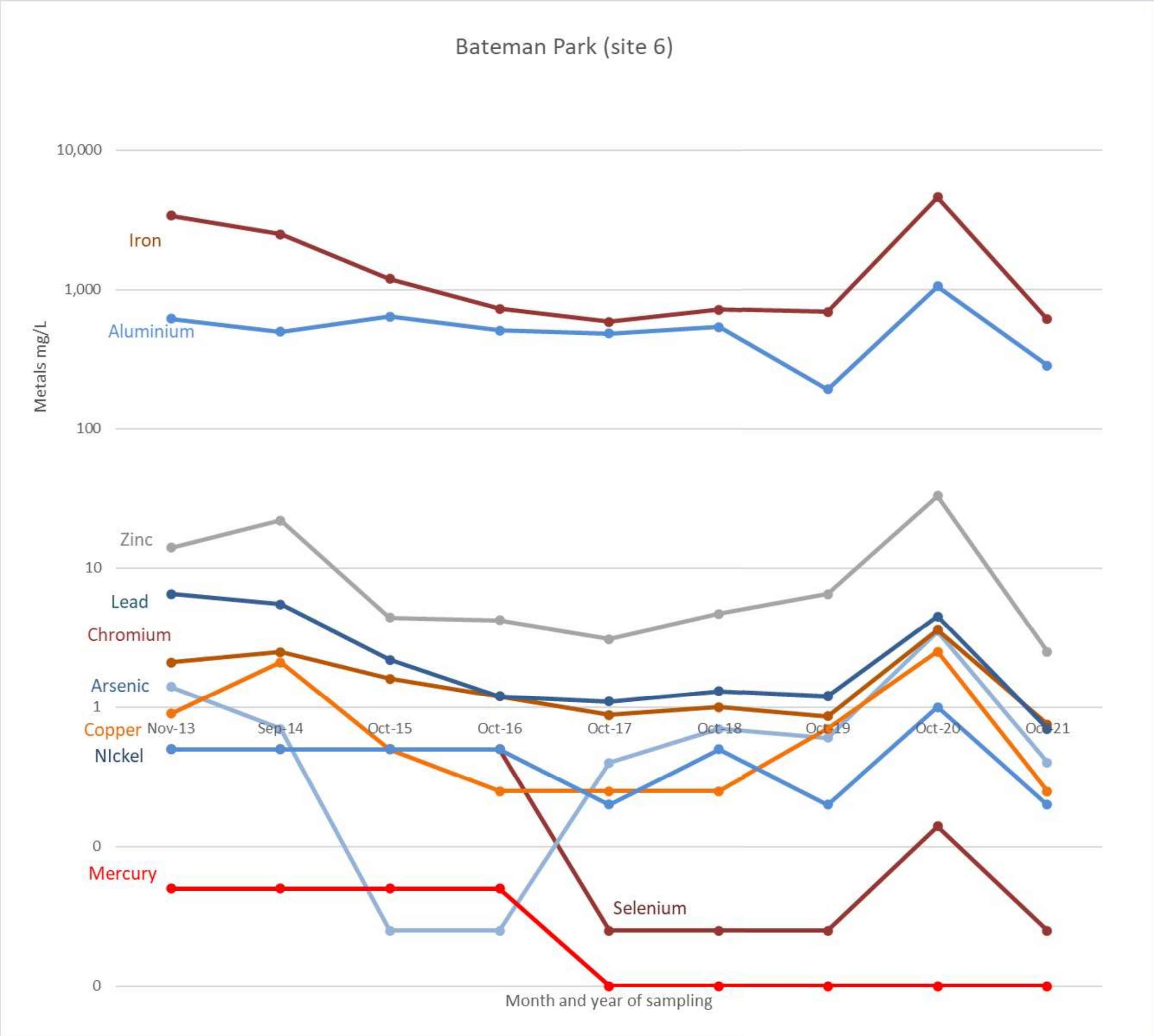


Figure 138. Historical logarithmic plot of the total metals in sediments at the Brentwood Drain site 6.

Summary of metals in sediments

Site specific trends could be observed, with Brentwood Drain (site 13) having the highest levels of most metals compared to the other two sites (Table 33). Except for possible associations of aluminium and iron, no other associations between metals could be confirmed.

Table 33. Summary of pH levels and metals in the sediments in sites 13, 14, and 6.

Site	Mean and median pH (n) of water (ANZECC pH TV for lowland rivers = 1.5 – 8.0)	Metal trends in sediments
13. Brentwood Drain	6.72 and 6.68 (34)	Fe, Al were very high in sediments. Other metals slightly lower or similar to other sites. A peak was observed in 2016 for most metals. There is no discernible trend with time. Unlike sites 14 and 6 no October 2020 was taken at this site.
14. RAAF Drain	7.05 and 7.07 (34)	Fe and Al similar to site 6 and much lower than in site 13. Zinc and lead also seem to follow similar patterns to each other are tending slightly upwards.
6. Bateman Park	6.87 and 6.87 (59)	Fe and Al concentrations at this site are similar to that at site 14. Zinc is higher at this site than site 14, and there is a peak of all metals in October 2020.

When these trends are considered together with the knowledge that a drop in pH is known to increase the solubility of metals, there is a slight possibility that the lower pH in site 13 (compared to sites 14 and 6) may be linked to the release of metals from sediments into the water at this site. But because Fe and Al for example, is high in the sediments at this site and that pH is relatively high at all three of these sites when compared to other sites in this report, it is unlikely that pH is the main reason for the differences in metals in sediments at these sites. These results instead suggest one or more of the following is influencing metal levels in sediments;

- rivers bring metals downstream and these accumulate in sediments, in particular where flow is restricted
- wetlands near heavily trafficked roads are more likely to have inflows of metals
- wetlands closer to the river contain more metals in the sediments
- older and/or denser urban areas have contributed to accumulation of metals with time
- metals and the geochemistry of the metals in specific soils influence the retention of metals in sediments
- rehabilitation of wetlands may restrict flow and therefore removal of metals from wetlands
- other works done to reduce metal inflow and retention in wetlands are associated with these trends and observations.

There were also variations between sites in terms of the dominance of metals in the sediments. Overall, iron and aluminium were most abundant and tended to trend together. Then zinc, lead, chromium, copper, nickel, arsenic, selenium, and mercury in that order. While there appeared to be some clustering of lead and zinc as well of chromium, nickel and copper, these associations are not clear.

Lakes of the Bull Creek Catchment

This section covers the parameters measured for Booragoon Lake (7), Piney Lakes (8), Quenda Lake (9), Frederick Baldwin (10), Marmion Reserve (11) and Blue Gum Lake (12).

Physicochemical properties

pH

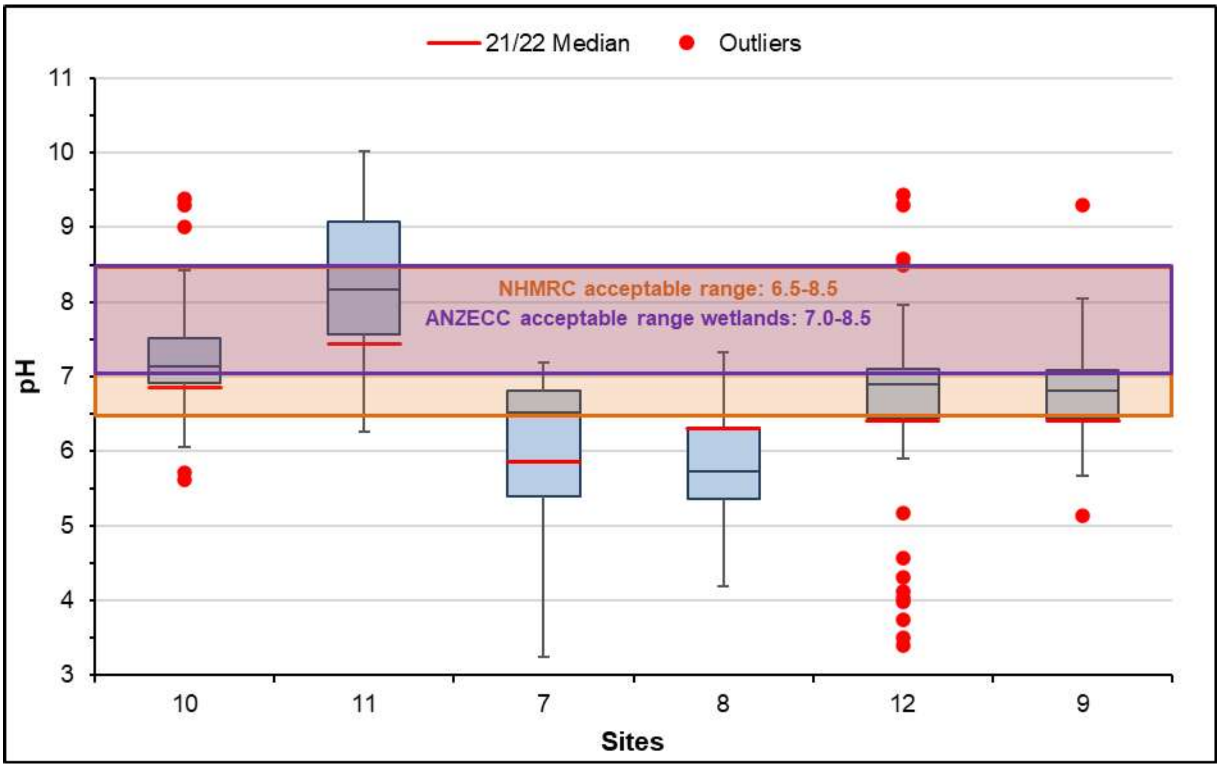


Figure 139. Box plots of pH refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

These sites in 2021 recorded pH values within the acceptable range (Figure 139). Sites 10 and 11 recorded pH medians within the ANZECC and NHMRC acceptable range (6.87, 6.67 and 7.07, respectively). Site 10 median was within the NHMRC acceptable range, however below the ANZECC acceptable range for wetlands. Site 11 median was within acceptable limits when compared to ANZECC acceptable range for wetlands, however the median sat above the NHMRC acceptable range.

Time series

When sampling began at these lakes in 2007, the variation in pH tended to be higher until 2017 than after this time (Figure 140). This was particularly the case in Blue Gum Lake (site 12). While the pH at all lakes have frequently been below 1. There seems to be a trend suggesting the pH has increased slightly with time, in particular in Blue Gum Lake (site 12) and Booragoon Lake (site 7). The pH at Piney Lakes (site 8) however has often been lower than that at the other two lakes. The pH at Fredrick Baldwin (site 10) and Quenda Lake (site 9) have remained mostly within the ANZECC and NHMRC acceptable ranges; that at Booragoon Lake, Piney

Lakes, and Blue Gum Lake (sites 7, 8 and 12 respectively) mostly below these; with that at Marmion Reserve (site 11) often exceeding the ANZECC and NHMRC values. The pH at site 12 occasionally exceeded these in the first years of sampling. Additionally, site 7 has recorded a pH close to 3 more often than any other site. Outliers have previously been recorded at sites 9, 10 and 12, although none of these occurred during 2021. There is a trend that suggests the pH at several of these sites, except for site 11, is stabilising closer to the ANZECC acceptable range of 6.5 to 8.0 (also Table 34).

Table 34. Descriptive statistics at the Bull Creek Catchment lakes. This includes all data up to and including that of 2021.

Site	Mean	SD	n
8	5.82	0.73	46
7	5.90	1.24	50
12	6.61	1.30	56
9	6.84	0.61	56
10	7.26	0.70	57
11	8.29	0.93	58

The pH at Marmion Reserve has often been high since sampling began in 2008 and the variation is pH at this site has not changed much (MELDR-11, x = 8.29, SD = 0.93, n = 58). In contrast however, the pH at Fredrick Baldwin seems to have been decreasing slightly and becoming more stable (MELDR-10, x = 7.21. SD = 0.760, n = 57). As for Quenda Lake (MELDR-09, x = 6.48, SD = 0.61, n = 56), the pH here has been quite stable, and remained lower than that at the other two lakes since sampling at this site began in 2008.

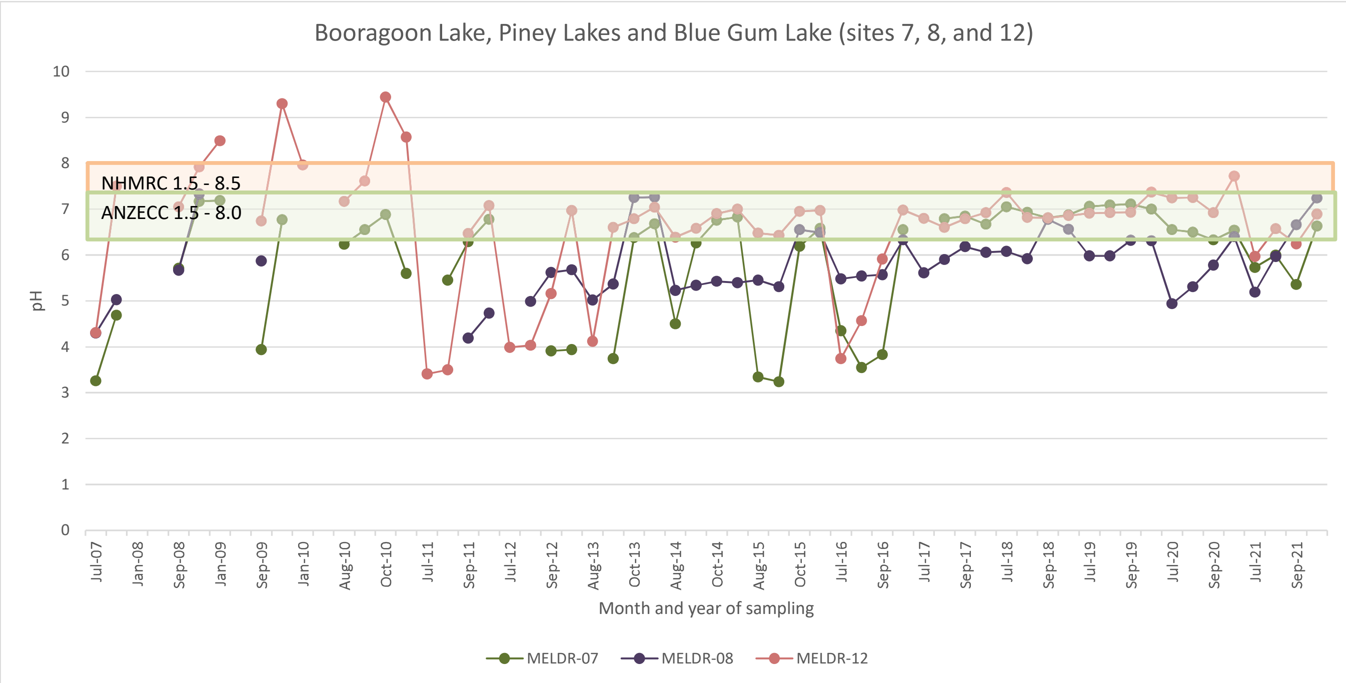


Figure 140. Historical data of pH at Booragoon Lake, Piney Lakes, and Blue Gum Lake.

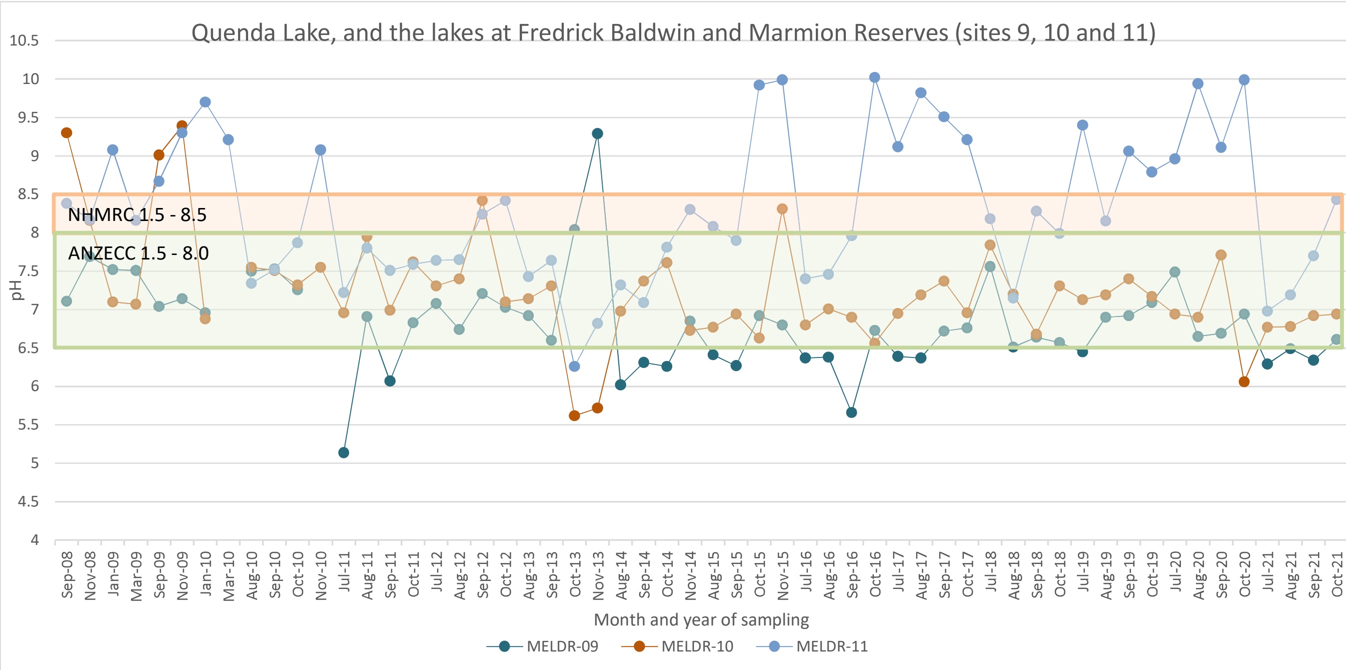


Figure 141. Historical data of the pH at Quenda Lake, and the lakes at Fredrick Baldwin and Marmion Reserves (MELDR-09, MELDR-10 and MELDR-11).

Oxygen saturation (%) and concentration (mg/L)

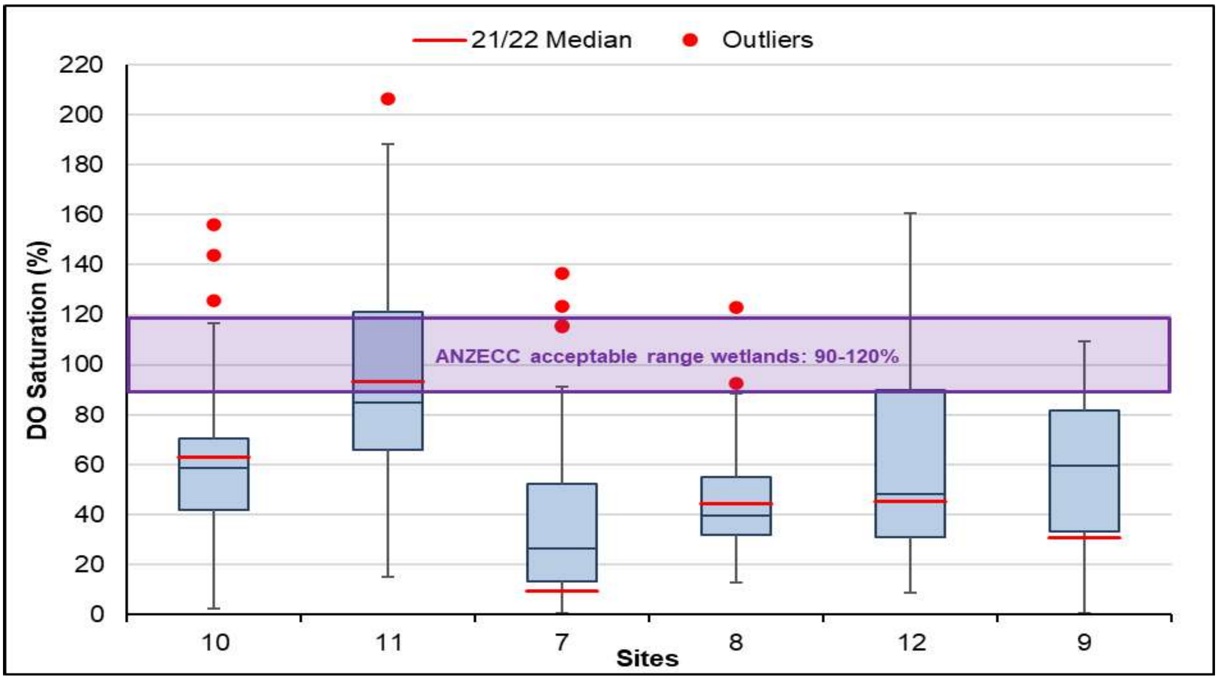


Figure 142. Box plots refer to the DO % 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

Five of the 6 samples collected from Lakes of the Bull Creek Catchment sites recorded dissolved oxygen (DO) saturations below the ANZECC acceptable ranges (lowland rivers: 80-120%, wetlands: 90-120%) and the NHMRC recreational guidelines lower limit (80%) (Figure 142 and Table D-5 in Appendix D). Site 7, 9, 10 and 12 recorded saturations below the acceptable range on all occasions when sampled. One sample from site 8 recorded DO saturations greater than the acceptable range with readings of 92.8% in October. This result is an outlier as it has not been seen since sampling began in 2007. Two samples at site 11 recorded a DO saturation greater than the acceptable range in September and October 2021 with a reading of 101.3% and 130.7% respectively. Site 7 recorded the lowest saturation in the catchment of 5.9% in August, the highest concentration of 130.7% was seen in site 11.

Sites within the Lakes of the Bull Creek Catchment in 2021 recorded a median DO concentration between 2.515mg/L, and 7.89mg/L deeming most sites to be generally low oxygen (<2-<4mg/L) to oxygenated water (<6mg/L) in accordance with DBCA standards (DPaW, 2015) (Figure 144 and Table D-6 in Appendix D). The only exception is Site 11, of which had a median of 7.89mg/L indicating that the water at this site was well oxygenated.

Time series

The % dissolved oxygen at all bar Quenda Lake has exceeded the ANZECC acceptable TV for low land rivers and wetlands of 120% at least once since sampling began in 2007 (Figures 143A and B). At Marmion Reserve, Blue Gum Lake, Fredrick Baldwin, Booragoon Lake, Piney Lakes this has occurred 15, 6, 3, 2, and once respectively in these lakes since sampling began. Overall, however, the % dissolved oxygen at these lakes have been below 80% and remained slightly lower since 2013 than in the previous years. Additionally, in spite of outliers, the variation in the % dissolved oxygen in Booragoon Lake (and Piney Lakes has tended to remain lower than that of Blue Gum Lake.

At most of the sampling times at these sites the oxygen concentration was between 2 mg/L and 6 mg/L (Figures 145 and 146). On some occasions, in particular prior to 2013 and again in 2019, Blue Gum Lake (MELDR-12) in particular, was well oxygenated (above 6 mg/L). The trend in Booragoon Lake (MELDR-07) suggests the oxygen saturation is decreasing. In addition, the trend is also suggesting that oxygen (% and mg/L) is has been decreasing or remained stable in all lakes except for Marmion Reserve, where there are a slight upwards trend. The oxygen saturation seems to have dropped in October at Frederick Baldwin reserve in 2010, 2012, 2015, 2016 and Quenda Lake in 2014, 2018 and 2021 more often to hypoxic or near hypoxic levels (between 0 and 2 mg/L DO) than in other sites.

Although there is a trend that % oxygen prior to 2013 had been decreasing, this does not seem to be the case since 2013. There is instead a slight upwards trend of % oxygen at these lakes, in particular at Marmion Reserve. The % oxygen as well as the variation of mg/L oxygen tends to be highest at Marmion Reserve (site 11) compared to Quenda Lake (site 9) or at Fredrick Baldwin Reserve (site 10). The trend in dissolved oxygen mimics that of % oxygen saturation (r = 0.996, n = 14 pairs of means), and that at sites 7 and 12 (Booragoon Lake and Blue Gum Lake) was very variable, having a coefficient of variation (CV = SD/mean) of over 50% compared to the other sites where the CV was between 35% to 50% (see also Table 36).

The high pH at Marmion Reserve (Table 34) may be a result of higher levels of alkaline ions at this lake. When oxygen saturation (%) and dissolved oxygen (mg/L) at all 14 sites are correlated with pH, it appears that as pH increases the oxygen (% and mg/L) in the water also increases (r = 0.75 and 0.74 respectively, using 14 pairs of means). Conductivity was however weakly and negatively associated with the % and mg/L oxygen (r = -0.48 for both, using 14 pairs of means for each), which is possibly a result of the finding that when pH increases at these 14 sites, the conductivity drops (r = -0.64, n = 14 pairs of means). In the absence of any correlation between temperature and % or mg/L oxygen (r = 0.11 and 0.12 respectively, 14 pairs of means) it is likely that other factors, such as the influence of groundwater, organic matter and biological life may have on the oxygen levels in these lakes.

Table 35. Oxygen saturation and dissolved oxygen at the Bull Creek Lake sites.

	Oxygen saturation %			Dissolved oxygen mg/L		
Site	Mean	SD	n	Mean	SD	n
7	37.8	33.3	50	3.54	3.11	50
8	45.5	21.3	46	4.35	1.97	46
9	57.7	29.2	56	5.61	2.75	56
10	60.9	29.6	57	5.67	2.57	57
11	93.3	38.2	57	8.54	3.07	58
12	62.0	37.5	56	5.51	3.32	55

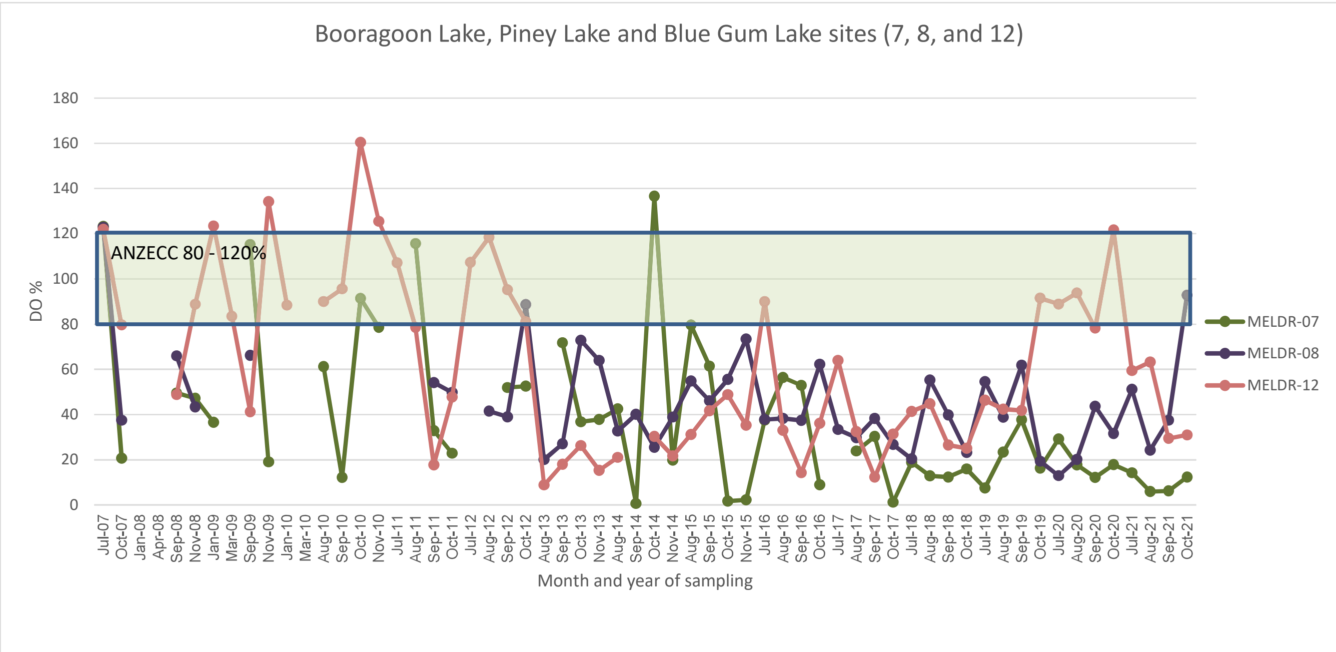


Figure 143A. Oxygen saturation at Booragoon Lake, Piney Lakes and Blue Gum Lake.

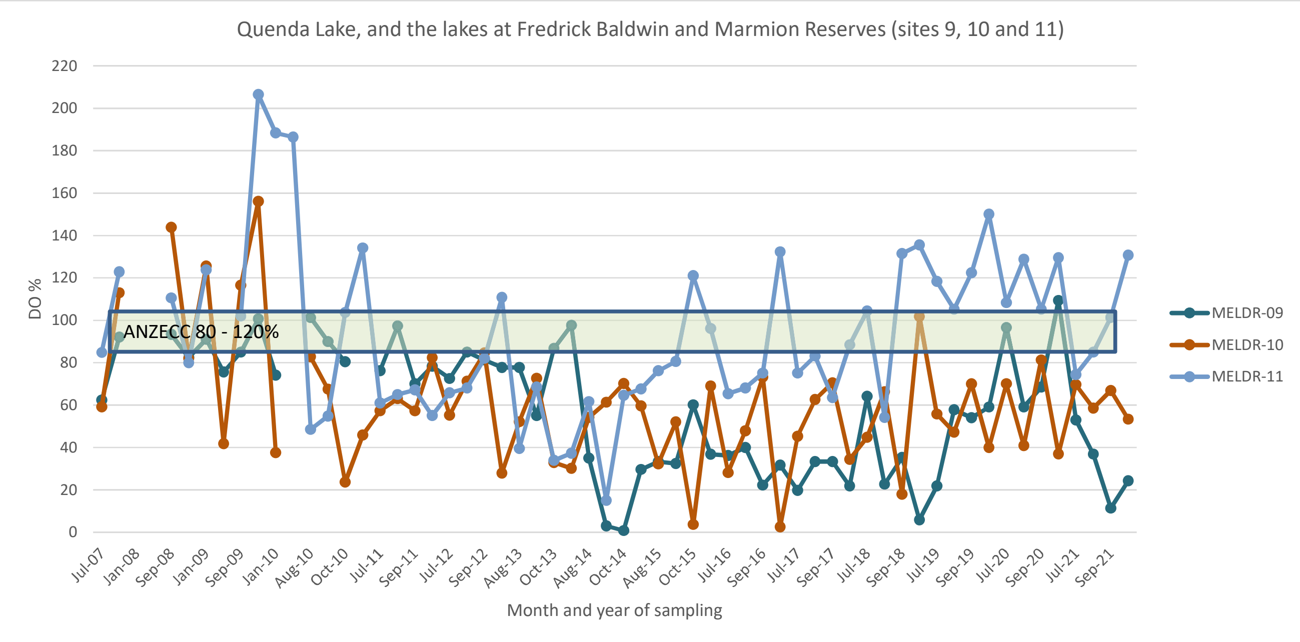


Figure 143B. Historical data of oxygen saturation at Quenda Lake, Fredrick Baldwin, and Marmion Reserves.

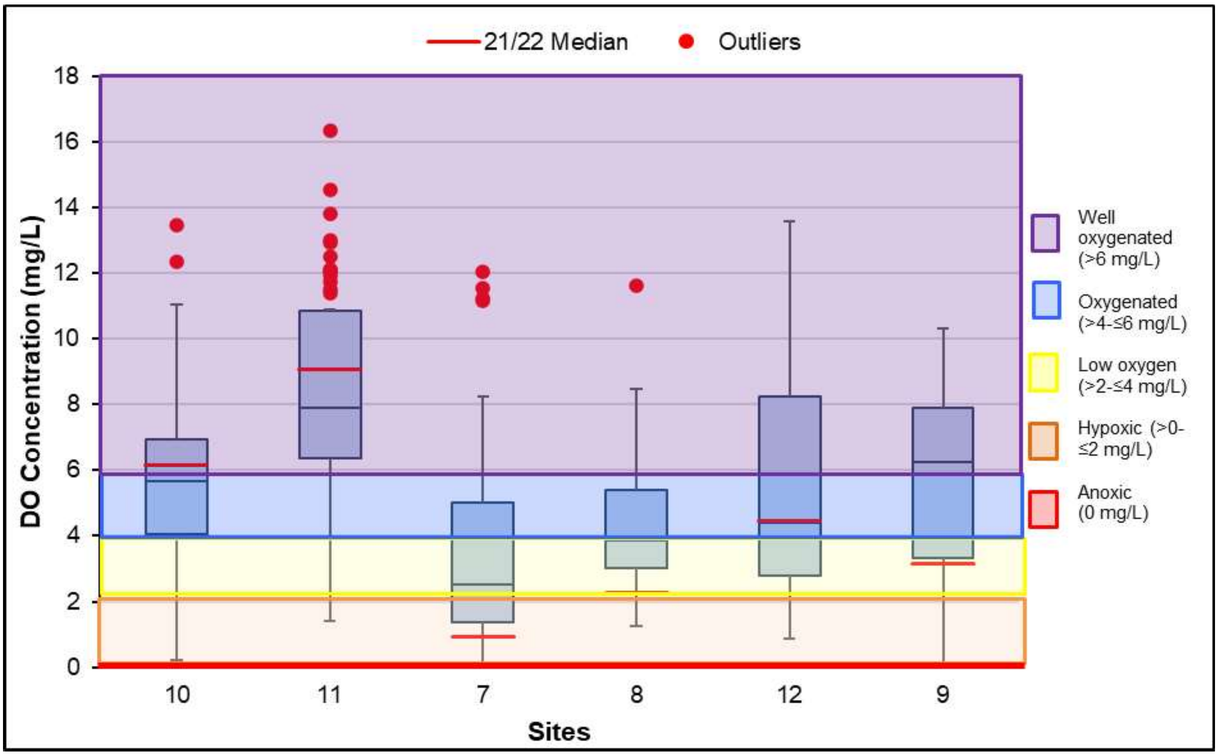


Figure 144. Box plot of DO mg/L 2007-2020 historical median values, with a red line indicating the median value in 2021.

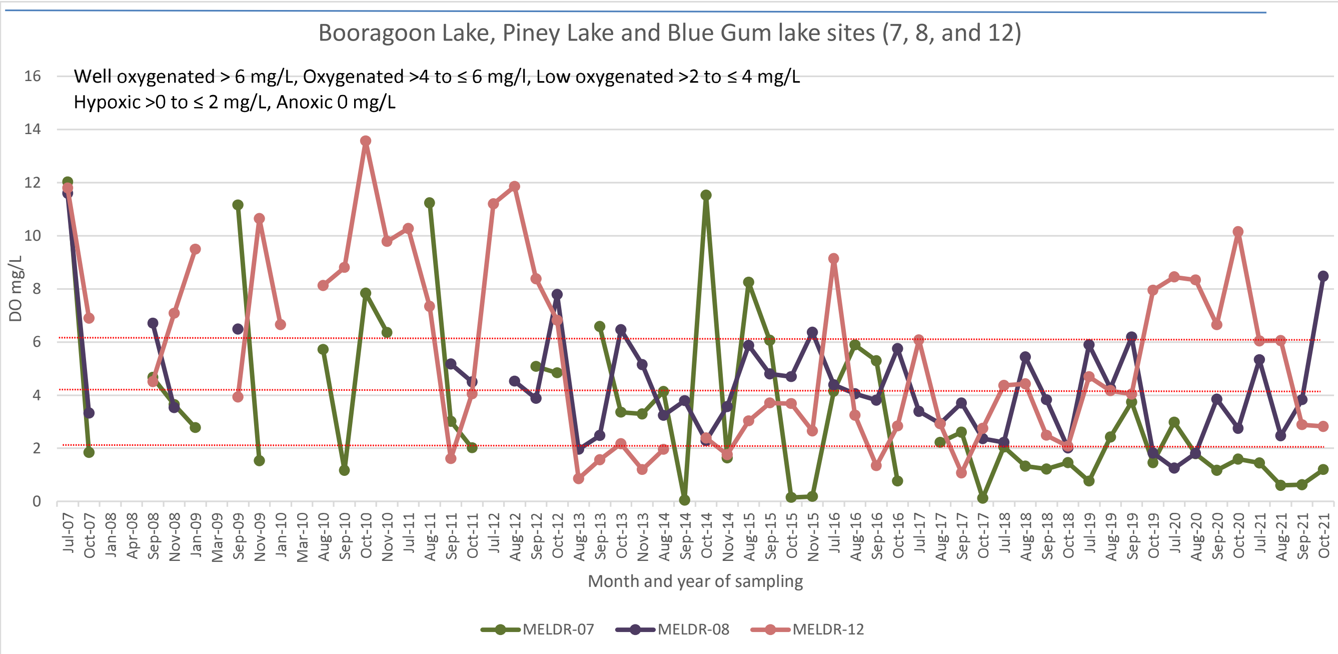


Figure 145. Historical data of dissolved oxygen at Booragoon Lake, Piney Lakes and Blue Gum Lake.

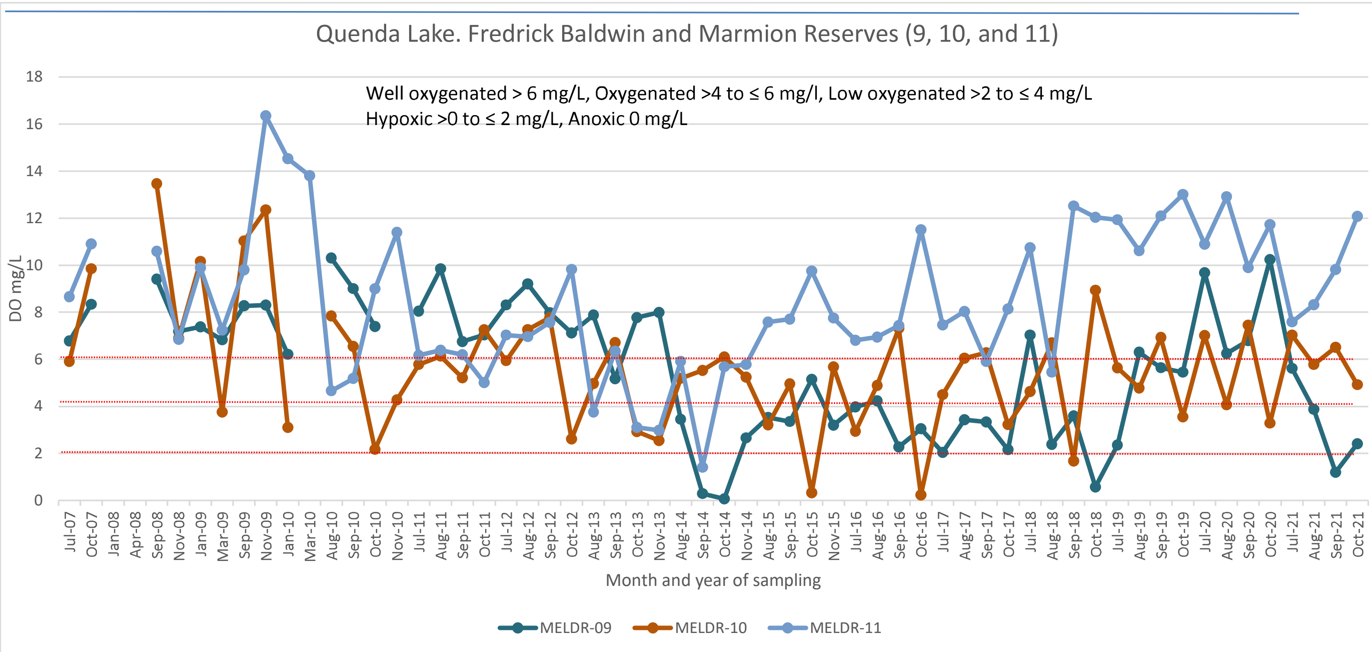


Figure 146. Historical data of the dissolved oxygen at Quenda Lake, Fredrick Baldwin and Marmion Reserve.

Electrical conductivity

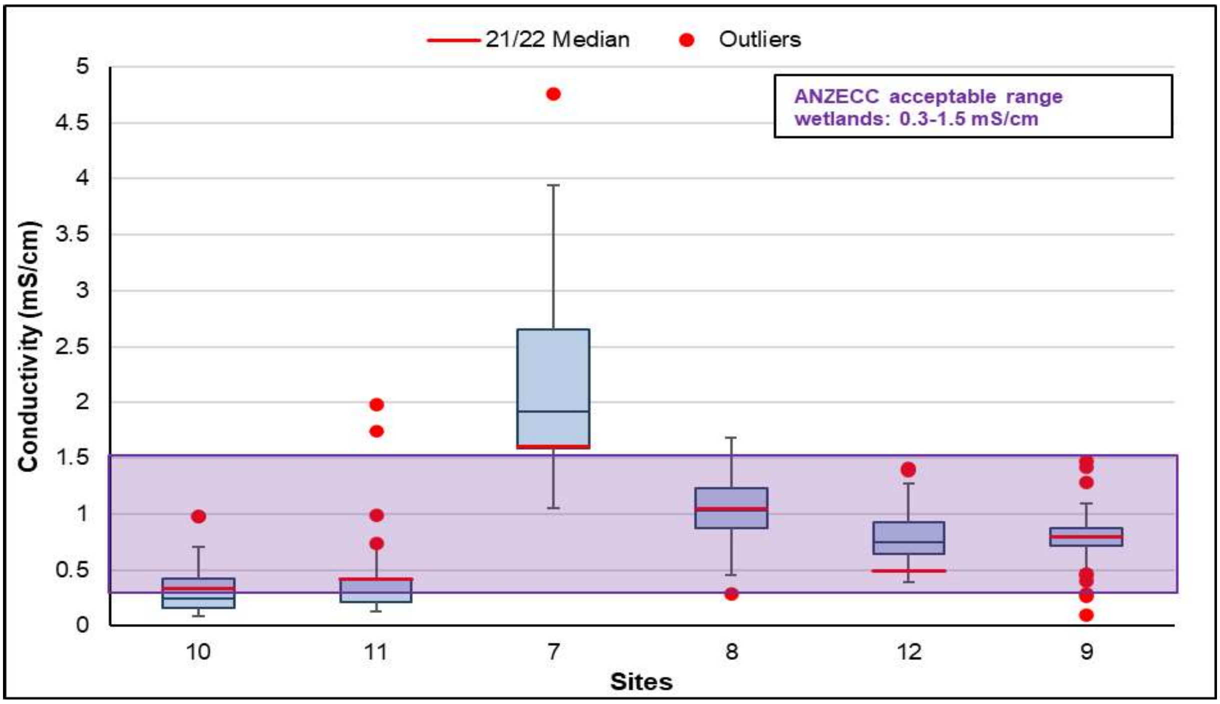


Figure 147. Box plots refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

The median EC values recorded in the Lakes of the Bull Creek Catchment were mainly seen to be within acceptable limits of ANZECC wetlands range of 0.3-1.5mS/cm (Figure 147). The medians see all samples collected between sites 9 and 12 are within acceptable limits of the acceptable range for wetlands (0.3-1.5 mS/cm). Three samples collected in the 2021 sampling event were above ANZECC acceptable ranges for lowland rivers (0.12-0.3 mS/cm), twice at site 7 in July and August, 1.711 mS/cm and 1.701 mS/cm respectfully and once at site 8 in July with a concentration of 1.674mS/cm. The lowest concentrations are below the ANZECC wetlands range of 0.3-1.5mS/cm being 0.13 mS/cm at site 10 in July and 0.145 mS/cm at site 11 in July.

Time series

The conductivity at all sites except for Booragoon Lake (site 7) since sampling began, reflect those found in lakes in the south-west Western Australia. At Booragoon Lake the conductivity was consistently both higher and more variable.

Although there are several outliers for some sites, in particular at Booragoon Lake, the conductivity is trending to stabilise within the ANZECC range for wetlands, lakes and reservoirs at all sites (Figures 148 and 149). Blue Gum Lake, Piney Lakes, Fredrick Baldwin and to an extent also Marmion Reserve (sites 12, 8, 10 and 11 respectively) have a conductivity more frequently within the ANZECC range for wetlands, lakes, or reservoirs than Booragoon Lake or Quenda Lake.

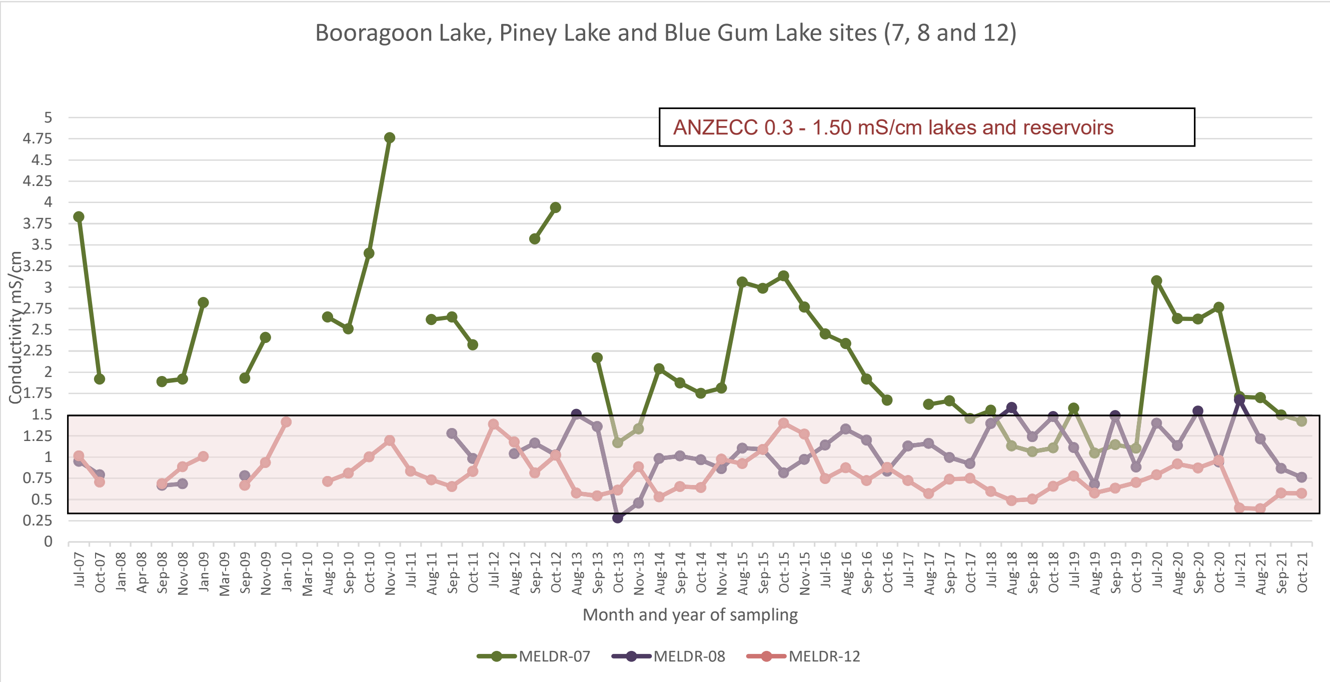


Figure 148. Historical data of conductivity at Booragoon Lake, Piney Lakes, and Blue Gum Lake.

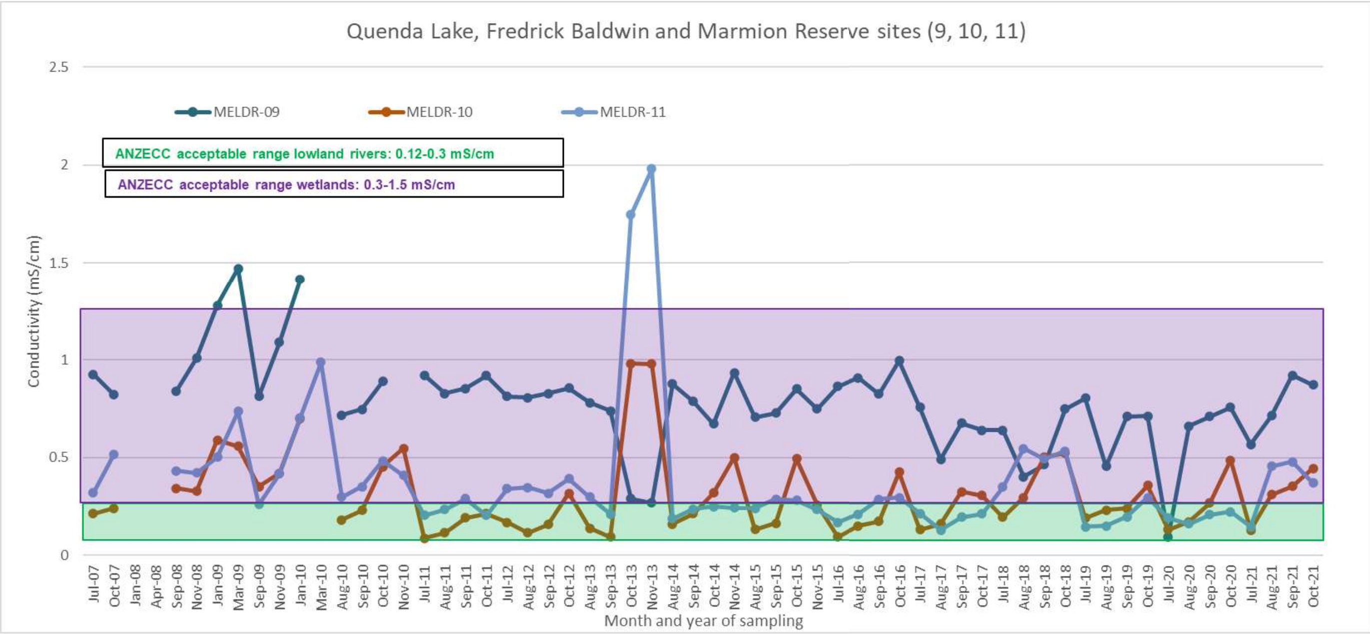


Figure 149. Historical data of conductivity at Quenda Lake, Fredrick Baldwin and Marmion Reserve.

Total suspended solids

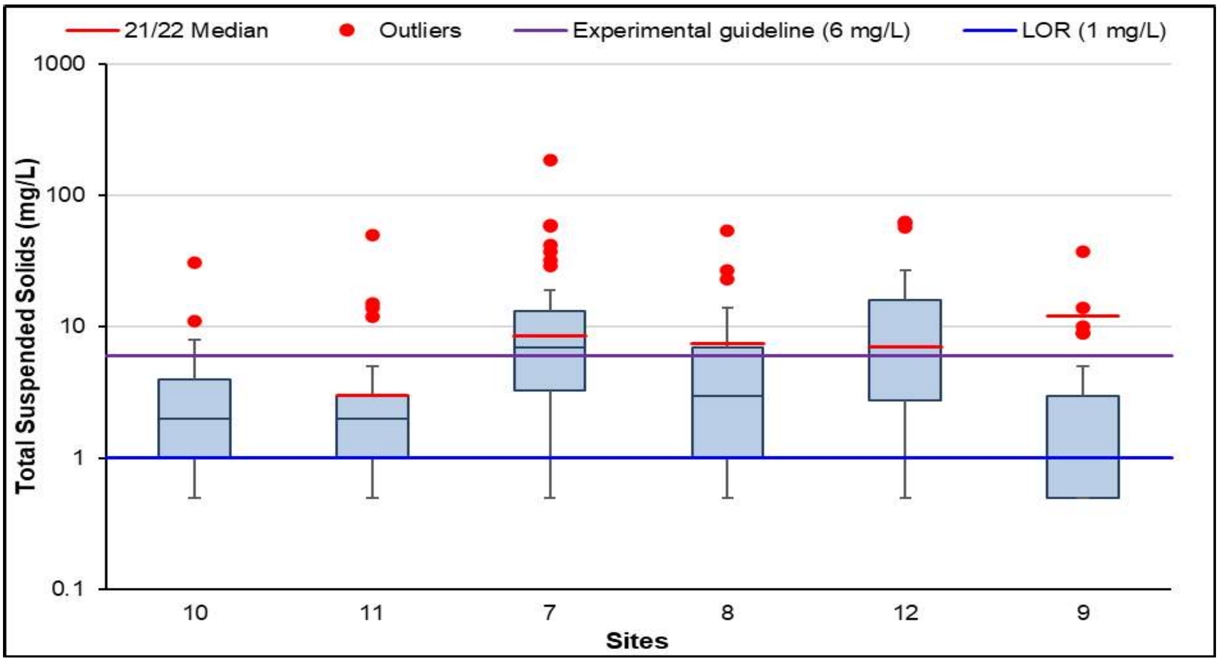


Figure 150. Box plot of TSS 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

TSS concentrations were similar to previous results seen in the Lakes of the Bull Creek Catchment, with all sites having at least one exceedance recording concentrations equal to or above the experimentally derived guideline (6 mg/L) therefore the were 13 exceedances rather than 8 in the 2020 sampling event (Figure 150 and Table D-8 in Appendix D). Five of the exceedances in 2021 were recorded in August in sites 7, 8, 10,11 and 12, four in September in sites 7, 8, 9 and 10 and three in October within sites 7, 8 and 9, with only one in July in site 12. The highest concentrations of 41 mg/L were recorded at site 10 in August. There were no samples in 2021 that recorded a concentration below the LOR of 1.0 mg/L. Medians at sites 7 and 12 were both above the experimental guideline of 6mg/L, whereas sites 8, 9, 10 and 11 medians were below.

Time series

Several high values of TSS at sites could be associated with rainfall as high TSS tend to occur in winter. When comparing results between sites, TSS levels have historically been lower at site 11 (Marmion Reserve) than any of the other lakes (Figures 151 and 152). This site did, however, record its first exceedance of the trigger value for TSS in 2021 (of 50mg/L) since 2010. Overall, the TSS at these lakes was above the experimental guideline of 6 mg/L at about 40% of the sampling sessions. The TSS at Piney Lakes, Quenda Lake, Fredrick Baldwin, and Marmion Reserve (sites 8, 9, 10, and 11) were more frequently below the experimental guideline of 6 mg/L than that at Booragoon Lake or Blue Gum Lake (sites 7 and 12). Blue Gum Lake (site 12: x = 12.31, SD = 14.08, n = 52) and Booragoon Lake (site 7: x = 12.17, SD = 13.93, n = 47) recorded the highest overall and variable TSS. In spite of some high values at Piney Lake, the TSS at this site has remained below this guideline (site 8: x = 7.49, SD = 9.95, n = 35) at this lake, even when these guidelines were exceeded in the other two lakes.

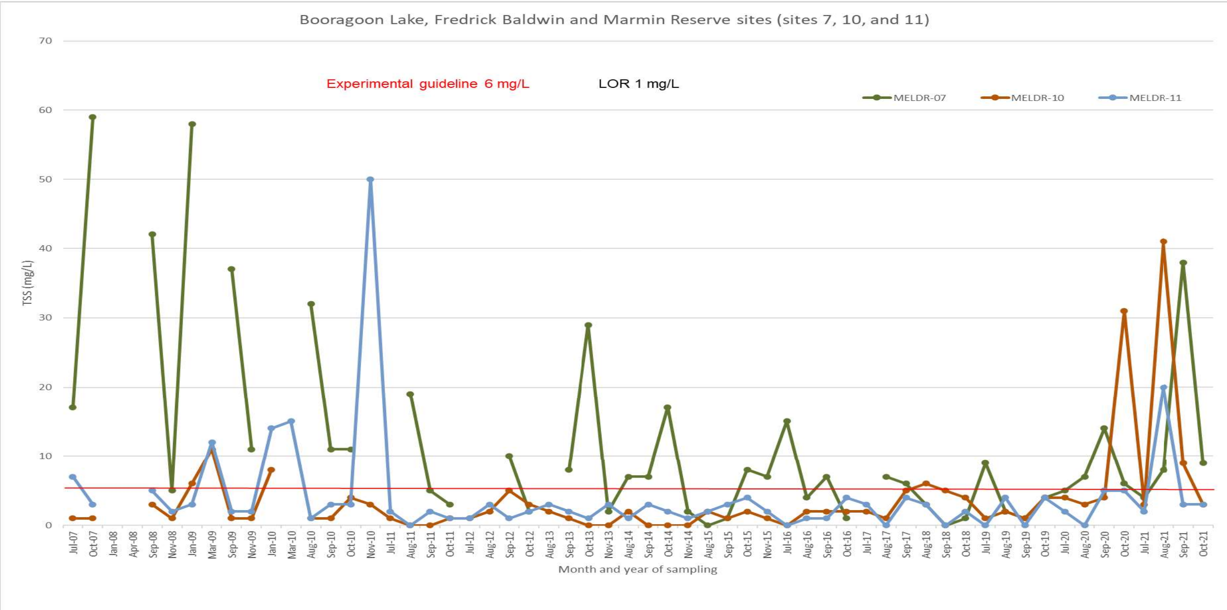


Figure 151. Historical data of TSS at Booragoon Lake, Fredrick Baldwin and Marmion Reserve. Note; an unusually large outlier of 184 mg/L TSS recorded at Booragoon Lake (site 7) in November 2010 was removed from the plot and calculations, in order to make interpretations of the more common data clearer. This high value could be a result of the exceptionally low rainfall in 2010.

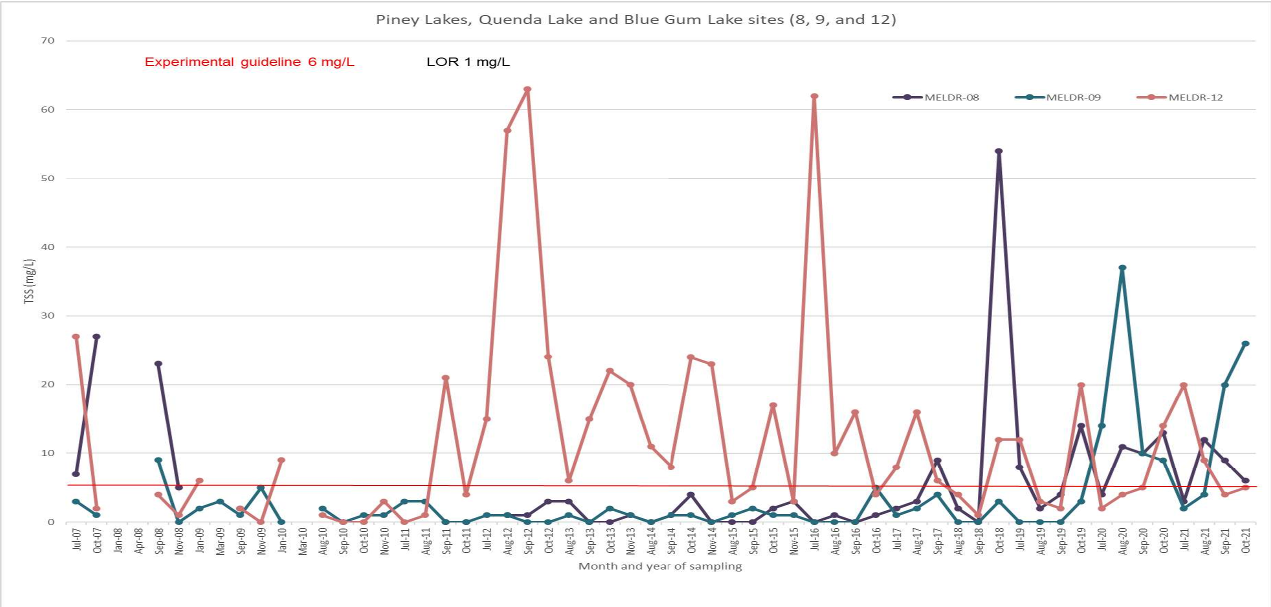


Figure 152. Historical data of TSS at Piney Lakes, Quenda Lake and Blue Gum Lake.

Temperature

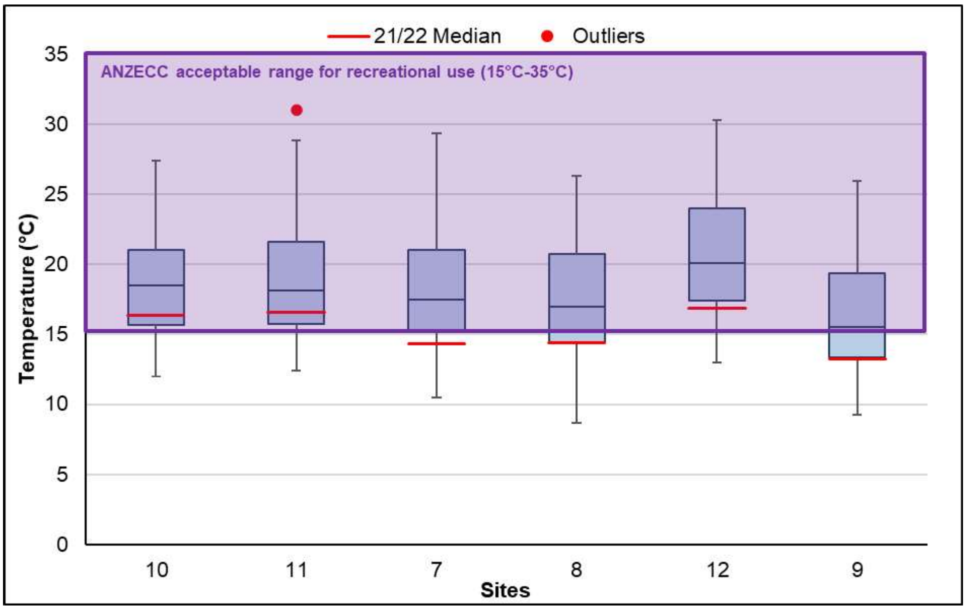


Figure 153. Box plot of temperature 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

No samples collected at sites in the Lakes of the Bull Creek Catchment in 2021 recorded temperatures above the ANZECC acceptable range (15°C-35°C). Temperatures in the surface waters of the Lakes of the Bull Creek Catchment ranged from 12.8°C in July at site 9 to 19.9°C in October at site 12 (Figure 153 and Table D-9 in Appendix D). Temperatures at all sites were considered to lie within a normal seasonal range however when compared to those recorded in the previous 14 years of monitoring, the 2021 results were slightly lower, this is potentially due to the unusually cold winter with heavier and more frequent rainfall.

Time series

Although the temperature at these lakes was similar to that of other sites examined in the Melville area, the temperatures at these lakes varied more in these lakes than at other Melville sites (3.40< SD < 4.65 compared to 0.19 < SD < 2.54 respectively) (Figure 154). The temperature at Blue Gum Lake (site 12) was often the highest, and that at Piney Lakes and Quenda Lake (sites 8 and 9) lowest. In spite of predictable seasonal differences, there seems to be an overall decreasing trend in water temperatures in these lakes.

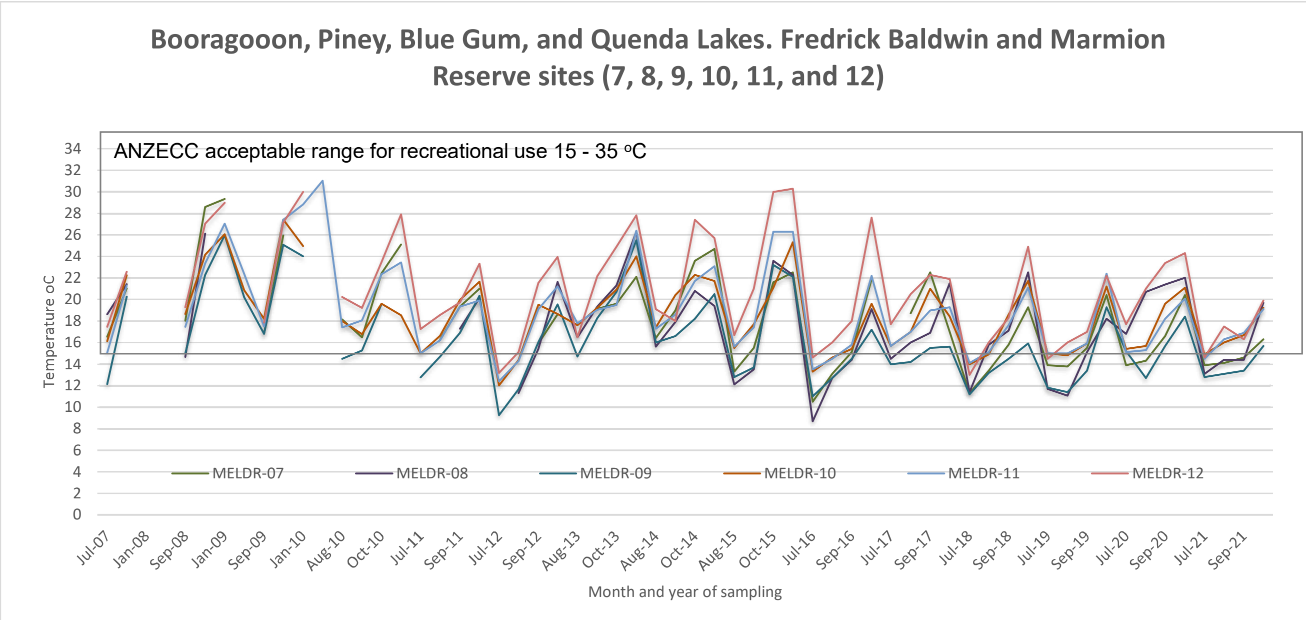


Figure 154. Historical data of temperature at all six lakes. A composite plot was produced as there were similar seasonal trends at all sites.

Nutrients

The complete table of descriptive statistics of nutrients below allows for an overview of all nutrients in these lakes (Table 36).

Table 36. Descriptive statistics of all nutrients samples at the Melville lake sites.

Site	**Total Nitrogen**			**Total oxidised nitrogen**			**Nitrogen as ammonia/ ammonium**			**Dissolved organic nitrogen**		
	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
7	4.69	4.19	50	0.673	1.330	31	2.424	3.315	46	1.777	1.137	49
8	1.12	0.66	46	0.463	0.693	13	0.025	0.012	40	0.919	0.487	44
9	0.91	0.35	57	0.232	0.338	15	0.039	0.101	36	0.788	0.374	56
10	0.53	0.44	57	0.098	0.143	37	0.063	0.072	46	0.243	0.109	57
11	0.55	0.29	58	0.095	0.132	28	0.055	0.108	38	0.344	0.161	56
12	2.32	1.24	56	0.384	1.064	36	0.400	0.491	51	1.212	0.494	55

Site	**Total organic nitrogen**			**Total phosphorous**			**Filterable reactive phosphorous**		
	Mean	SD	n	Mean	SD	n	Mean	SD	n
7	2.056	0.990	39	1.821	1.832	50	1.0196	1.3548	48
8	1.073	0.640	41	0.031	0.033	46	0.0114	0.0106	13
9	0.904	0.382	44	0.016	0.008	50	0.0093	0.0031	4
10	0.421	0.466	44	0.041	0.056	57	0.0091	0.0041	12
11	0.413	0.129	44	0.047	0.025	58	0.0135	0.0074	26
12	2.027	1.238	44	0.331	0.250	56	0.1666	0.1688	49

Overall, Booragoon Lake (site 7) and Blue Gum Lake (site 12) have recorded most nutrients on average since sampling began in 2007. This is followed by Piney Lakes (site 8) and Marmion Reserve (site 11) that are more intermediate and finally Quenda Lake (site 9) and Fredrick Baldwin (site 10) that have the least nutrients in the water on average. The sites with less nutrients in the water may be influenced by one of more of the following factors: inflow of nutrients is low; outflow is high or nutrient uptake by plants is good. The opposite may be the case for the other lakes, in particular Booragoon Lake as well as Blue Gum Lake.

For the most part in most sites and since sampling began, total organic nitrogen and dissolved organic nitrogen have been the most common forms of nitrogen in the wetlands, particularly in Marmion Reserve (site 11) and Blue Gum Lake (site 12) when compared to the other sites. In these two lakes, nitrogen as ammonium/ammonia is particularly low. Of the other lakes, Piney Lakes, Fredrick Baldwin, and Quenda Lake (sites 8, 10, and 9) this is more intermediate. At Booragoon Lake (site 7) in contrast, nitrogen as ammonia and ammonium occurs more often than other forms of nitrogen, with oxidised nitrogen the less common form of nitrogen. These trends are also reflected in the proportion of reactive phosphorus as this form of phosphorus is lower in Marmion Reserve (site 11) and Blue Gum Lake (site 12) compared to the other sites. These insights may indicate that nitrogen and phosphorus cycling is occurring better in Blue Gum Lake (site 12) and Marmion Lake (site 11) than at the other lakes. This is followed by Fredrick Baldwin, Quenda Lake, and Piney Lakes (sites 10, 9, and 8) in that order. The least healthy lake in terms of nitrogen and phosphorus seems to be Booragoon Lake (site 7). These inferences are preliminary only and need to be explored in more detail.

Nitrogen

Total nitrogen

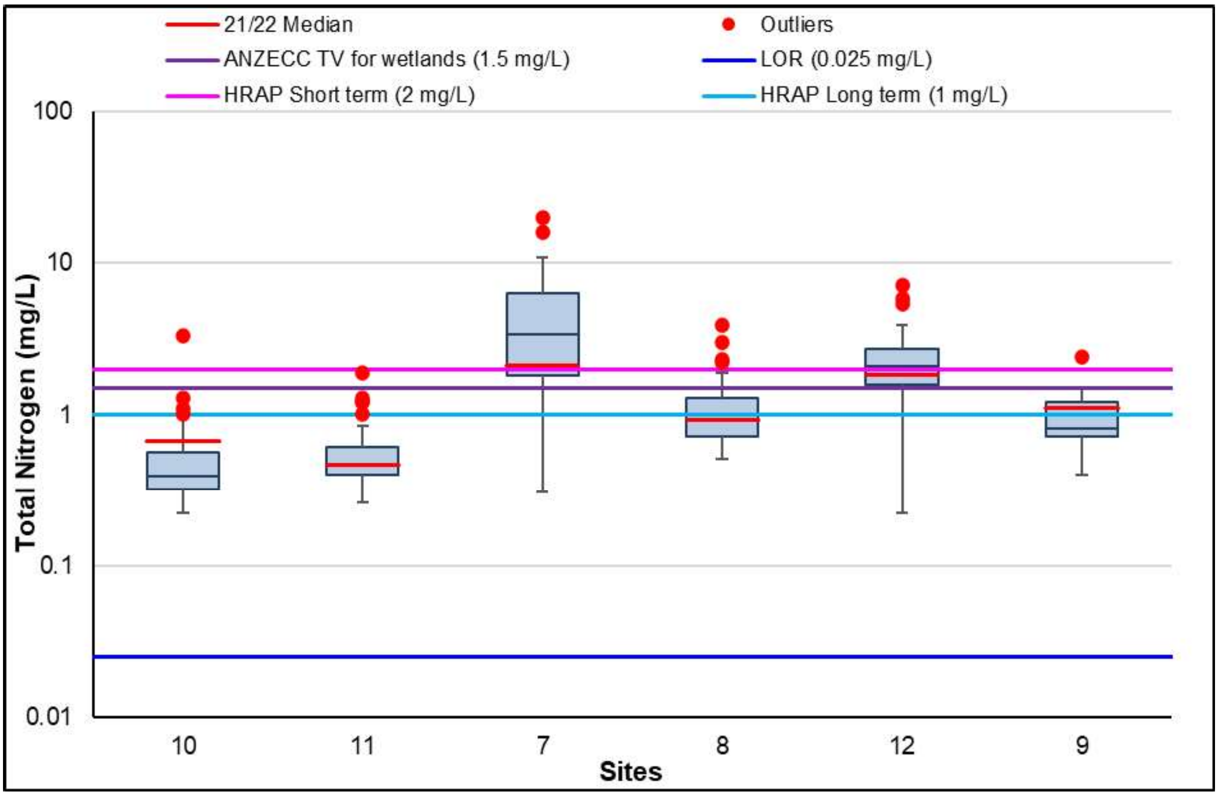


Figure 155. Box plot of total nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

TN concentrations exceeded ANZECC trigger values for lowland rivers (1.2 mg/L) or wetlands (1.5 mg/L) in 7 of 24 samples collected from Lakes of the Bull Creek Catchment site (Figure 155 and Table D-10 in Appendix D). The highest concentration was recorded at site 12 with a reading of 3.3 mg/L in September 2021. Site 12 had exceeding concentrations recorded on all sampling occasions throughout the 2021 sampling event. The lowest concentration was recorded at site 10, with a concentration of 0.35mg/L in July of 2021. Four of the 24 samples exceeded the HRAP short term target (2 mg/L) and 7 exceeded the long-term target (1 mg/L), three from site 7 in August, September, and October and all four samples from site 12 in the 2021 sampling event.

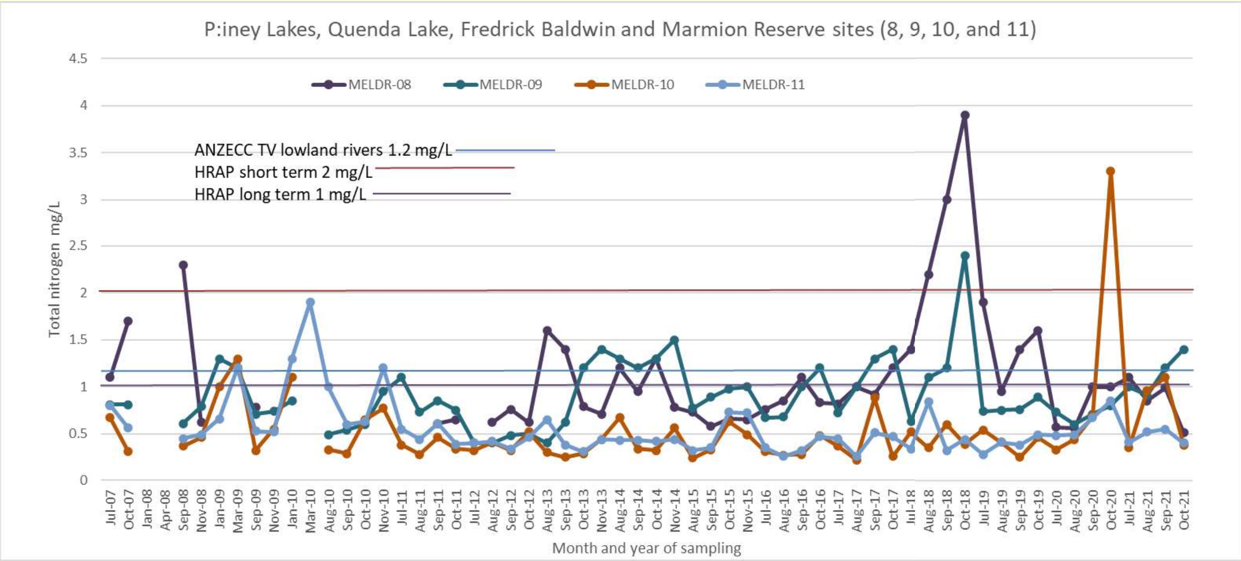


Figure 156. Historical plot of total nitrogen in Piney Lakes, Quenda Lake, Fredrick Baldwin and Marmion Reserve.

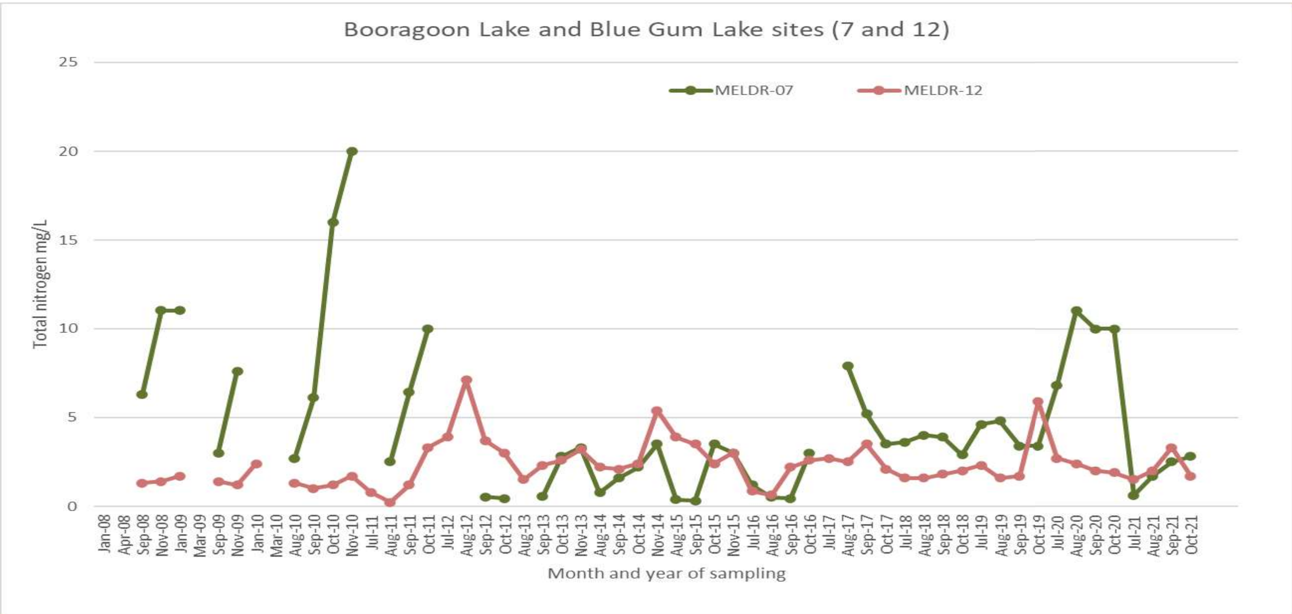


Figure 157. Historical data of total nitrogen at Booragoon Lake and Blue Gum Lake.

Time series

While most of the peaks in nitrogen in these lakes can be attributed to winter rains, there seem to be differences in how much rainfall contributes to peaks in nitrogen, which suggests there are also site-specific conditions that influence nitrogen levels in the lakes (Figures 156 and 157). For example, the higher total nitrogen in Piney Lakes and Quenda Lake (sites 8 and 9) in August through to October 2018 may indicate an unexpected inflow of nitrogen as peaks were not observed at the same time in other sites. Another set of spikes in total nitrogen through July to October 2020 occurred in several sites, and this could be linked to the slightly higher than normal monthly rainfall from June to October of 2020.

Overall, however, Piney Lakes, Quenda Lake, Fredrick Baldwin, and Marmion reserve have recorded nitrogen levels below the HRAP levels most often as well as Below the ANZECC TV on most sampling occasions. This contrasts with the almost consistently higher levels (exceedances of both the HRAP and ANZECC guidelines) of nitrogen in both Booragoon and Blue Gum Lake. It should be noted however, that there are indications that total nitrogen may be decreasing slightly with time at Booragoon Lake as very high values were recorded each year prior to 2012, but not as often of as high after this time.

Total oxidised nitrogen

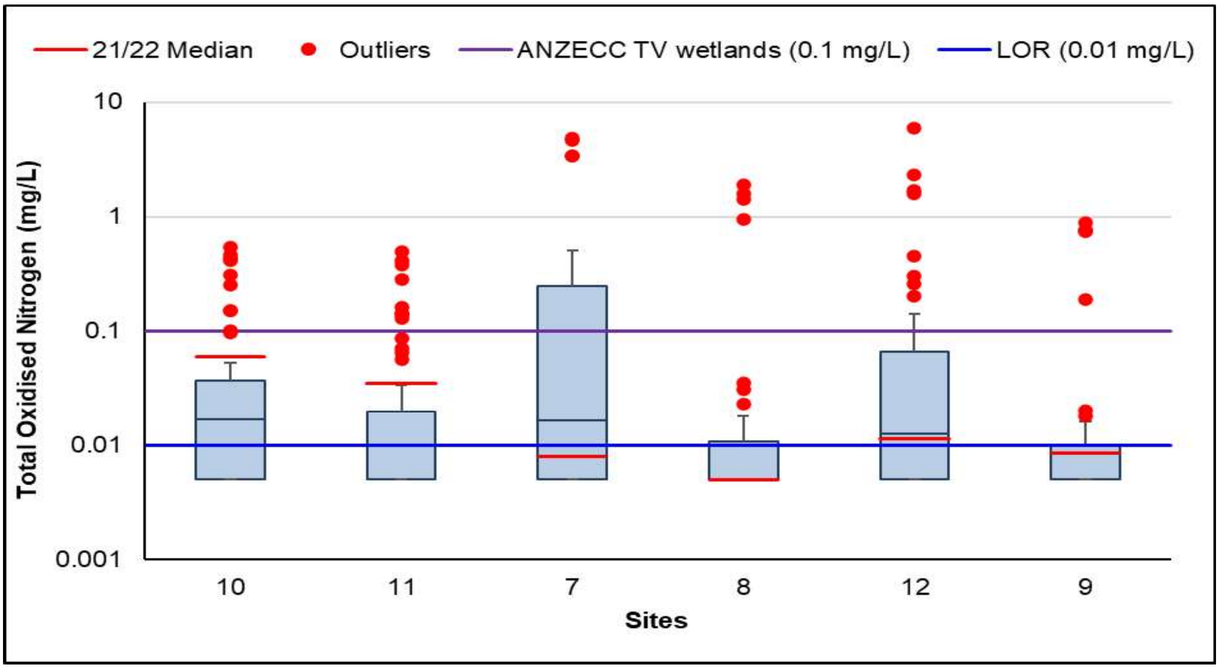


Figure 158. Box plots of total oxidised nitrogen refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

The NOx-N results, collected in 2021 display a very similar pattern that has previously been recorded in the Lakes of the Bull Creek Catchment. NOx-N concentrations across three sites were below relevant ANZECC trigger values for lowland rivers (0.15 mg/L) (Figure 158). Two samples had values above that for wetlands (0.1 mg/L), with samples at site 10 (Fredrick Baldwin) having a concentration of 0.1mg/L in July 2021, and site 11 (Marmion Reserve) having a concentration of 0.14mg/L in August 2021. The lowest concentration recorded in the Lakes at the Bull Creek Catchment was <0.010 mg/L, which is below the LOR (lowest delectable concentration) (Figure 158 and Table D-11 in Appendix D) for NOx-N. Eleven of the 24 samples collected in the 2021 sampling events recorded concentrations below the LOR. The highest concentration in the catchment was 0.14mg/L recorded at site 11 in August.

The sampling event in 2019 was the only year exceedances were seen above ANZECC trigger values for lowland rivers (0.15 mg/L) and wetlands (0.1 mg/L) in all samples and at all sites. TN concentrations collected in 2019, exceeded ANZECC trigger values for lowland rivers (1.2 mg/L) and wetlands (1.5 mg/L) in 9 of the 24 samples collected from the Lakes of the Bull Creek Catchment site (Figure 158 and Table D-10 in Appendix D).

Time series

There were no obvious trends in oxidised nitrogen with time. Site 11 (Marmion Reserve) however, tended to have the lowest overall oxidised nitrogen compared to the other sites. The exceptionally high levels observed during 2019 (Figure 159) may have been a result of the unusually dry year.

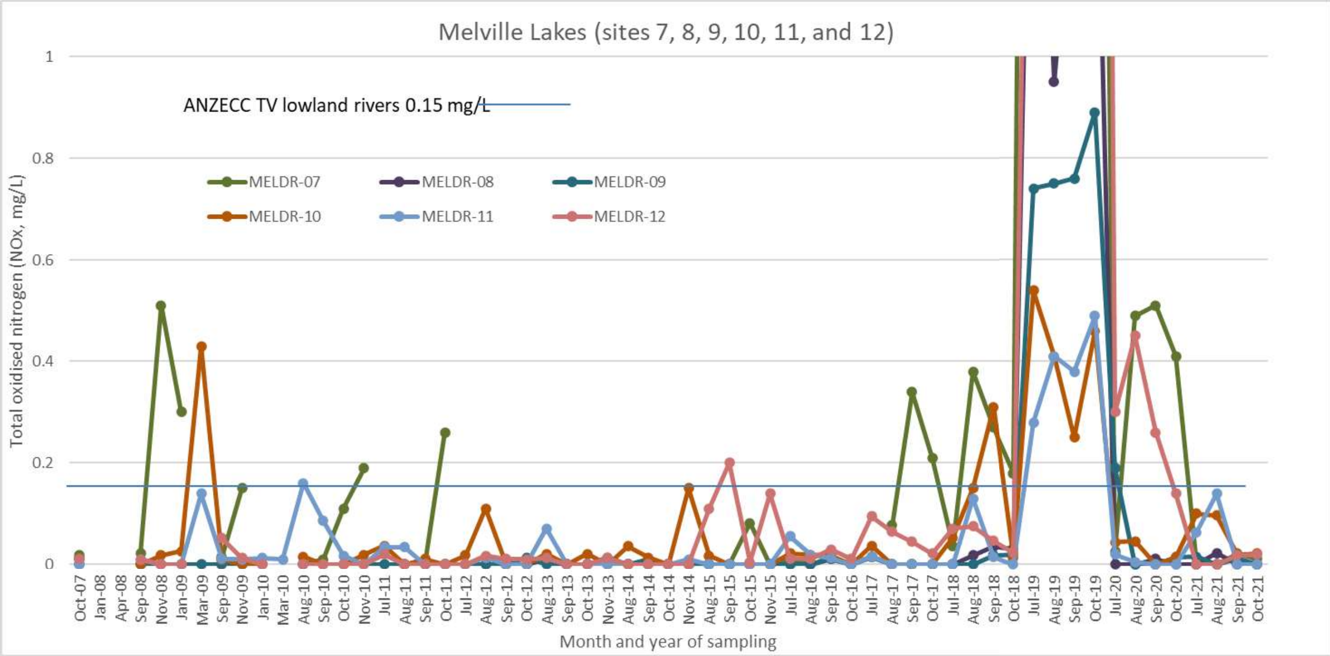


Figure 159.Total oxidised nitrogen at the Melville Lakes. Although there are exceedances and outliers, particularly in 2019 in site 7, 12, 8 and 9, all the data was plotted together to allow visual inspection.

Nitrogen as ammonium/ammonia

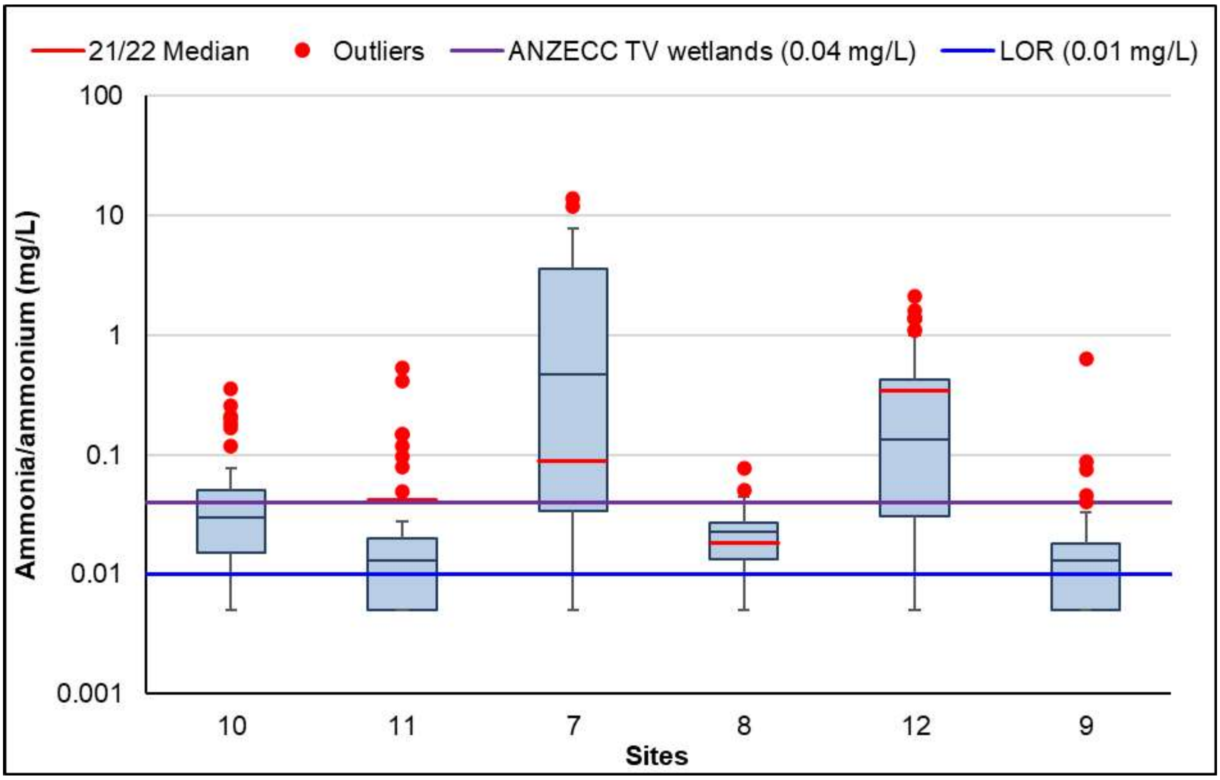


Figure 160. Box plot of ammonium/ammonia 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Nitrogen as ammonium/ammonia (NH4+/NH3-N) had a range of concentrations that were compared to ANZECC trigger values (wetlands: 0.04 mg/L, lowland rivers: 0.08 mg/L). Exceedances occurred in 8 out of 24 samples from across the sites when compared to the ANZECC trigger values for wetlands and lowland rivers (Figure 160 and Table D-12 in Appendix D). It is important to mention that the trigger value for 95% level of protection is only applicable at pH 8 and 20°C according to the ANZECC guidelines (ANZECC and ARMCANZ 2000, see table 8.3.7, page 8.3-161). The trigger value decreases with increasing pH and increases with decreasing pH.

Site 12 (Blue Gum Lake outlet) recorded NH4+/NH3-N concentrations exceeding the trigger values for lowland rivers and wetlands on all sampling occasions, except the July 2021 sampling event where concentrations were below the LOR (lowest detectable limit). Two samples at site 11 (Marmion Reserve) exceeded trigger values in July and August, 0.079mg/L and 0.097mg/L respectively. Two exceedances were also seen in site 7 (Booragoon Lake outlet) in September and October with concentrations of 0.15 mg/L and 0.96 mg/L respectively. Site 10 (Fredrick Baldwin) had one exceedance, with a concentration of 0.063 in August. All other samples were below the ANZECC trigger values (lowland rivers: 0.08 mg/L, wetlands: 0.04 mg/L) as well as NHMRC (2008) recreational trigger value of 0.5 mg/L. Eight samples recorded a concentration below the LOR of 0.01 mg/Lin 2021; one in July at site 12 (Bluegum Lake outlet); three in September at sites 9 (Quenda Lake outlet), 10 (Fredrick Baldwin) and 11

(Marmion Reserve) and four in October at sites 8 (Piney Lakes outlet), 9 (Quenda Lake outlet), 10 (Fredrick Baldwin) and 11 (Marmion Reserve).

Time series

Looking at nitrogen as ammonia/ammonium levels with time, it becomes clear that this is highly variable, particularly in Booragoon Lake (site 7) and Blue Gum Lake (site 12) compared to that at Piney Lakes (site 8) and Quendas Lake (site 9) in particular (Figure 161). The association between weather, nitrogen cycles and site-specific ecology needs further examination.

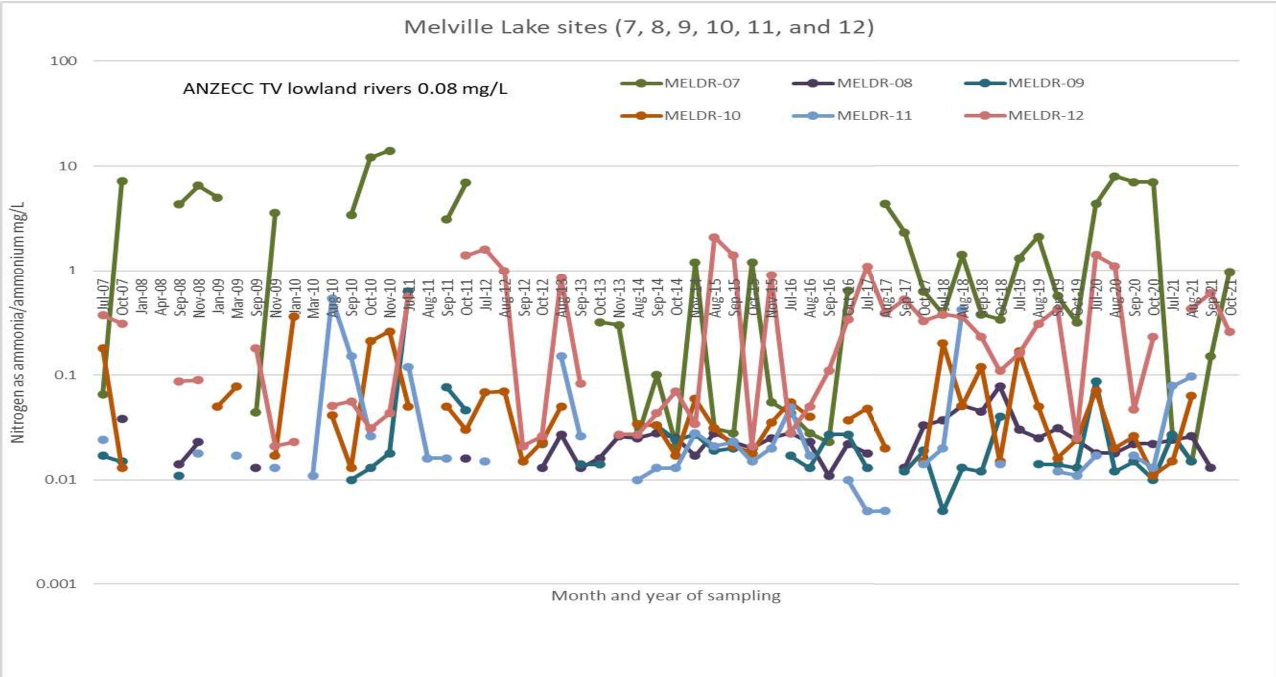


Figure 161. Logarithmic plot of historical nitrogen as ammonia/ammonium levels at the Melville Lake sites.

Organic nitrogen (dissolved and total)

As no guideline currently exists for TON and DON it is difficult to assess the results for these parameters in terms of the threats they may pose to ecosystems and/or human health. This is despite the LOR for organic nitrogen being <0.025 mg/L. There is, however, some evidence that organic nitrogen compounds are taken up by phytoplankton and bacteria, and this nitrogen may therefore influence composition and densities of phytoplankton and bacteria. It is therefore valuable to collect this information and determine source/s of total nitrogen. Site 7 (Booragoon Lake outlet) recorded the highest median concentration of TON of 2.4mg/L, with concentrations between 2.3mg/L, and 0.58mg/L. Site 11 (Marmion Reserve) recorded the lowest TON concentrations in the range of 0.27 to 0.55 mg/L, with a median of 0.4mg/L.

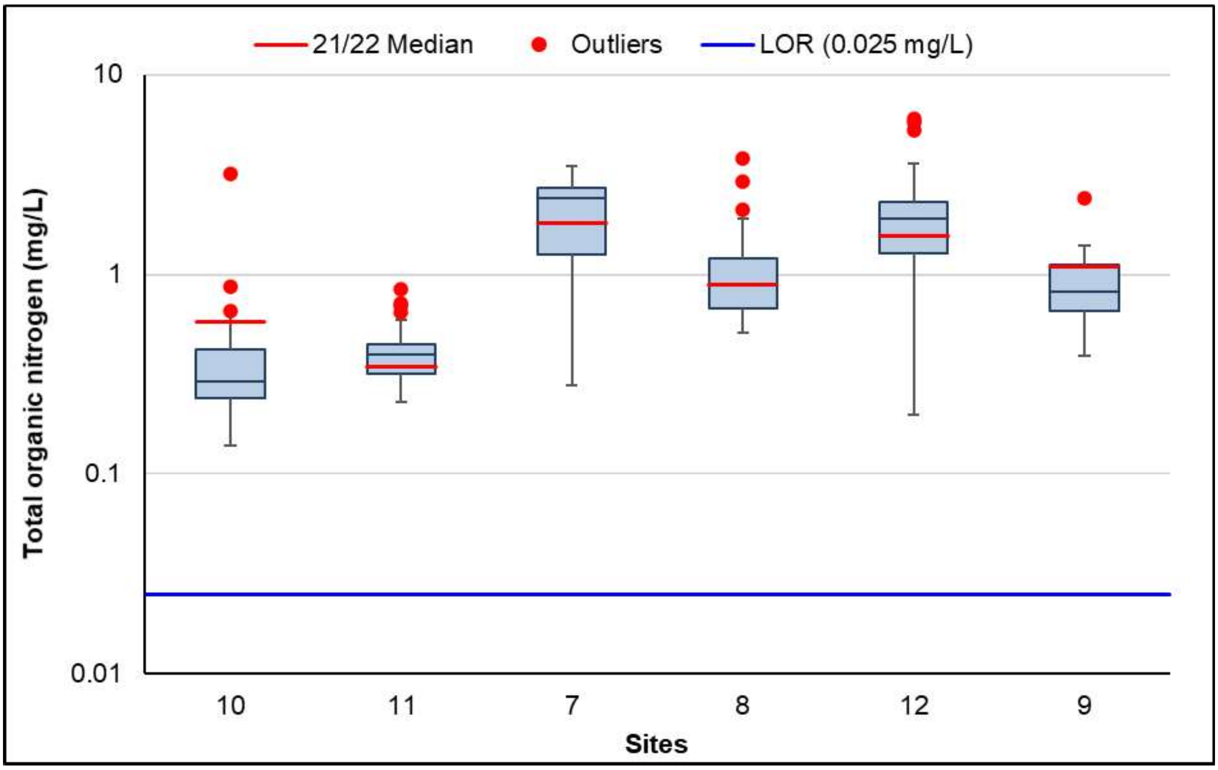


Figure 162. Box plot of total organic nitrogen 2007-2020 historical median values, with a red line indicating the median value in 2021.

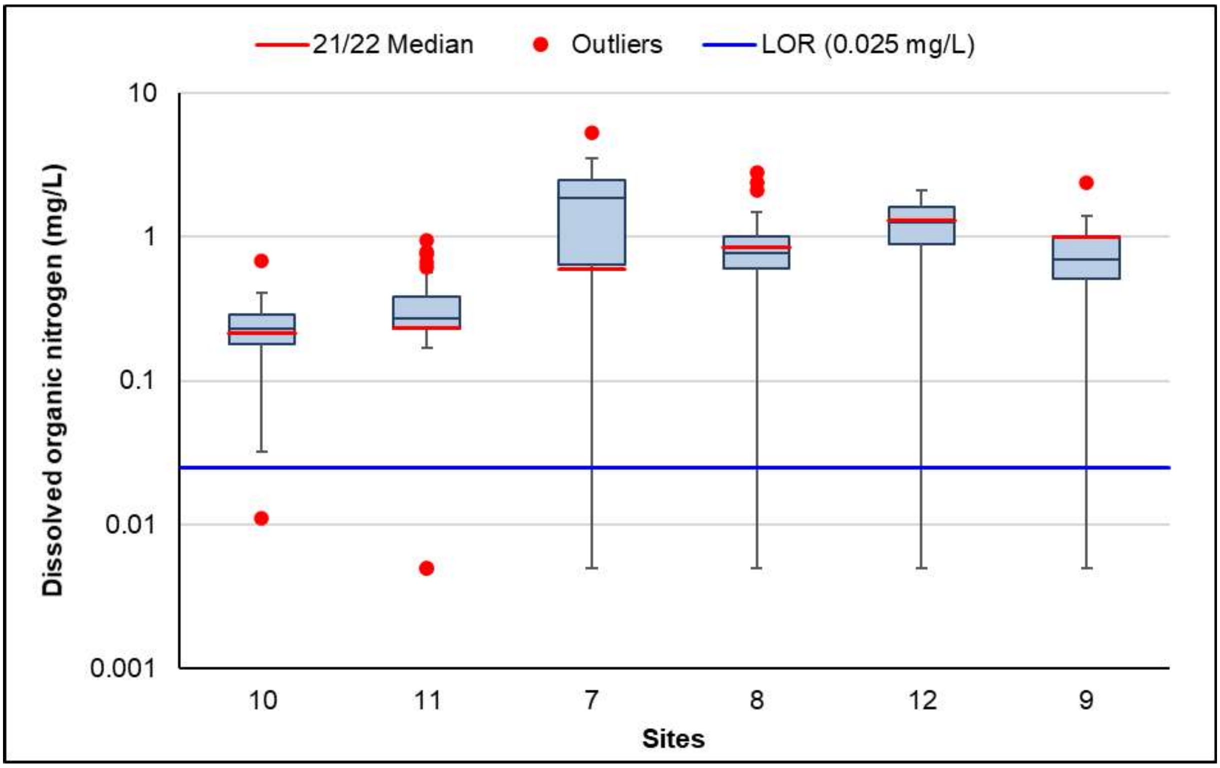


Figure 163. Box plots of dissolved organic nitrogen refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

Total (TON, Figure 162) and dissolved organic (DON, Figure 163) nitrogen follow similar patterns at most sites, except for Booragoon Lake (site 7) which has the highest overall DON and Blue Gum Lake (site 12) which has the highest overall TON. Overall, the DON and TON at Quenda Lake (site 9) and Marmion Reserve (site 11) were lowest and that at Fredrick Baldwin (site 10) and Piney Lakes (site 8) intermediate. DON concentrations were not too dissimilar to TON concentrations. Site 7 had the highest median of 1.85mg/L followed by site 12 at 1.25mg/L. The lowest median DON concentration occurred in site 10 at 0.23mg/L followed by site 11 with a median concentration of 0.28 mg/L, with the highest median of 1.3 mg/L in site 12 (see Appendix G). This is usually predominantly in the form of organic nitrogen, with nitrogen as ammonium/ammonia concentrations also often exceeding the wetlands trigger value at these sites and occasionally exceeding the trigger value for protection of biota at site 7 (Booragoon Lake). High total nitrogen concentrations tended to respond with high phosphorus concentrations at these sites.

Time series

The historical data of dissolved (Figure 164) and total (Figure 165) nitrogen show that levels in sites 10 and 11 (Fredrick Baldwin and Marmion Reserve) have remained lower and more stable than those at sites 7 and 12 in particular. In these latter sites, the dissolved organic nitrogen in site 7 seems to be higher than in site 12, while the reverse situation tends to occur when examining total organic nitrogen. The dynamics of nitrogen in these wetlands, in particular those with high levels of nitrogen in various forms needs further study.

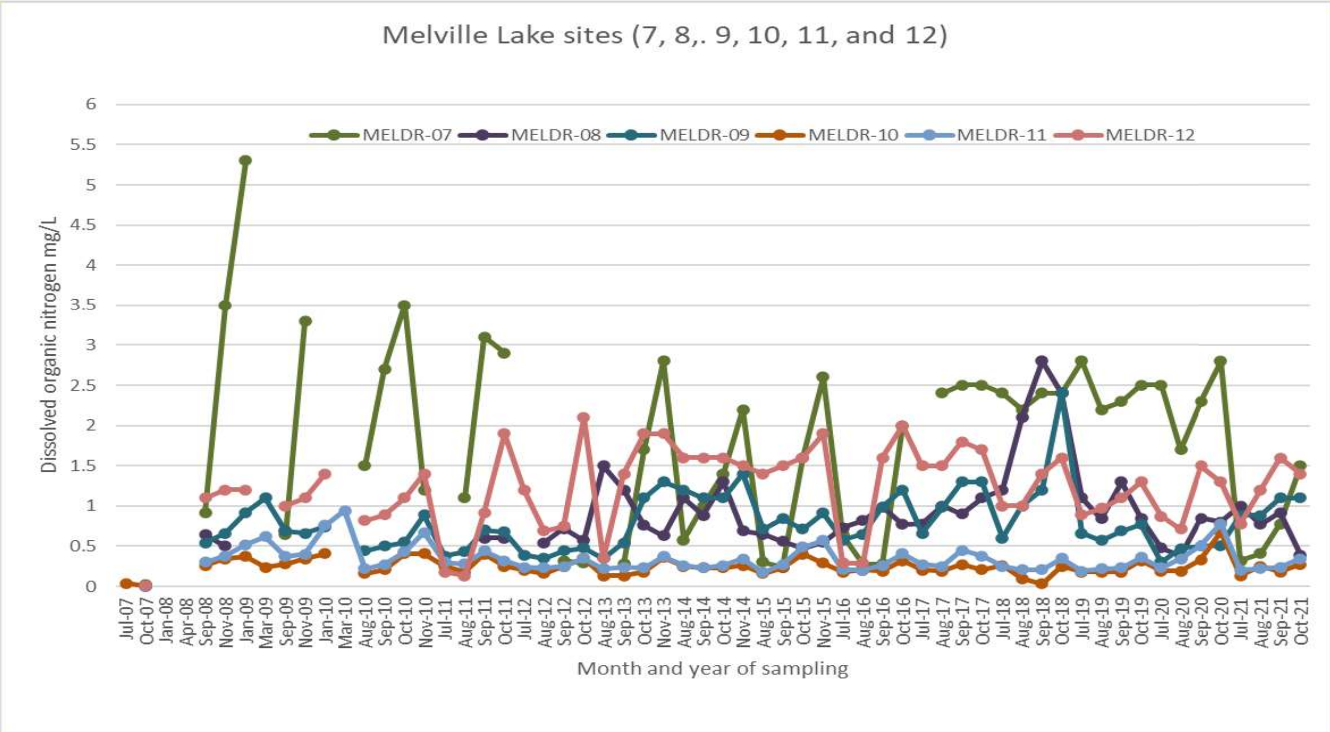


Figure 164. Historical data of the dissolved organic nitrogen in the Melville Lake sites.

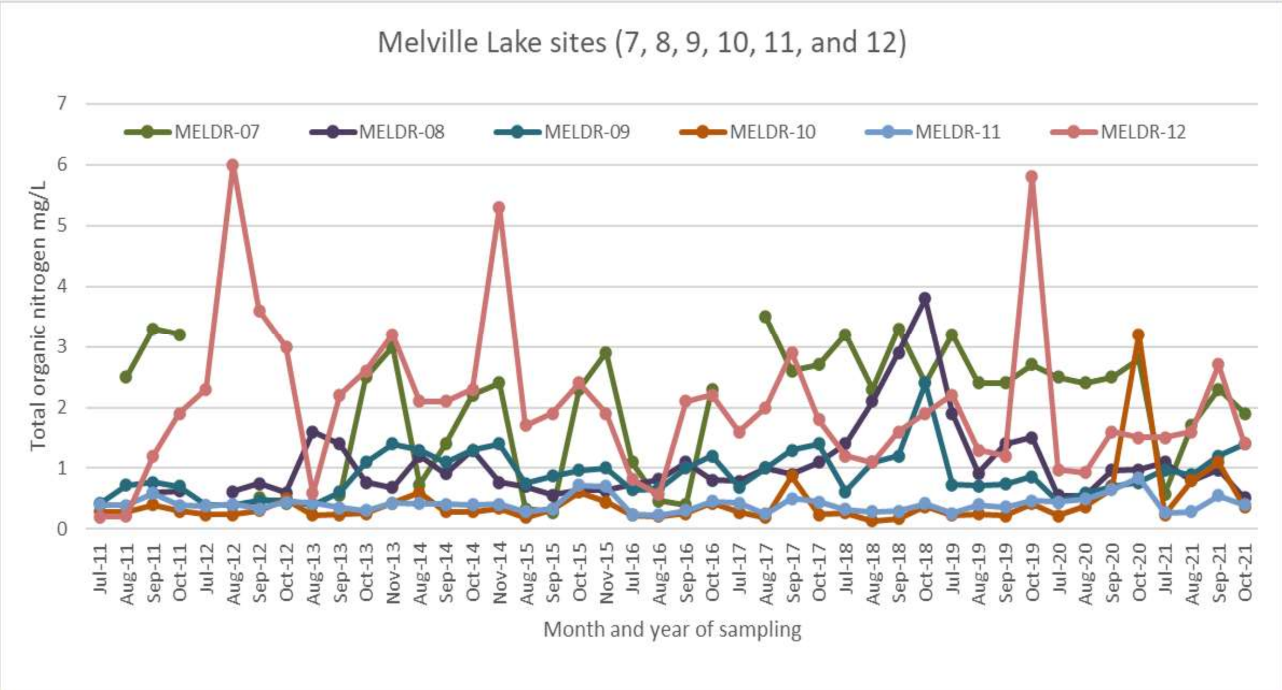


Figure 165. Historical data of the total organic nitrogen at the Melville Lake sites.

More specific information identified that at site 12 the maximum concentrations of TON recorded in all the years of monitoring was 7.1 mg/L, 5.4 mg/L and 5.9 mg/L in August 2012, November 2014, and October 2019, with all other TN values at all sites below 4 mg/L. It should be noted that site 7, while although consistently recording very high and variable concentrations, has recorded TN values similar to that previously observed during sampling between 2007 and 2011 after a period of lower (in terms of this site) values from 2012 to 2019. In addition, the TN at both Fredrick Baldwin (site 10) and Marmion Reserve (site 11) has remained below 1 mg/L and that at Quenda Lake (site 9) and Piney Lake (site 8) below 1.5 mg/L on most occasions since sampling began at these sites. That at Blue Gum Lake (site 12) has in general been below 2 mg/L since sampling began.

Phosphorus

Total and filterable reactive phosphorus

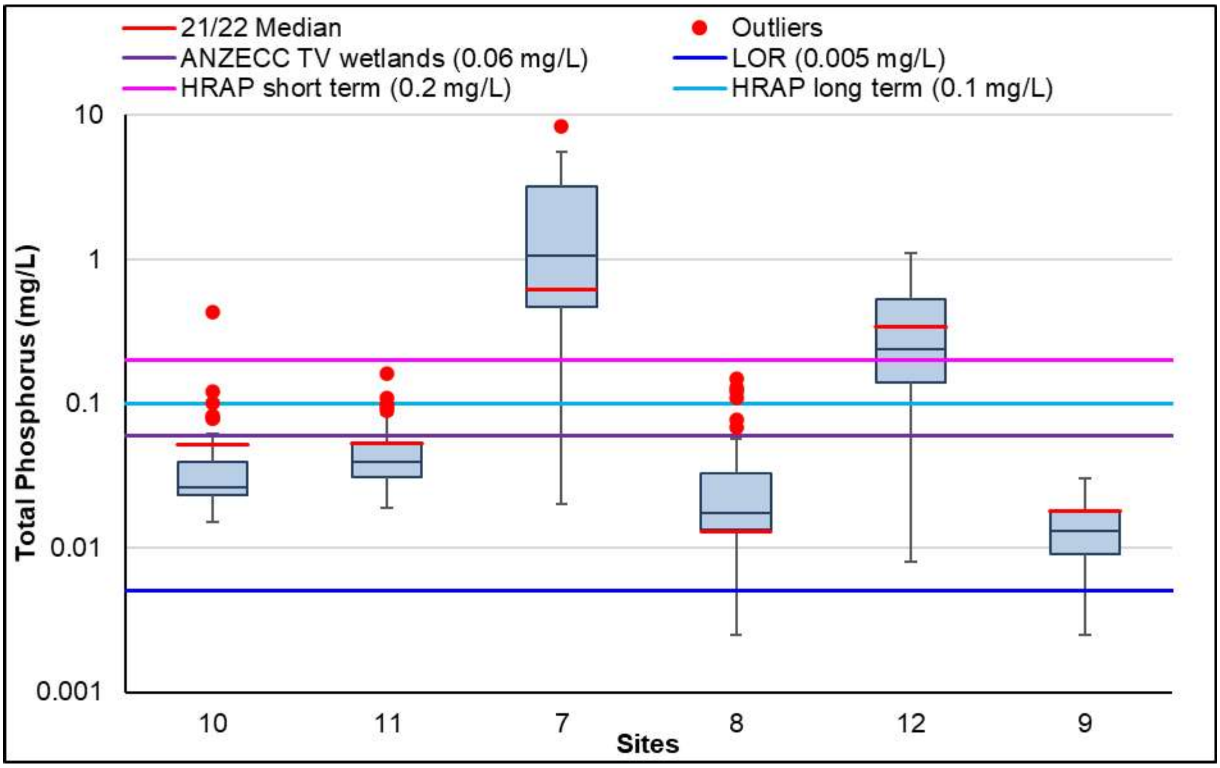


Figure 166. Box plots of total phosphorus refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

TP is a measure of all phosphorus in the water encompassing both soluble and particulate forms. Eleven TP concentrations recorded in Lakes of the Bull Creek Catchment sites in 2021 exceeded relevant ANZECC trigger values (lowland rivers: 0.065 mg/L, wetlands: 0.06 mg/L) and eight exceeded the HRAP long term 0.1mg/L, six of the samples from the Lakes of the Bull Creek Catchment had exceedances when compared against HRAP short term 0.2mg/L assessment criteria (Figure 166 and Table D-15 in Appendix D). TP concentrations were the highest in site 12 with detections between 0.19 and 0.53mg/L and a median of 0.24mg/L. The lowest TP concentration were seen in site 9 with detection between 0.008mg/L and 0.053mg/L and a median of 0.0154mg/L. There were no samples that recorded concentrations below the LOR (0.005 mg/L) throughout the sampling events of 2021.

The samples collected from the sites within the Lakes of the Bull Creek Catchment had eleven detections of FRP concentrations within sites 7, 8, 10, 11 and 12. There were four exceedances relevant to ANZECC trigger values (lowland rivers: 0.04 mg/L, wetlands: 0.03 mg/L). All other concentrations were recorded below the LOR (0.005 mg/L). (Figure 167 and Table D-16 in Appendix D). Site 7 had one exceedance of the ANZECC trigger values (lowland rivers: 0.04 mg/L, wetlands: 0.03 mg/L) in October, with a concentration of 0.48mg/L. Site 12 had the highest levels of FRP, with three samples having exceedances of the trigger values in August, September, and October with concentrations of 0.17mg/L, 0.42mg/L and 0.3mg/L respectfully.

Time series

When the TP (Figure 168) and FRP (Figure 169) are examined over time, there have been persistent differences between the sites but no overall trends. In particular, both TP and FRP has been high in Booragoon Lake (site 7). Both have been quite high in Quenda Lake and Piney Lakes (sites 9 and 8), intermediate at Fredrick Baldwin (site 10) and lowest in Blue Gum Lake and Marmion Reserve (sites 12 and 11).

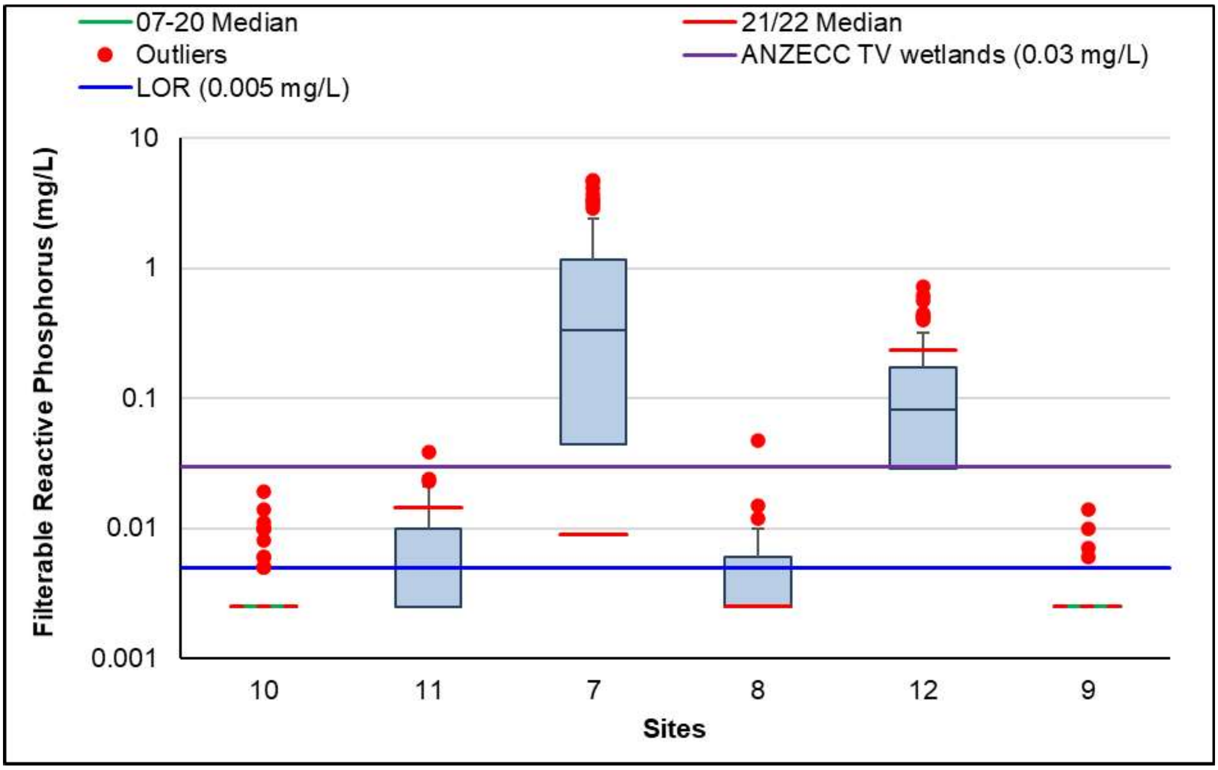


Figure 167. Box plots of FRP refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

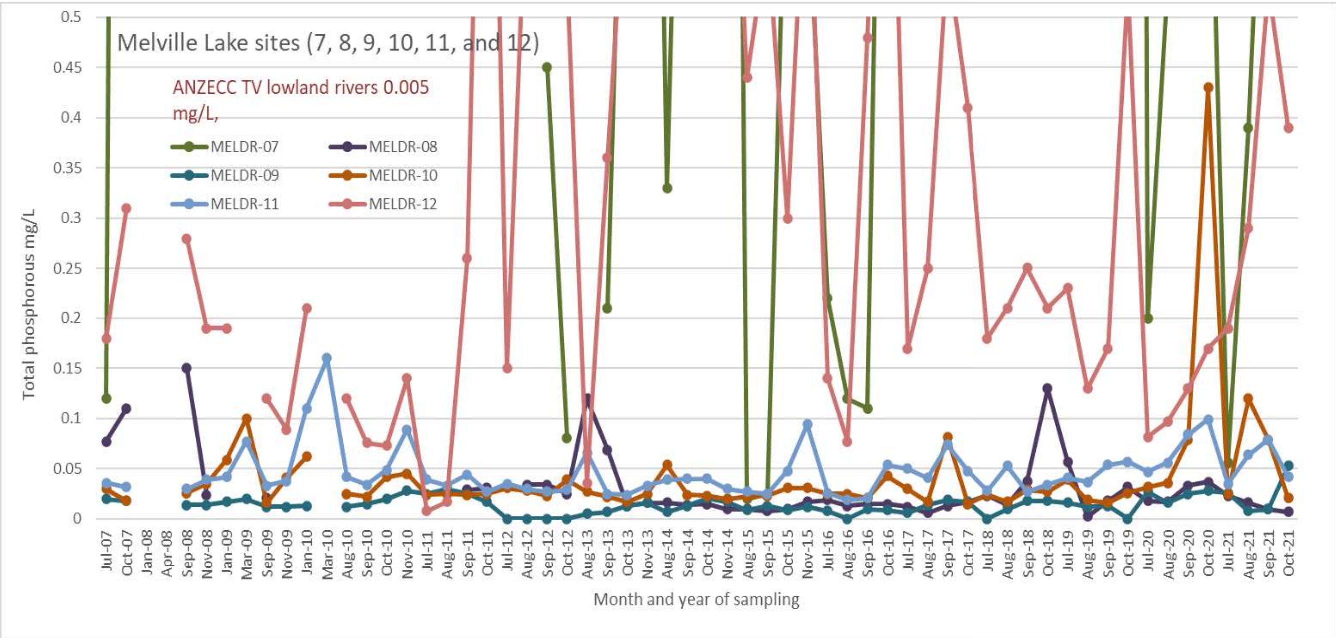


Figure 168. Historical data of the total phosphorus in the Melville Lakes. The y values excluded several values from sites 7 and 12 to be seem. This was done to make overall variations and trends visually clearer.

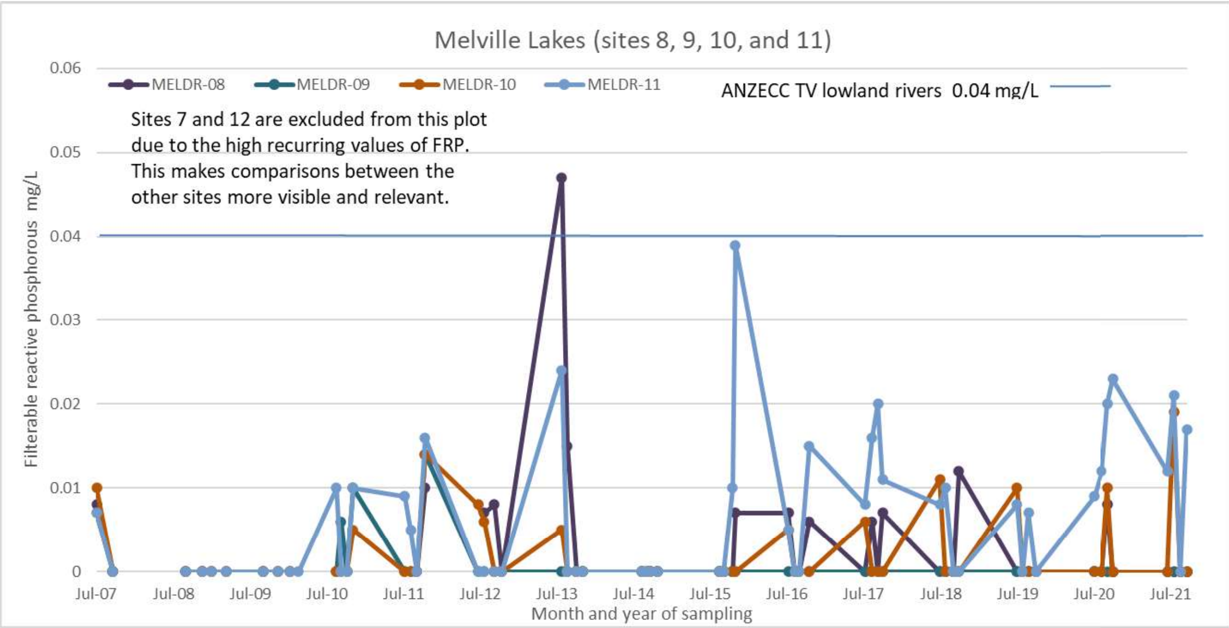


Figure 169. Historical data of FRP at the Melville Lake sites.

Metals

Metals in water

Hardness

The ANZECC guidelines classifies Soft water as having a hardness of 0 to 59 mg/L, Moderate water with 60 to 119 mg/L and Hard water with 120 to 179 mg/L calcium carbonates. In 2021 water hardness in the surface water of the Lakes of the Bull Creek Catchment varied extensively from a minimum of 35mg/L in July at site 10, the maximum recorded at site 7 in September with a concentration of 420mg/L (Figure 170 and Table D-17 in Appendix D). The samples collected in July were seen to have varied the most with concentrations ranging between 35mg/L and 360mg/L. Site 7 had the highest results ranging between 360 and 420 mg/L and the water at this site can be classified as Hard. Site 12 had the lowest concentrations between 57mg/L and 80mg/L and can be classified as Soft to Moderate.

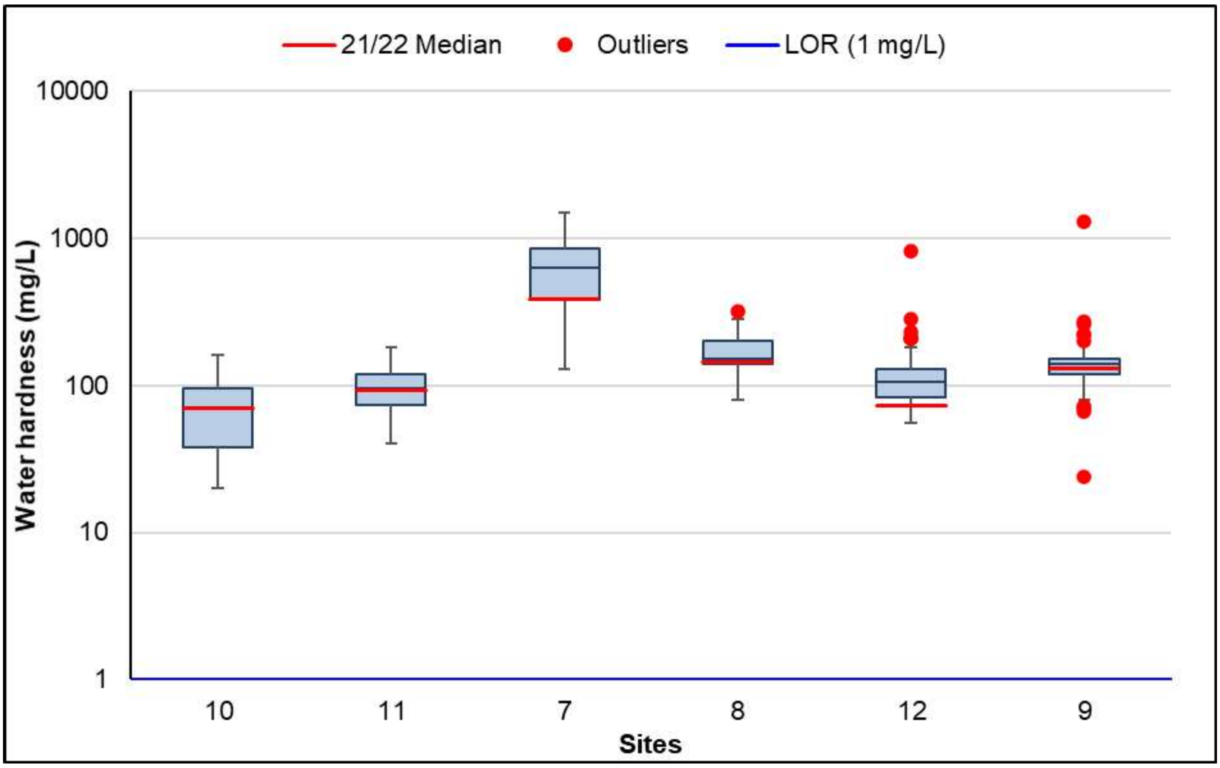


Figure 170. Box plot of water hardness 2007-2020 historical median values, with a red line indicating the median value in 2021.

Time series

There are some slight trends in the data. In particular that the water hardness at Booragoon Lake (site 7) is trending downwards with time, and that in Piney Lakes (site 8) is trending upwards, while that of the other lakes have remained constant (Figure 171). There are some spikes in hardness of waters in November 2010 in Marmion Reserve and October 2015 in Blue Gum Lake. The spike in Blue Gum Lake in 2015 coincides with a drop in Booragoon Lake. The cause of this is unknown, but site situations such as Blue Gum Lake being closer to the river and the depth to groundwater is less at this lake than at Booragoon Lake may influence this variation.

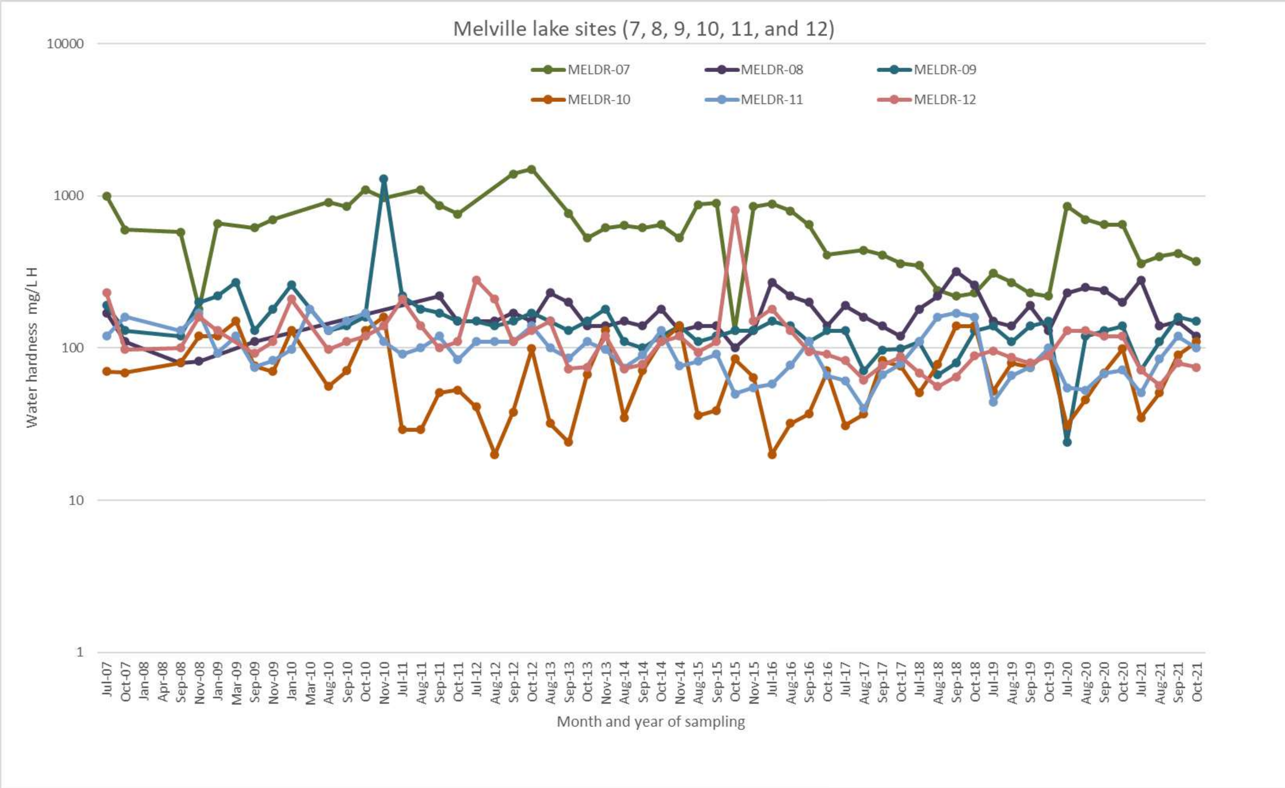


Figure 171. Logarithmic plot of water hardness at the Melville lake sites.

Aluminium

Box whisker

All samples collected in 2021 exceeded the minimum ANZECC TV associated with their total aluminium concentration (Figure 172). The influence of pH on metal solubilities was considered important to refer to as the pH at Booragoon Lake and Piney Lakes (sites 7, and 8) were below 6.5 and the total (Figure 172) and soluble (Figure 173) aluminium levels exceeded the ANZECC TVs of 0.0008 mg/L At the other lakes, where the pH was above 6.5, the 2021 medians exceeded the ANZECC TV of 0.055 mg/L. The highest variation in readings occurred in Booragoon Lake and the lowest variations at Piney Lakes, Fredrick Baldwin, and Marmion Reserve which suggests that site conditions such as pH may have a significant impact on the concentration of aluminium in these lakes.

Time series

When the data over time is examined, it reveals some differences between sites (Figure 174). In particular that the total aluminium in Fredrick Baldwin and Marmion Reserve (sites 10 and 11) remains lowest and unchanging. In contrast, that of the other sites is more variable, in particular in Booragoon Lake and Blue Gum Lake (sites 7 and 12) and possibly increasing in Piney Lakes and Quenda Lake (sites 8 and 9). Soluble aluminium in these sites show the same differences as total aluminium between sites, and while soluble aluminium was higher in most sites in 2016 through to 2019, there are no clear trends with time (no plot of soluble aluminium was therefore included in this report).

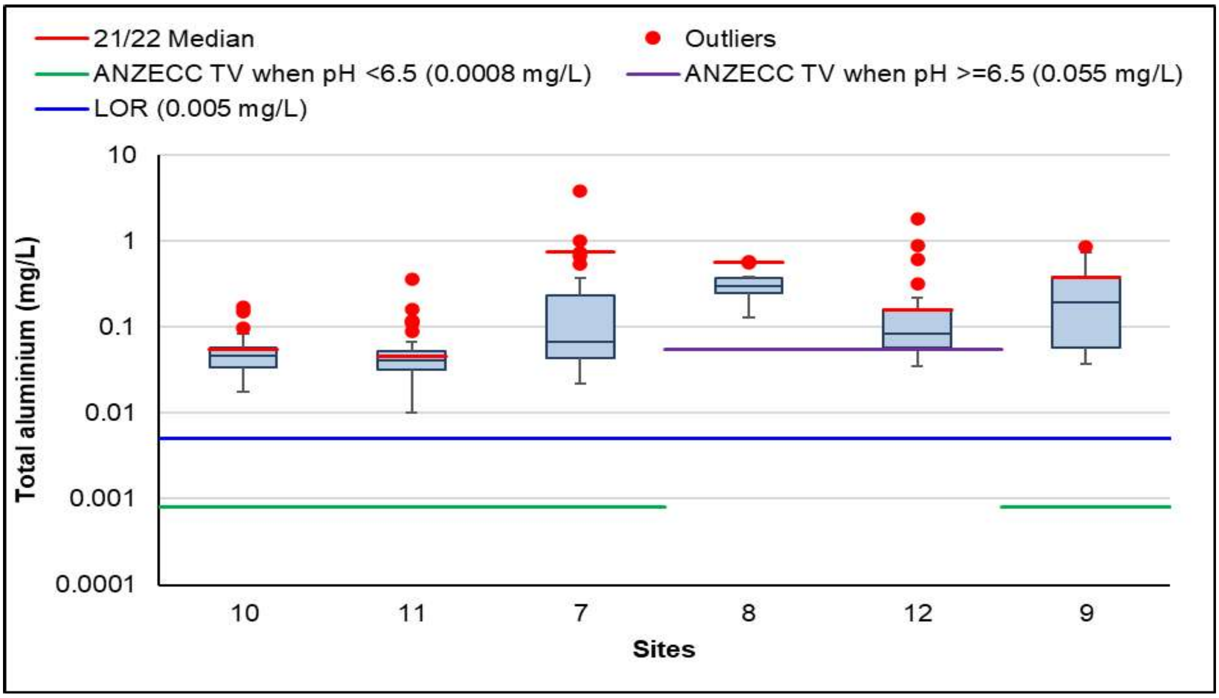


Figure 172. Box plots of total aluminium refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

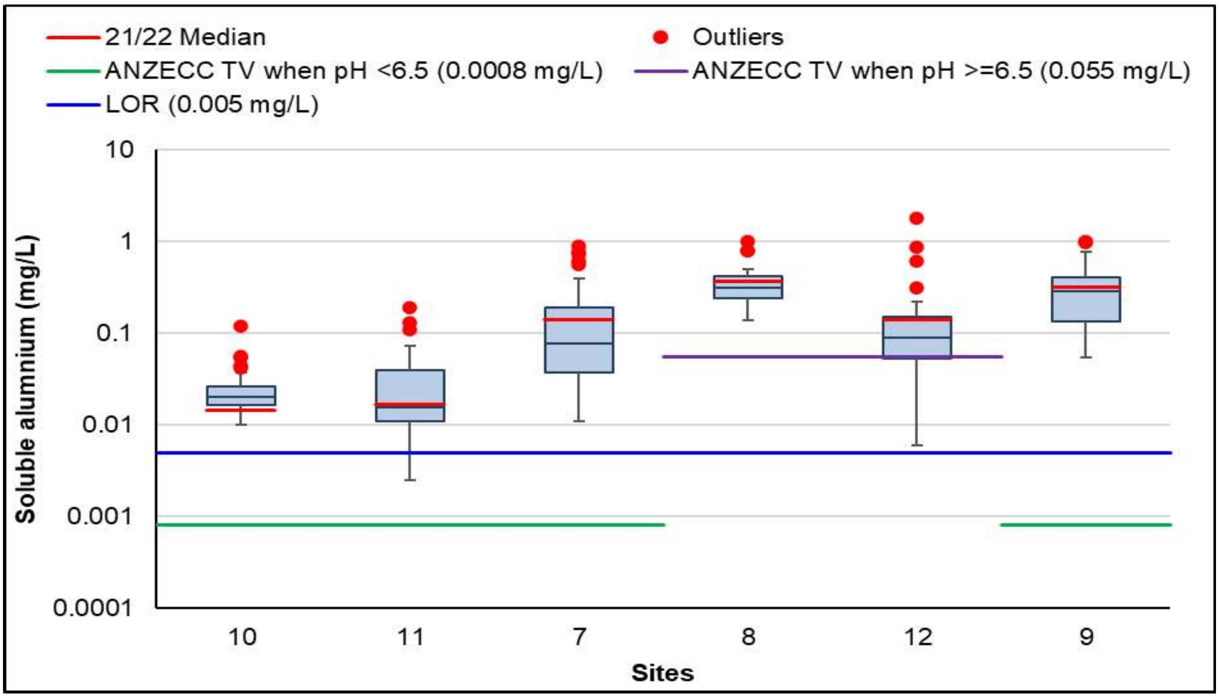


Figure 173. Box plots of soluble aluminium refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

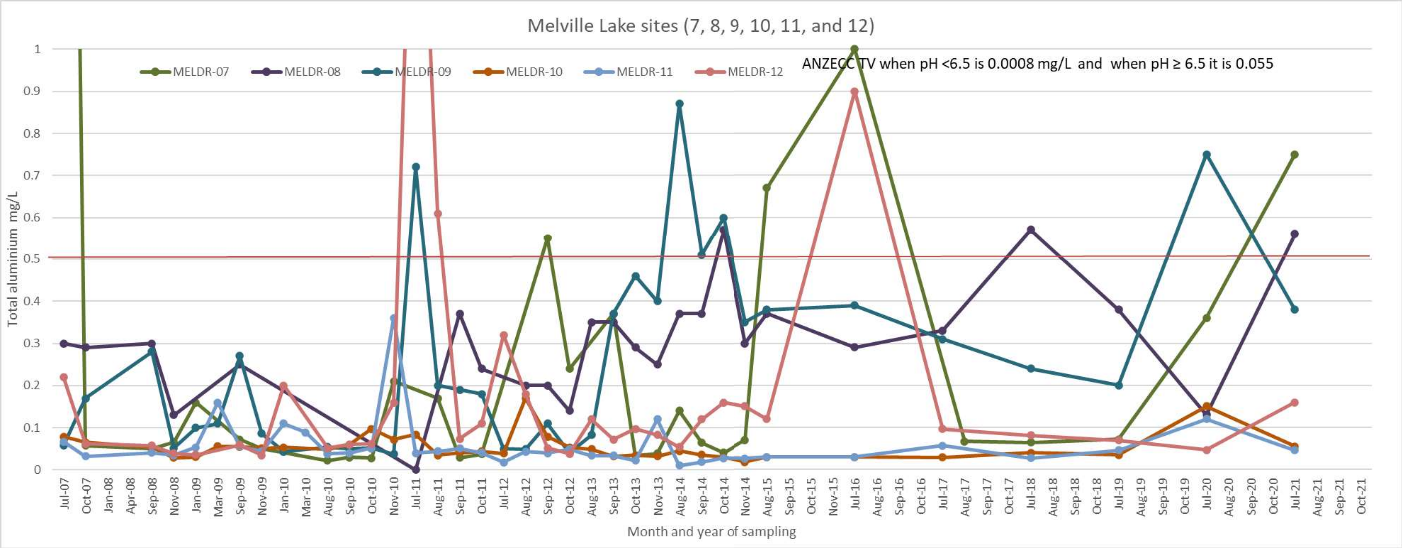


Figure 174. Total aluminium in the Melville Lakes. Note: the y axis is scaled to show details between sites. Two high values (2007 at site 7 and 2011, site 12) are therefore outside the margin of the plot.

Chromium

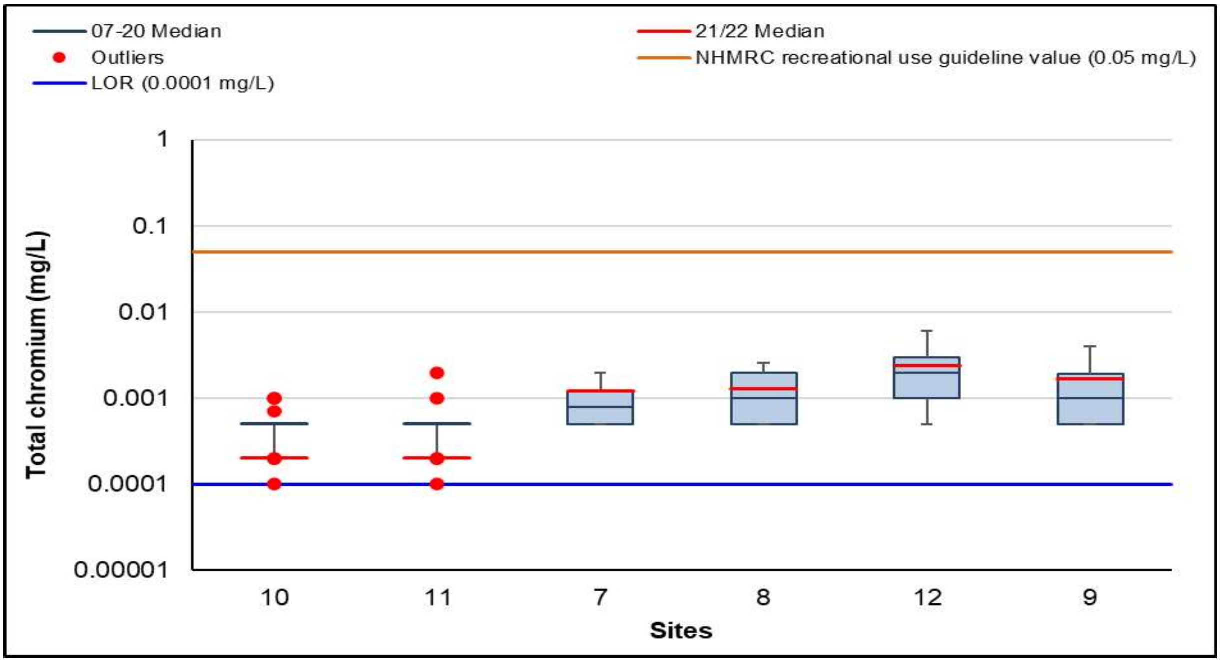


Figure 175. Box plots of total chromium refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

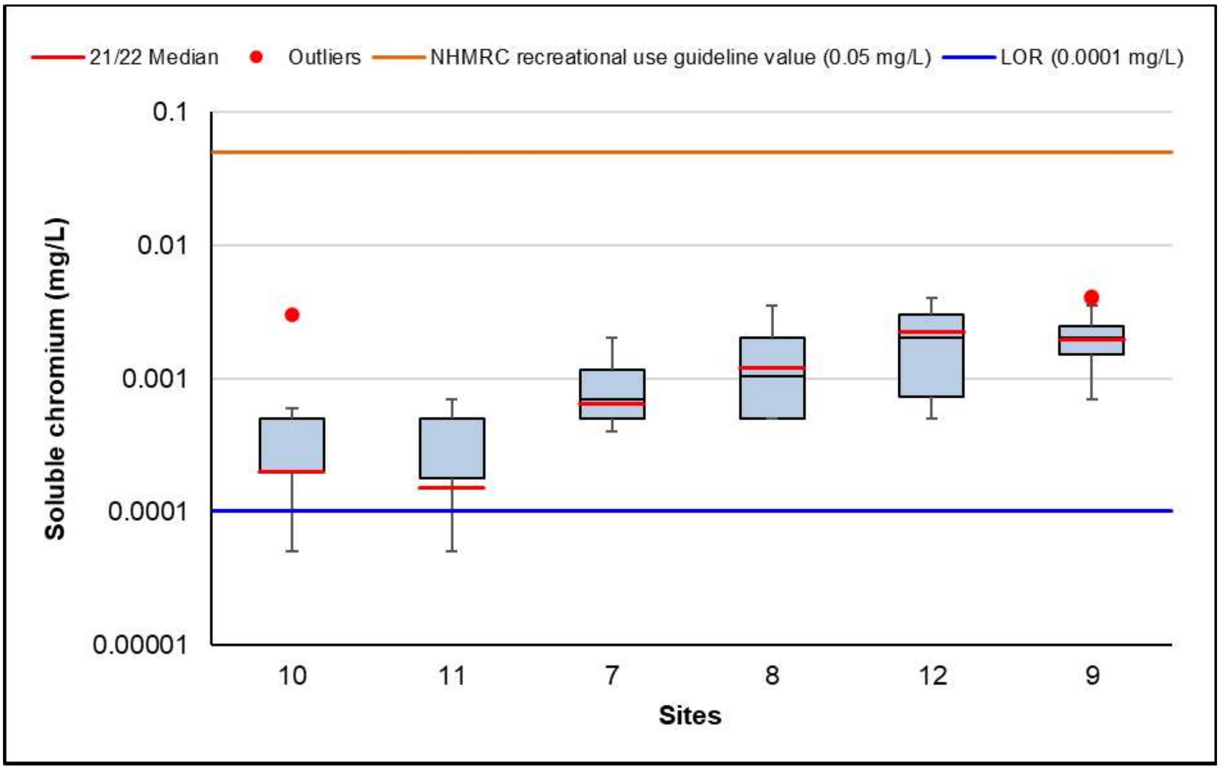


Figure 176. Box plots of soluble chromium refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

Total chromium and soluble chromium (where both include Cr3+ and Cr6+ chromium fractions) concentrations recorded at all Melville Lake sites were below ANZECC hardness adjusted trigger values for 95% protection of biota (unmodified trigger value for chromium: 0.0033 mg/L) in 2021 (Figures 175 and 176, Table D-20, and Table D-21 in Appendix D). The trigger value for Cr3+has been selected (and not Cr6+) as in natural water Cr3+ is the predominant species present due to a range of factors. The trigger value for chromium is affected by water hardness. Therefore, the modified trigger values shown on the graph vary, dependent on the water hardness concentration recorded at each site (see Table D-17 in Appendix D). While all concentrations of soluble chromium were below the NHMRC recreational guidelines of 0.05 mg/L, the highest records was from a sample obtained in September 2021 from site 12 (0.0026 mg/L).

Time series

There are possible patterns in total (Figure 177) and soluble (Figure 178) chromium since sampling began, in particular when exploring trends pre- and post- 2011. Accordingly, that of Quenda Lake and Blue Gum Lake (sites 9 and 12) have been settling in to become higher in comparison to the other sites, while these parameters at Marmion Reserve and Fredrick Baldwin (sites 11 and 10) are remaining lowest. Booragoon Lake and Piney Lakes (sites 7 and 8) are intermediate to these.

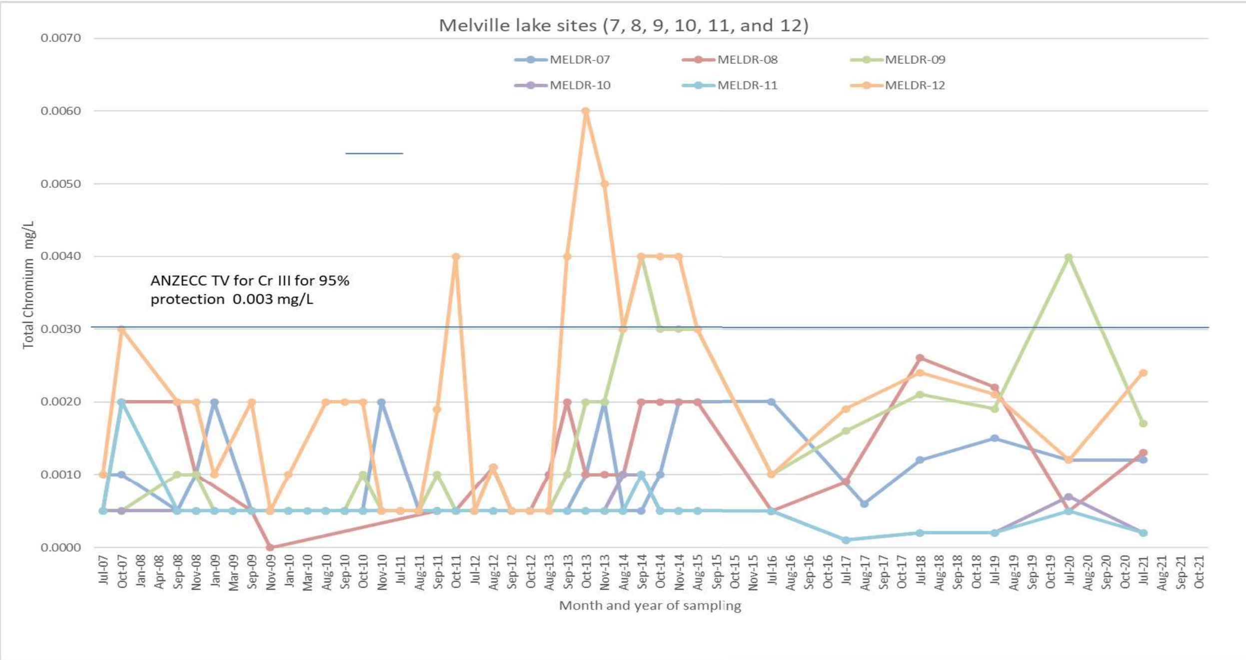


Figure 177.Total chromium at the Melville lake sites.

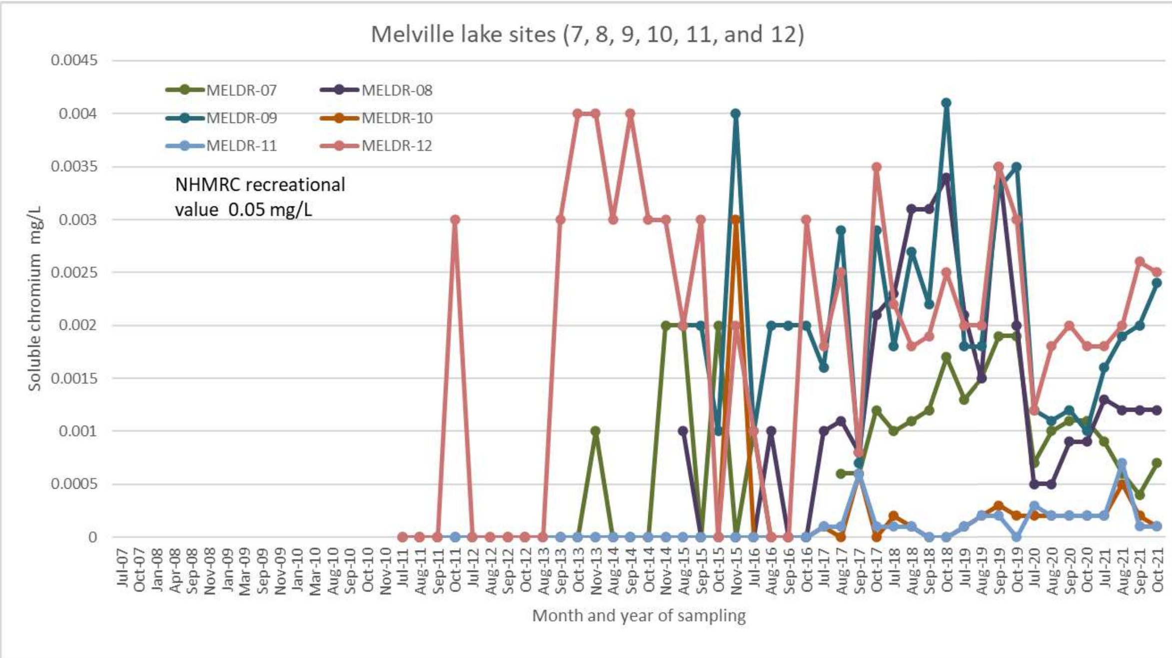


Figure 178. Soluble chromium at the Melville Lake sites.

Copper

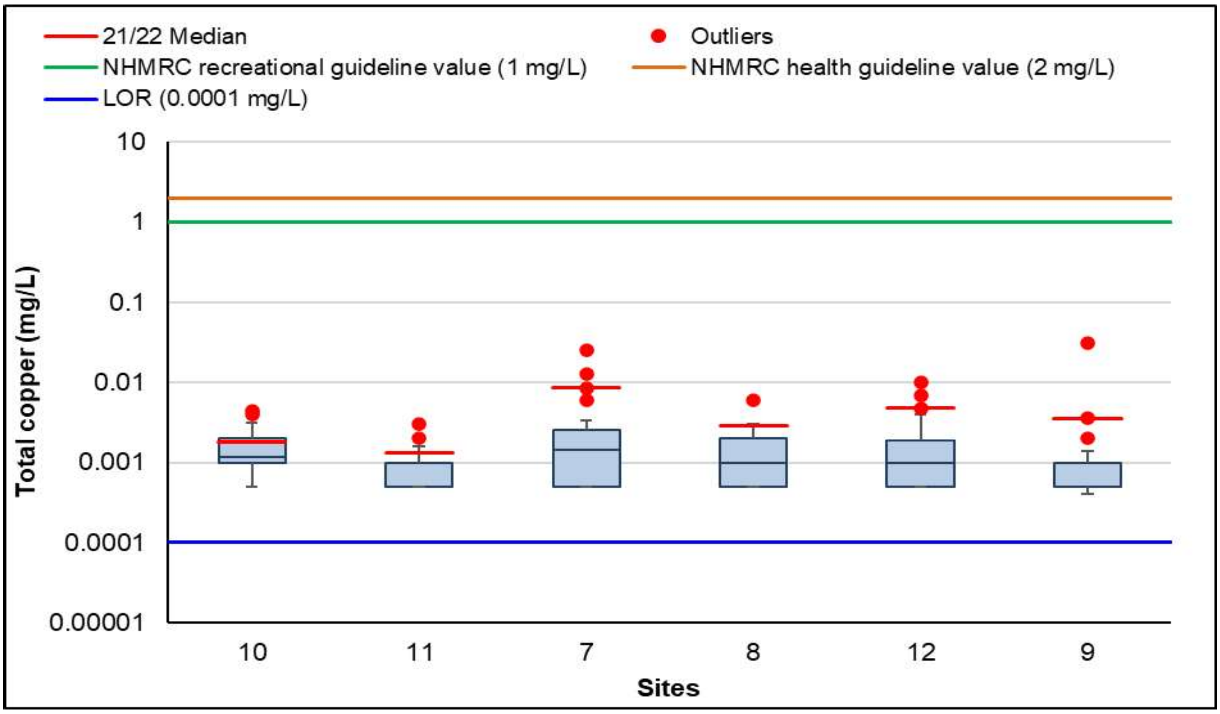


Figure 179. Box plots of total copper refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

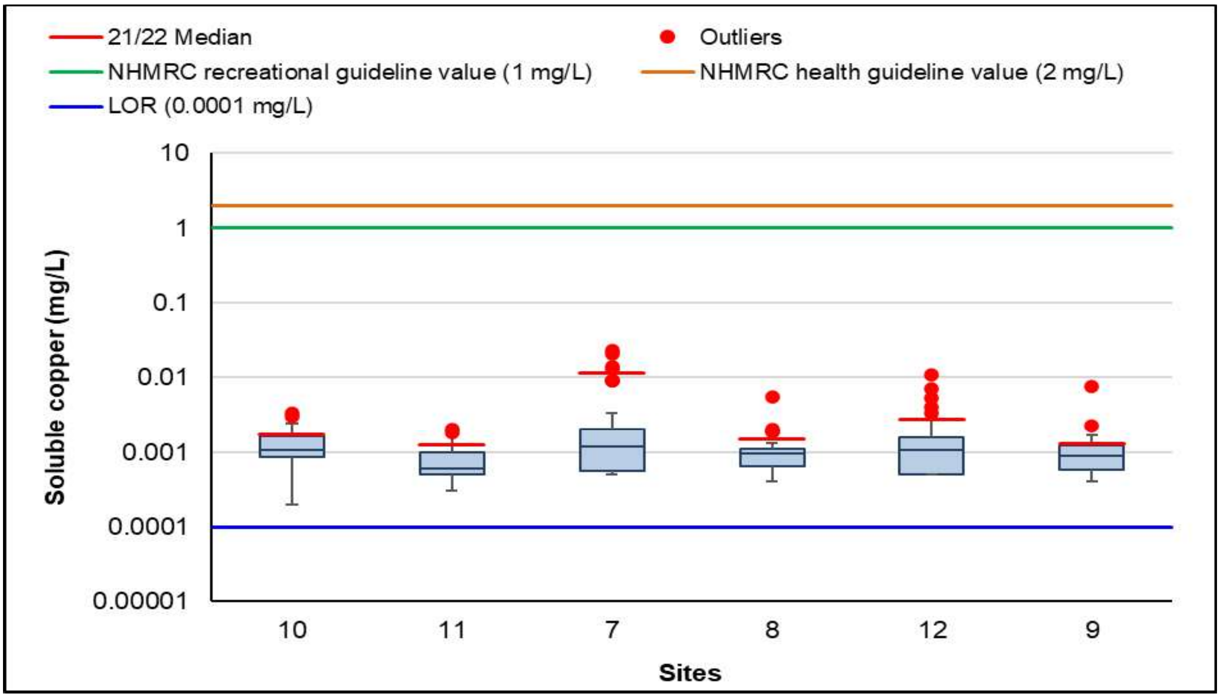


Figure 180. Box plot of soluble copper 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

The variation in total and soluble copper was highest in Booragoon Lake and Quenda Lake (sites 7 and 9) and the median for these year highest in Booragoon Lake, Blue Gum Lake, and Quenda Lake (sites 8, 12 and 9) in order in 2021 (Figures 179 and 180). All these values were however, below ANZECC guidelines unmodified trigger value for copper in water for 95% level of protection is 0.0014 mg/L. The 95% protection trigger value for copper is affected by water hardness and the modified trigger values shown on the graph may be dependent on the water hardness concentration recorded at each site (for the details and calculations see Table D-22 and Table D-23 in Appendix D).

Time series

Examining total (Figure 181) and soluble (Figure 182) copper results over time reveals that since 2016 the large variation in values seems to be stabilising with indications of upwards trends in all sites with total and soluble copper exceeding ANZECC guidelines.

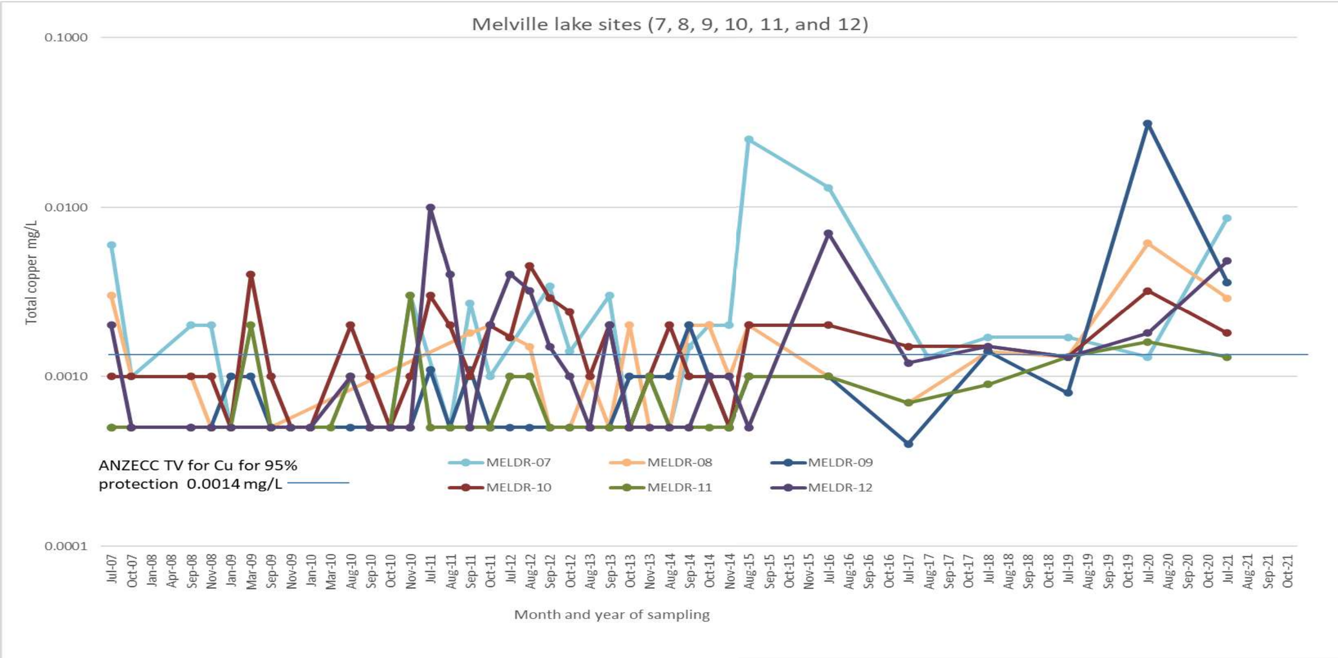


Figure 181. Total copper at the Melville Lakes sites.

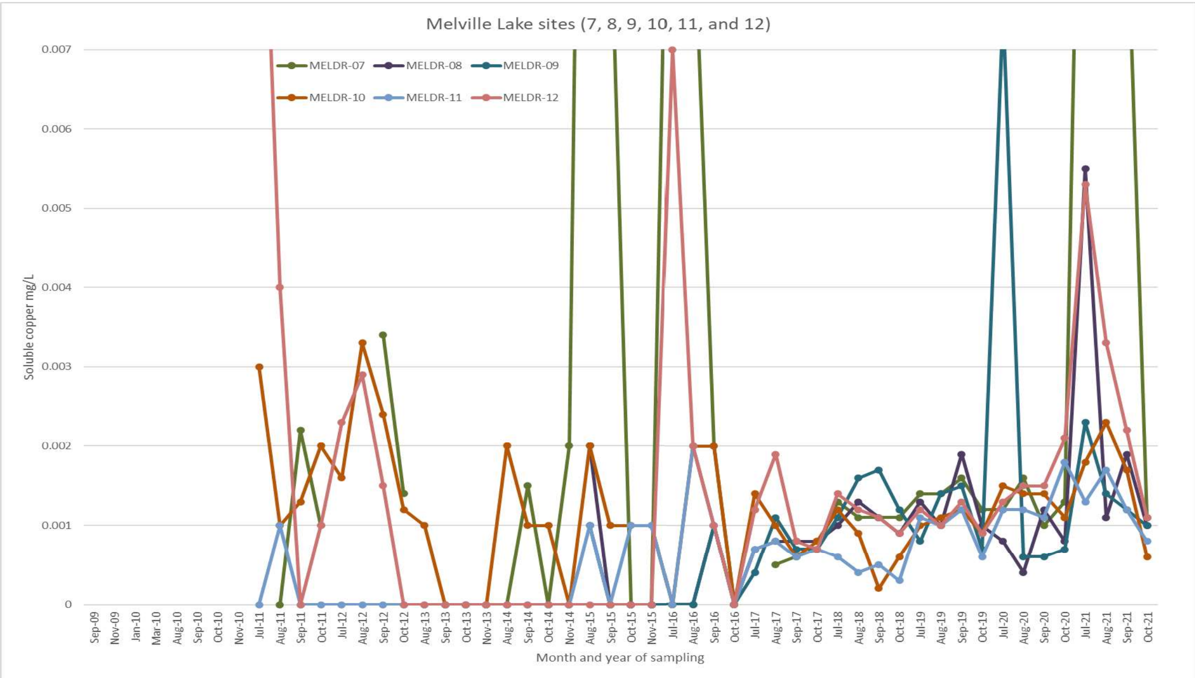


Figure 182. Soluble copper at the Melville Lakes sites. Note; values over 0.007 mg/L are not shown on the plot. The purpose was to 'pull out' the lower-level variation for visibility.

Iron

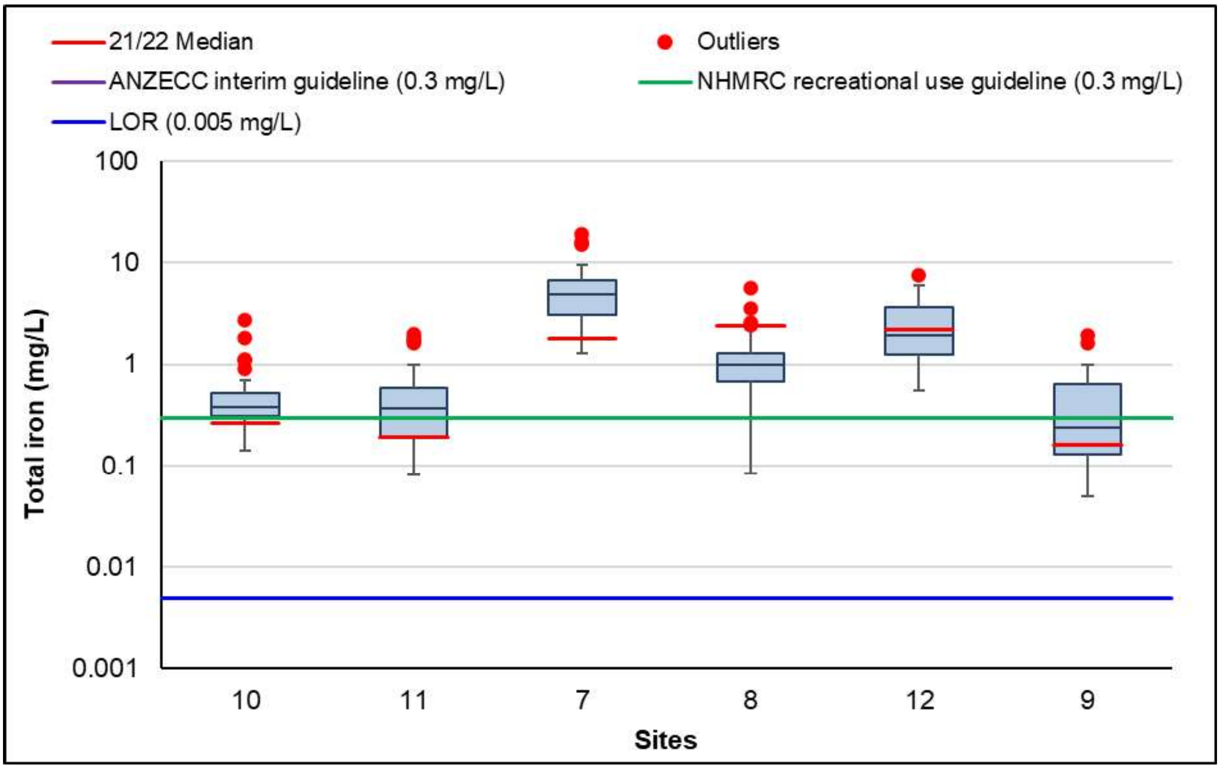


Figure 183. Box plots of total iron refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

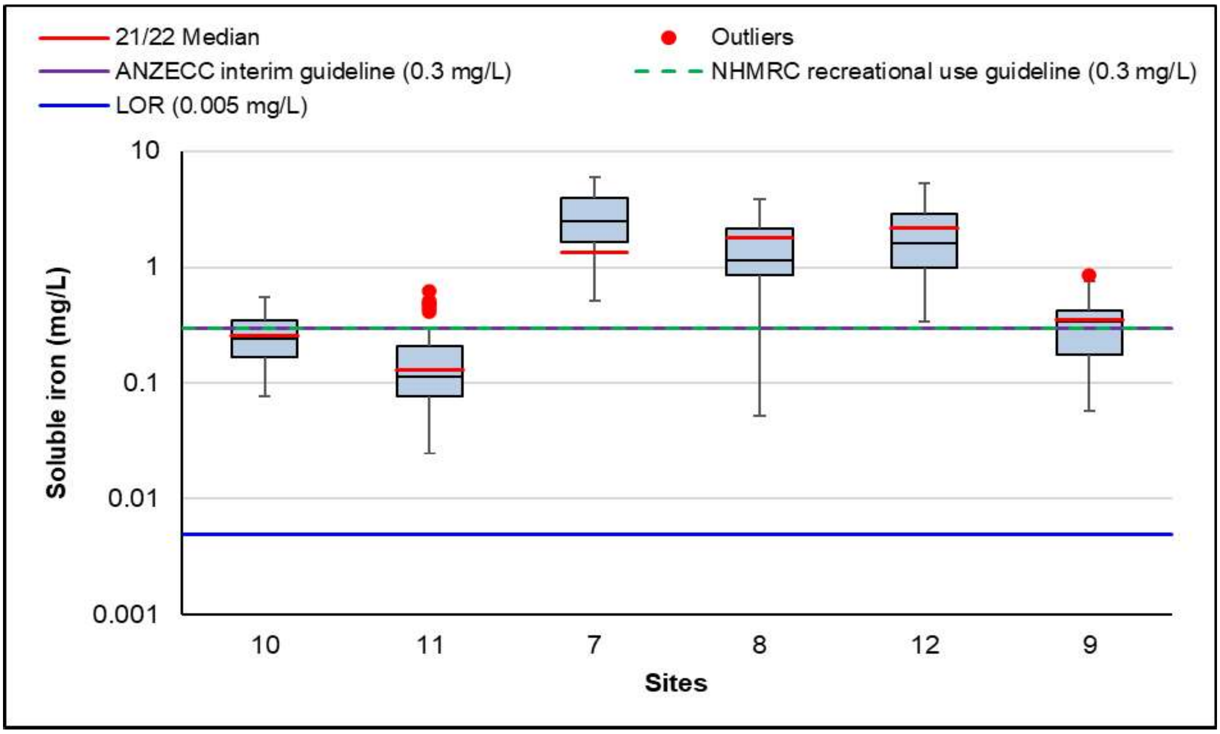


Figure 184. Box plots of soluble iron refer to the 2007-2020 historical median values and

Box whisker

ANZECC & ARMCANZ advise there continues to be insufficient data at this stage to determine a reliable trigger value for iron in freshwater ecosystems. The current Canadian guideline level is 0.3 mg/L, could be used if required if iron is seen to be an issue. Due to this, it is difficult to gauge the severity of any potential impact arising from the concentrations recorded in the water collected from the Melville Lakes sites.

Total (Figure 183) and soluble (Figure 184) iron concentrations are generally highest at site 7, 8 and 12 with concentrations between 0.520mg/L and 4.400mg/L. The 2021 sampling event showed that soluble iron concentrations have exceeded the interim trigger value at 18 of 24 samples taken at sites within the Melville Lakes sites with the lowest total soluble iron is seen in sites 9, 10 and 11 with concentration between 0.100mg/L and 0.370mg/L.

Time series

When trends with time for total (Figure 185) and soluble (Figure 186) iron are explored, there are indications that while total iron is almost consistently higher in Booragoon Lake and Blue Gum Lake (sites 7 and 12), it also seems to be trending down with time in these two lakes. Although the total iron has remained low in Marmion Reserve, it also seems to be trending down in this site. The total and soluble iron at the other sites show no obvious site-specific changes with time the red line indicates the median value in 2021

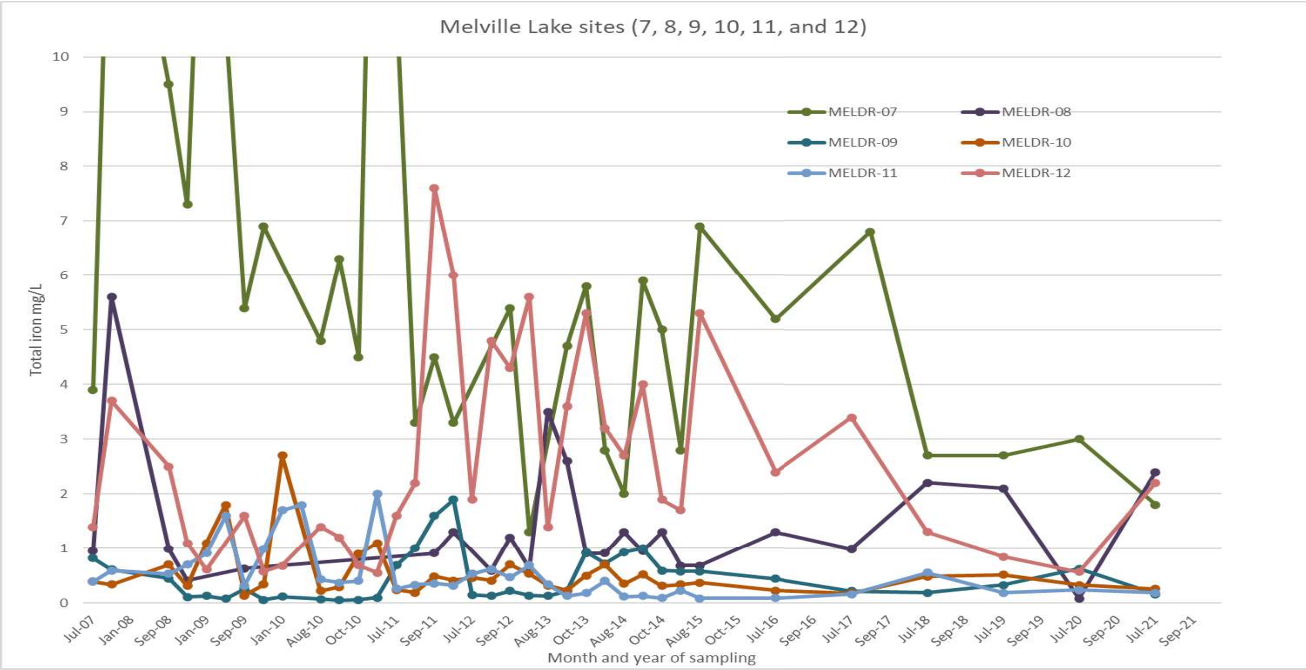


Figure 185. Total iron at the Melville Lakes sites. Note; high values pre-2012 are not shown here as the purpose was to create a plot to show variation at lower levels.

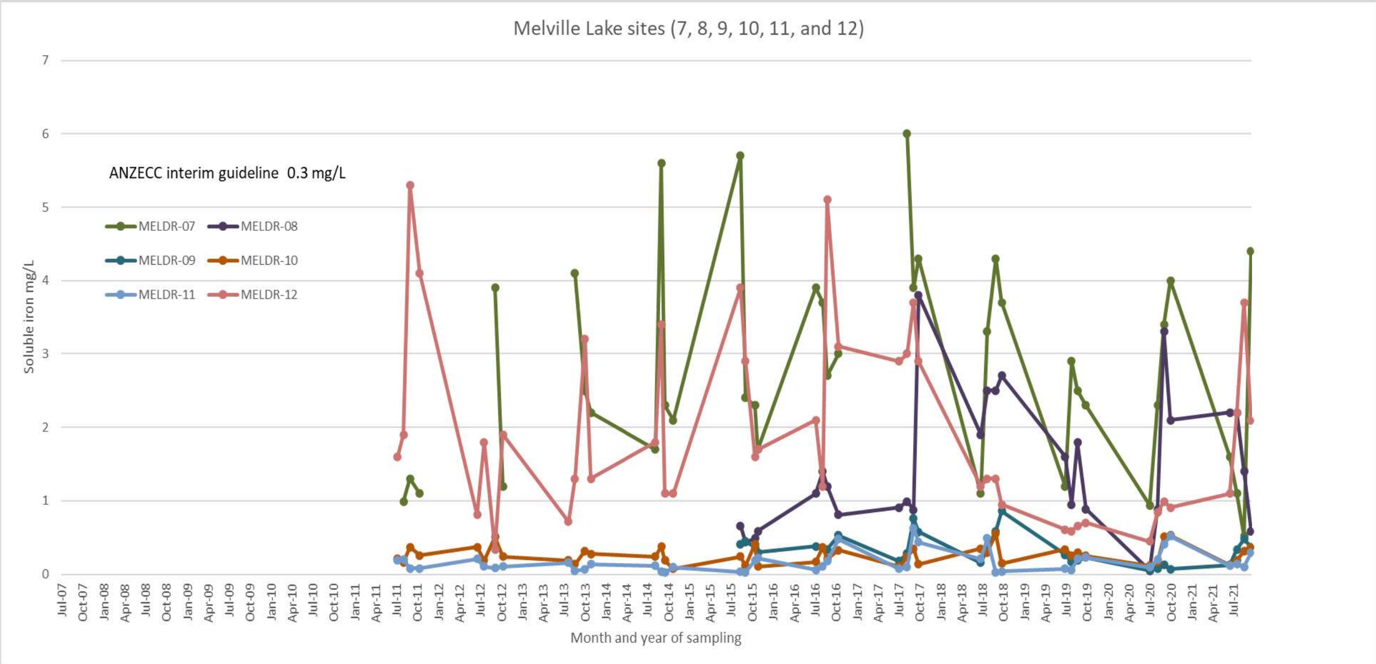


Figure 186. Soluble iron at the Melville Lakes sites.

Lead

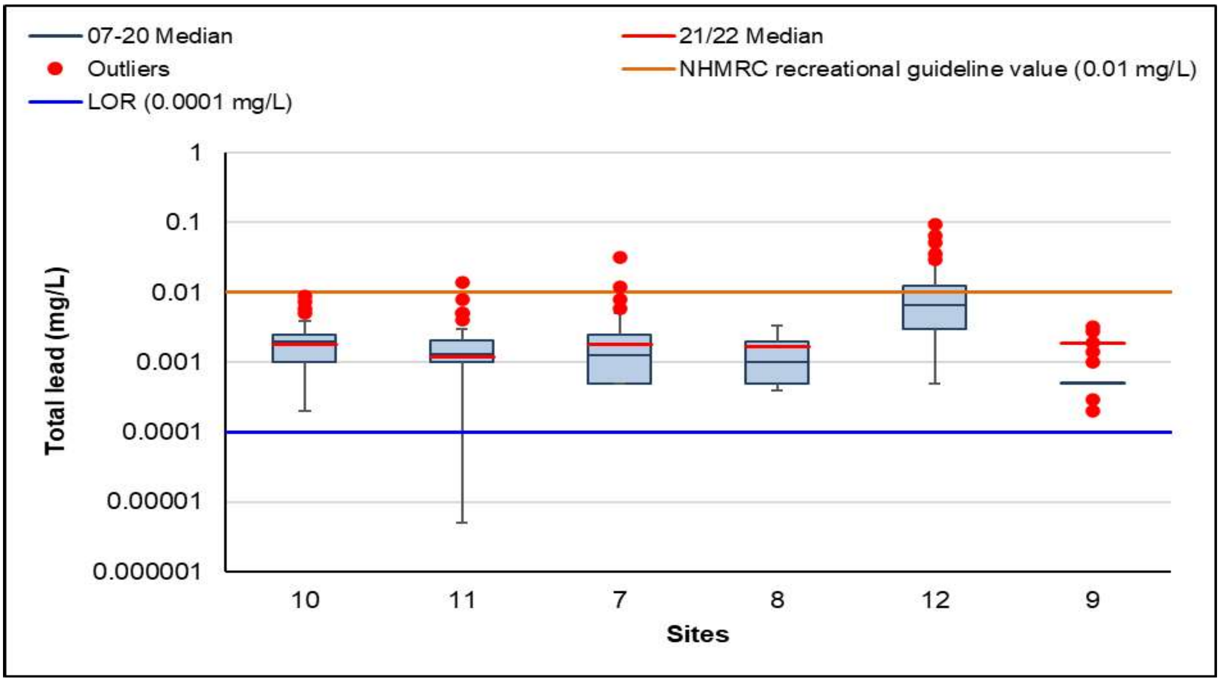


Figure 187. Box plots of total lead refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

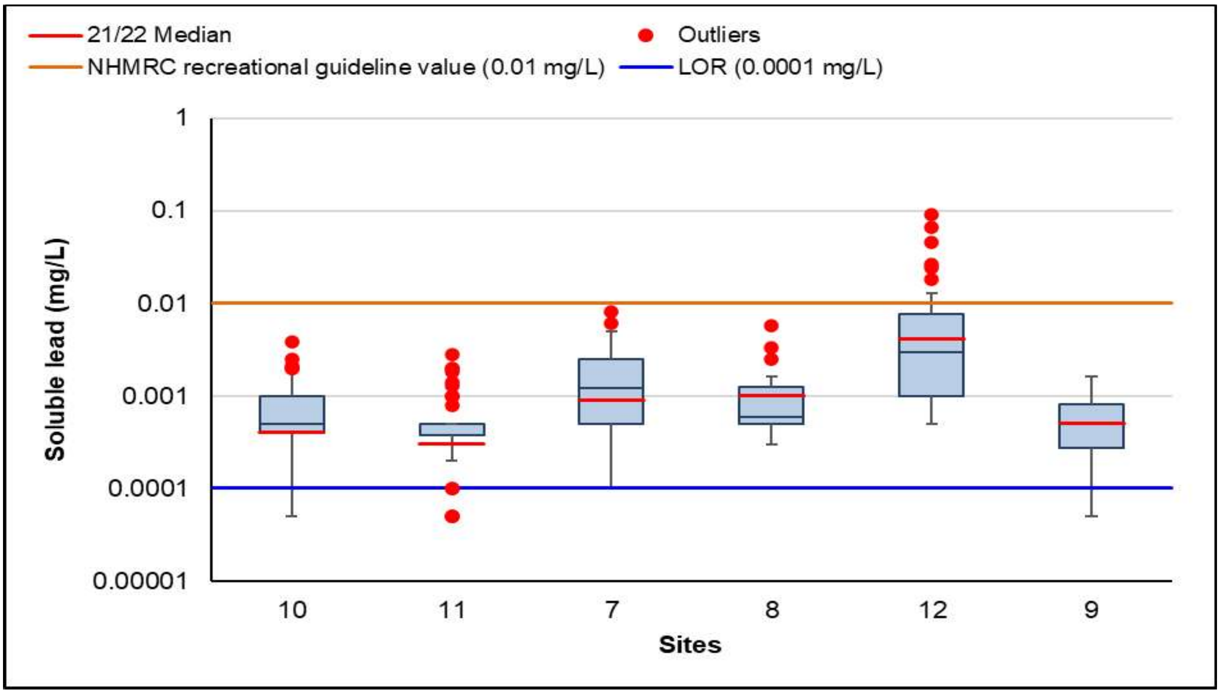


Figure 188. Box plots of soluble lead refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

None of the 6 samples collected from the Melville Lakes sites in 2021 recorded total lead concentrations above adjusted ANZECC trigger values for 95% protection of biota (unadjusted trigger value: 0.0034 mg/L) (Figure 187 and Table D-26 in Appendix D). All samples collected from the Melville Lakes sites in 2021 recorded soluble lead concentrations below the adjusted ANZECC trigger values for 95% protection of biota (unadjusted trigger value: 0.0034 mg/L) except for site 12 in August (Figure 188). The highest total lead concentration (0.01mg/L) was recorded at site 12 in July and the highest soluble lead concentration (0.0075 mg/L) was recorded at site 12 in July. The lowest total lead concentration of 0.0012 mg/L was recorded at site 11 in July.

Two sites recorded soluble lead concentrations equal or less than the LOR (0.0001 mg/L), being site 7 and site 11 in the September sampling event (Figure 188 and Table D-27 in Appendix D) which is an unreliable result and may indicate an error in the laboratory analyses. All recorded total and soluble lead concentrations were below the NHMRC recreational guideline for health value (0.01 mg/L).

Time series

Total lead concentrations recorded in most Melville Lakes sites in 2021 are similar to those recorded in the preceding 14 years of monitoring (Figure 189A, Table G-53 in Appendix G). The readings of total lead in all sites, except for Booragoon Lake, in 2021 was together closer to the ANZECC trigger value (0.0034 mg/L) than at any other time. Concentrations of total lead exceeding the hardness modified trigger values have frequently been recorded in Booragoon Lake and to some extent also in Fredrick Baldwin throughout the 14-year sampling period in particular. Although soluble lead (Figure 189B) is highest in Booragoon Lake in over 60% of the sampling times, the soluble lead levels seems however, to be trending down since 2011. But due to seasonal and site-specific differences and variations it is difficult to fully explain what causes these differences.

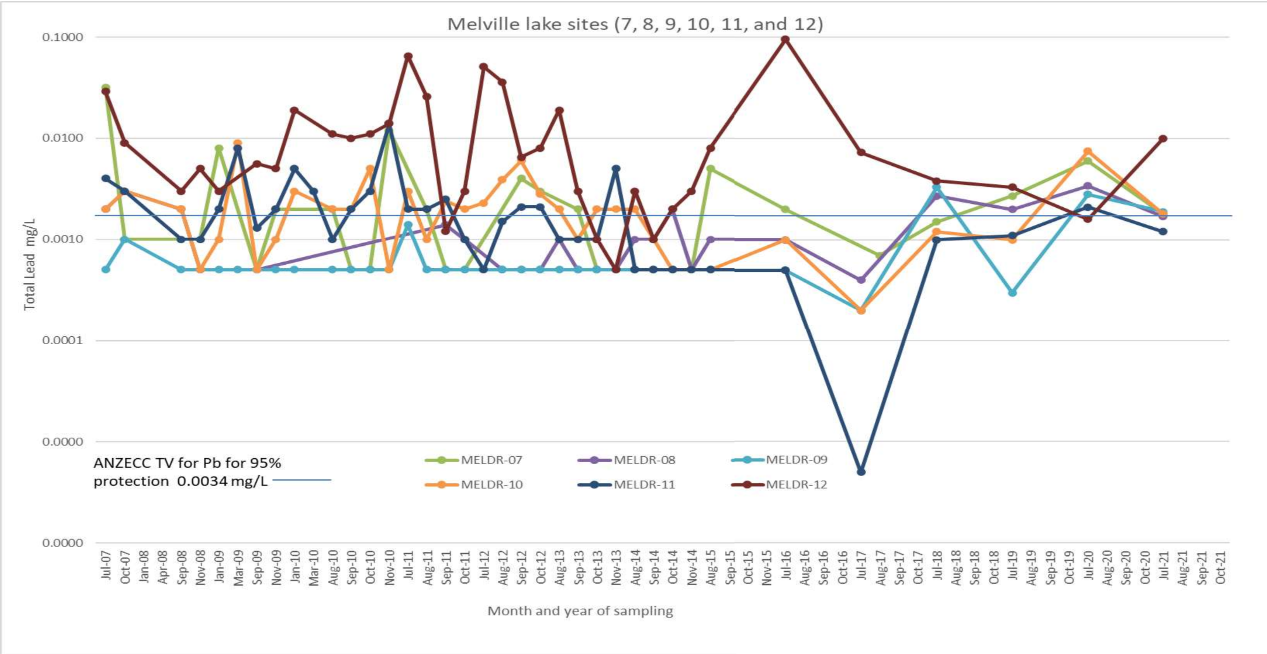


Figure 189A. Total lead at the Melville Lakes sites.

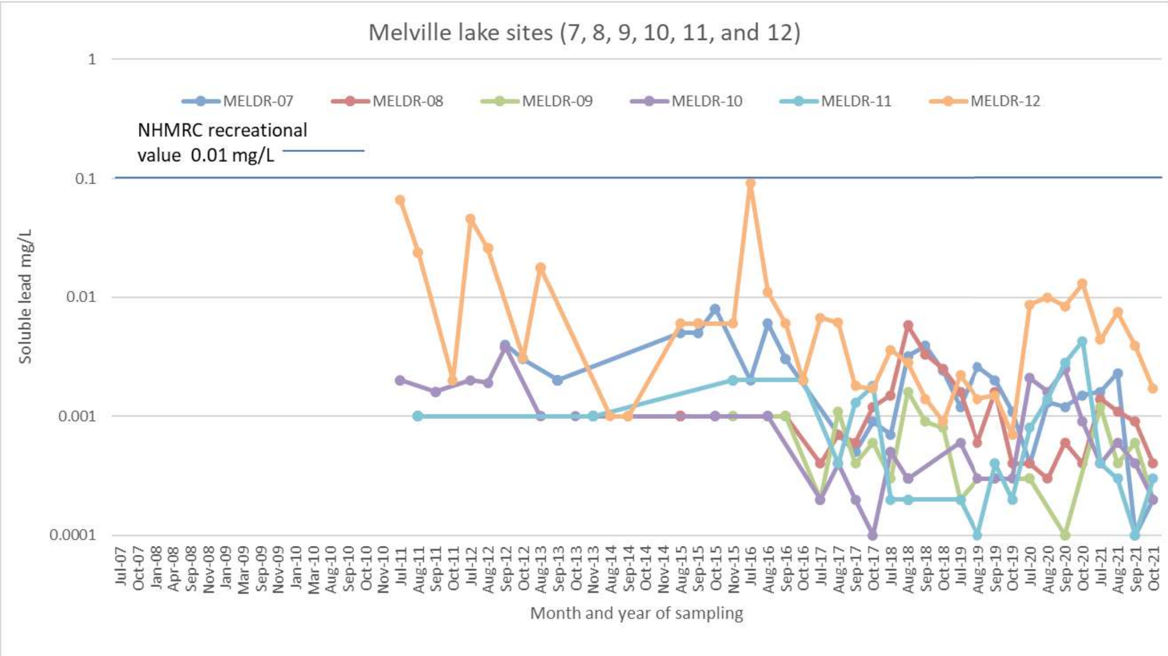


Figure 189B. Soluble lead at the Melville Lakes sites.

Mercury

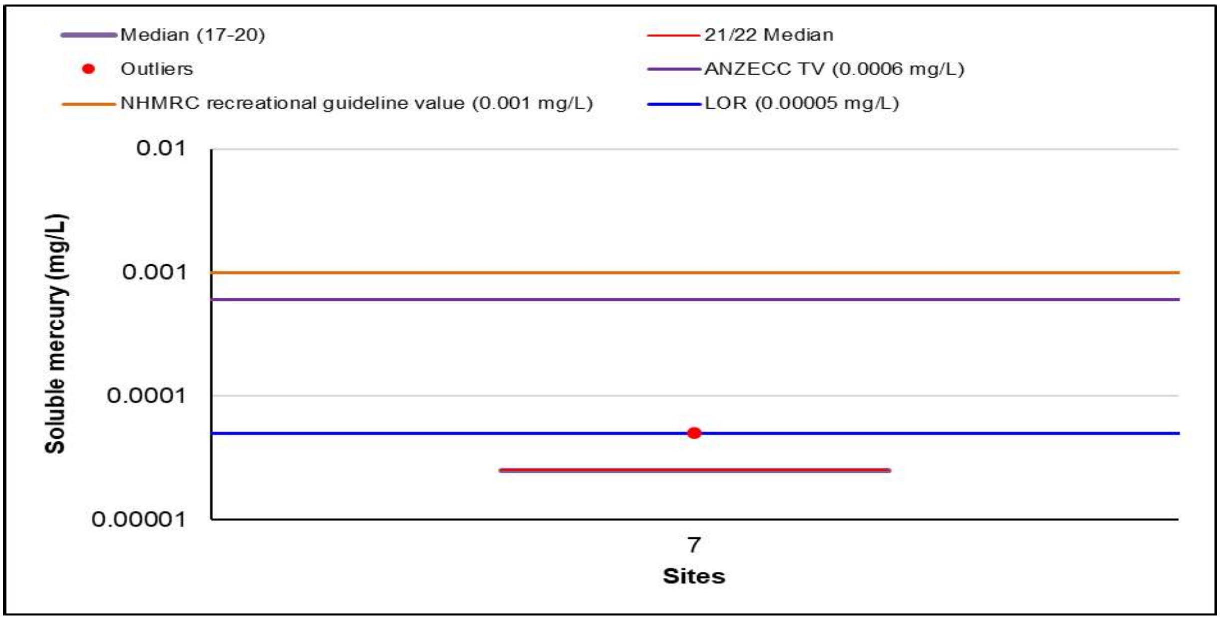


Figure 190. Box plots of total mercury refer to the 2007-2020 historical value and the red line indicates the median value in 2021.

Box whisker

Note – of the Melville Lakes only water from Booragoon Lake (site 7) were sampled for total mercury three times (July 2019, 2020, and 2021) and for soluble mercury (Figure 190) 11 times since 2019 (July to October in 2019 through to 2021, missing August 2019). Piney Lakes was sampled once for soluble mercury, August 2019. No other lakes were analysed for mercury. Sampling times were for soluble mercury and July in 2019, 2020, and 2021.

The results for these are as follows. At Piney Lakes, the single analysis (August 2019) of soluble mercury was recorded as less than 0.0001 mg/L. At Booragoon Lake, total mercury levels of 0.0001 mg/L were recorded in July 2019 and less than 0.001 mg/L (July 2019) and 0.0005 mg/L (July of 2020 and 2021) (Table G-53 in Appendix G). At this lake, soluble mercury was 0.0001 mg/L in July 2019 and all 10 other sample below the LOR of 0.00005 mg/L (July to October 2019 to 2021)

Time series

The total mercury sampled at Booragoon Lake (July 2019, 2020, and 2021) were very low and apart from one of the 11 readings in soluble mercury at 0.0001 mg/L all others were below 0.00005 mg/L (LOR) and below recommended guidelines. The most reliable conclusions is that total mercury at this lake has remained low since sampling began. Due to the low sample sizes levels and unreliability in drawing conclusions from levels close to LOR values, no time series interpretations were made.

Zinc

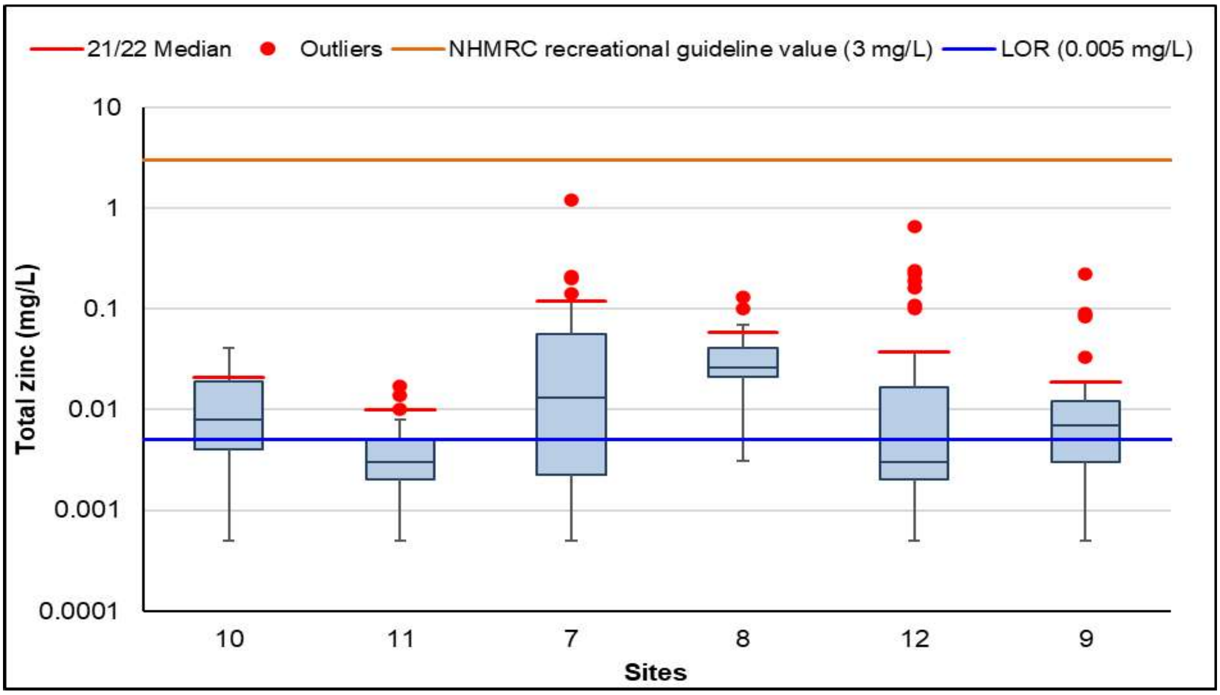


Figure 191. Box plot of total zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

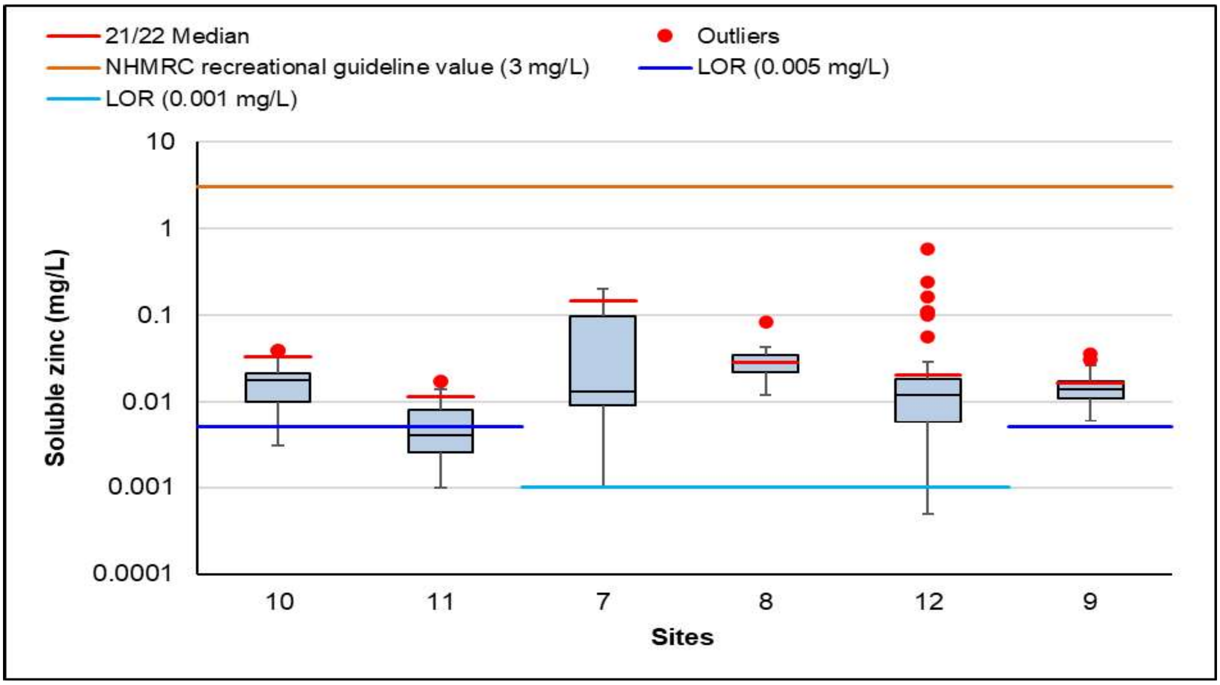


Figure 192. Box plots of soluble zinc refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

Concentrations of total zinc exceeded hardness adjusted ANZECC trigger values for 95% level of protection (unmodified trigger value: 0.008 mg/L) at 4 the 6 Melville Lakes sites in July 2021, (Figure 191 and Table D-30 in Appendix D). Eleven out of 24 samples recorded soluble zinc concentrations exceeding hardness adjusted ANZECC trigger values with all sites having at least one exceedance throughout the 2021 sampling events, (Figure 192 and Table D-31 in Appendix D). The highest total zinc concentrations (0.12 mg/L) was in July at site 7 while the highest concentration for soluble zinc (0.1900 mg/L) in site 7 during the September sampling event. No total or soluble zinc concentration exceeded the NHMRC recreational guideline for aesthetic value (3 mg/L).

Time series

Although overall the total (Figure 193) soluble (Figure 194) zinc concentrations recorded in 2021 are similar to those recorded in the previous 14 years of monitoring (Table G-53 in Appendix G), more exceedances for both total and soluble zinc were recorded in 2021 than in the preceding years of sampling. The total zinc is also possibly trending upwards in all sites, though this trend is not clear when examining the data of soluble zinc. The total and soluble zinc in Booragoon Lake and Blue Gum Lake (sites 7 and 12) have been higher more often that in the other lakes and lowest most often in Marmion Reserve (site 11). The other sites were intermediate for both parameters of zinc.

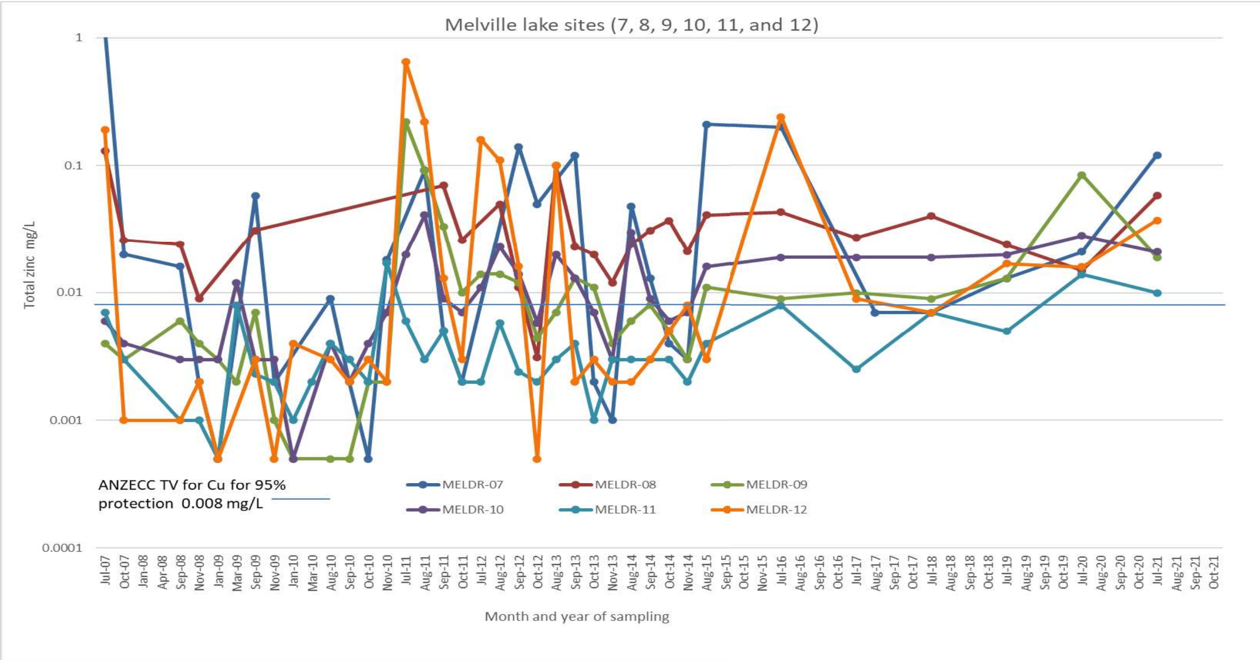


Figure 193. Total zinc at the Melville Lakes sites.

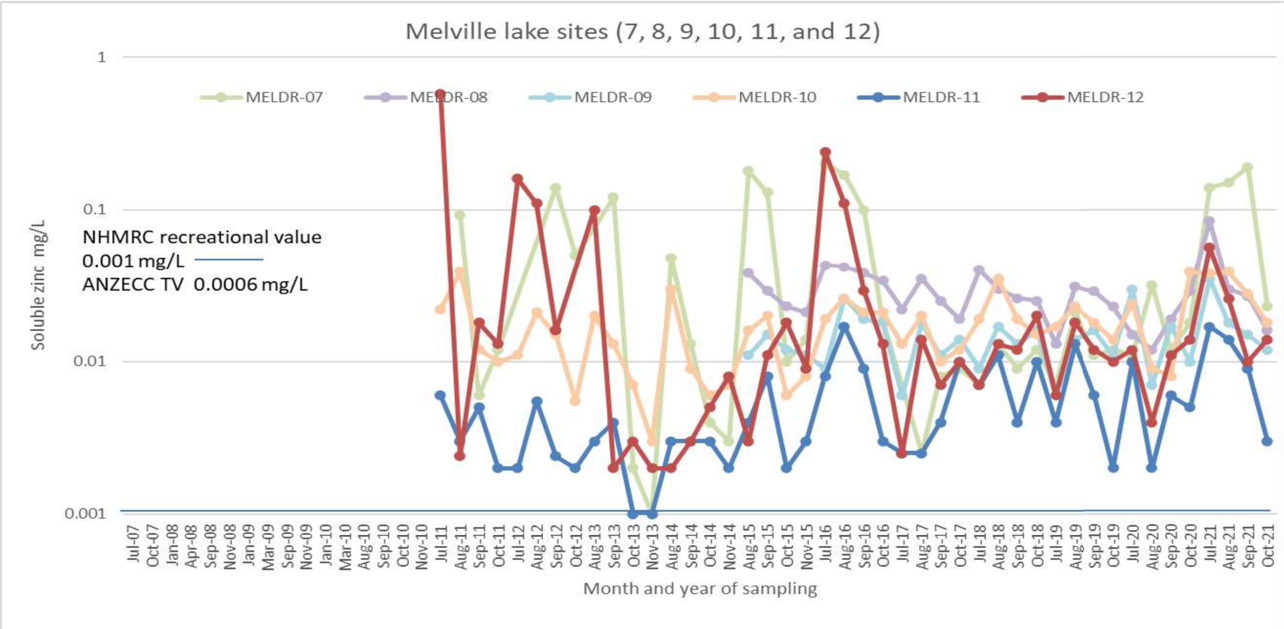


Figure 194. Soluble zinc at the Melville Lakes sites.

Arsenic

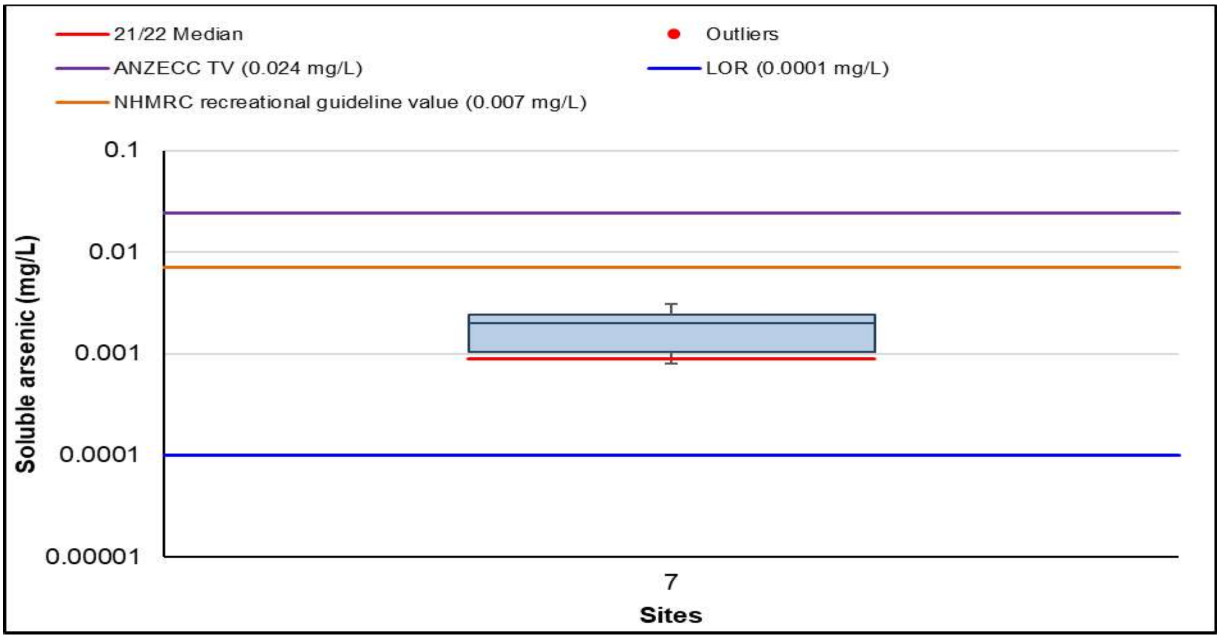


Figure 195. Box plot of soluble arsenic 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total and soluble arsenic concentrations were low (often at LOR) and therefore only assessed at site 7 where values above LOR were available. These were below the ANZECC trigger value (of 0.024 mg/L for 95% level of protection of biota) (ANZECC and ARMCANZ 2000) and the NHMRC recreational use guideline value for arsenic in water (of 0.007 mg/L for health value) (NHMRC 2008) at site 7 (Booragoon Lake) where this parameter was analysed (Figure 195). The highest soluble arsenic (0.0014 mg/L) was recorded in October (Figure 195, Table D-32 and Table D-33 in Appendix D).

Time series

Soluble arsenic was sampled since 2019 in site 7 (Figure 198) and once in site 8. At Booragoon Lake (site 7) there is a possible downwards trend in soluble arsenic. The sample at Piney Lakes in July 2019 recorded a concentration of 0.0009 mg/L. All these values are below the ANZECC and NHMRC recommended guidelines.

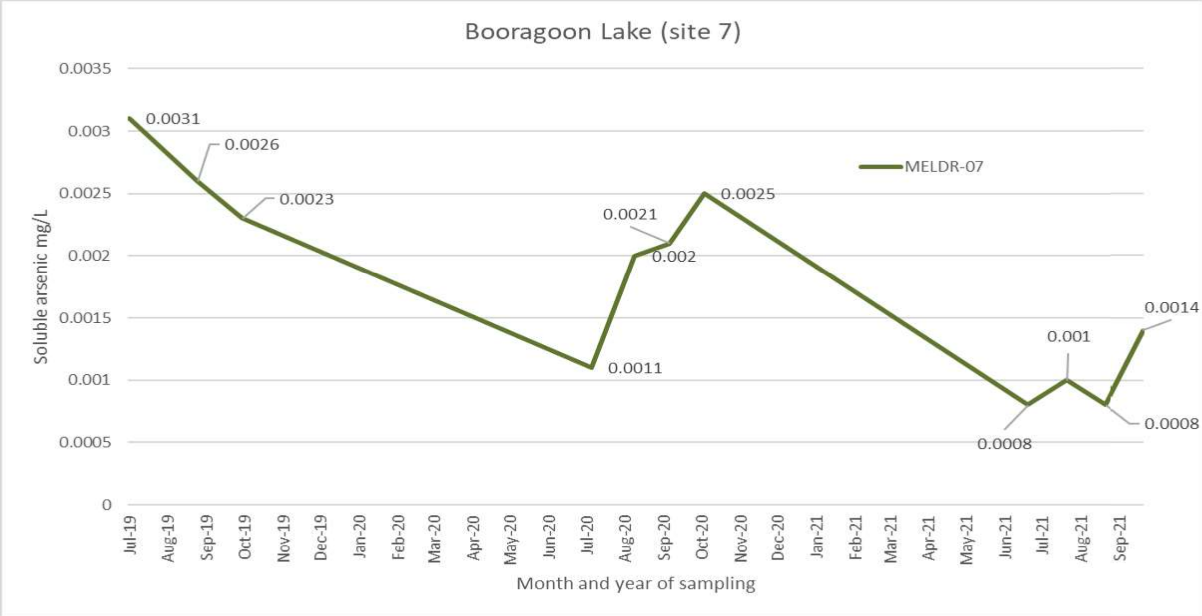


Figure 196. Soluble arsenic at Booragoon Lake.

Nickel

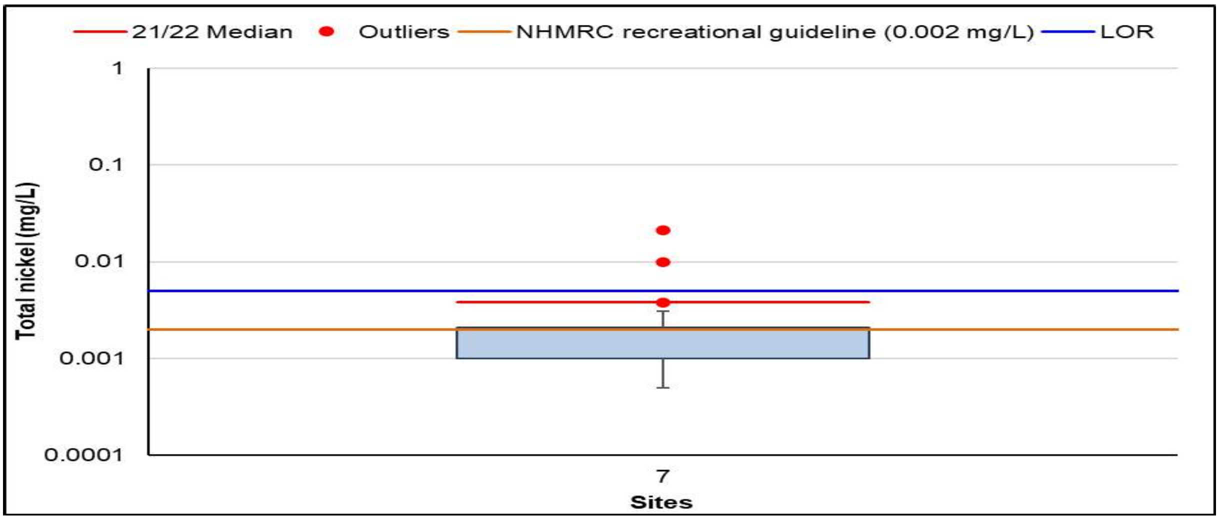


Figure 197. Box plots of total nickel refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

Total nickel was sampled between 2007 to 2014 in the Melville Lakes and again only in Booragoon Lake in July 2020 (0.0014 mg/L) and 2021 (0.0038 mg/L).

Note; more recent NHMRC guidelines (2011) for nickel include for drinking water at 0.02 mg/L and for recreation at 0.1 mg/L. The lower limit for detection is also noted as 0.02 mg/L. Care must therefore be taken when examining these results as if the guideline is 0.02 mg/L then exceedances have only occurred once, Booragoon Lake in July 2007 (Figure 197).

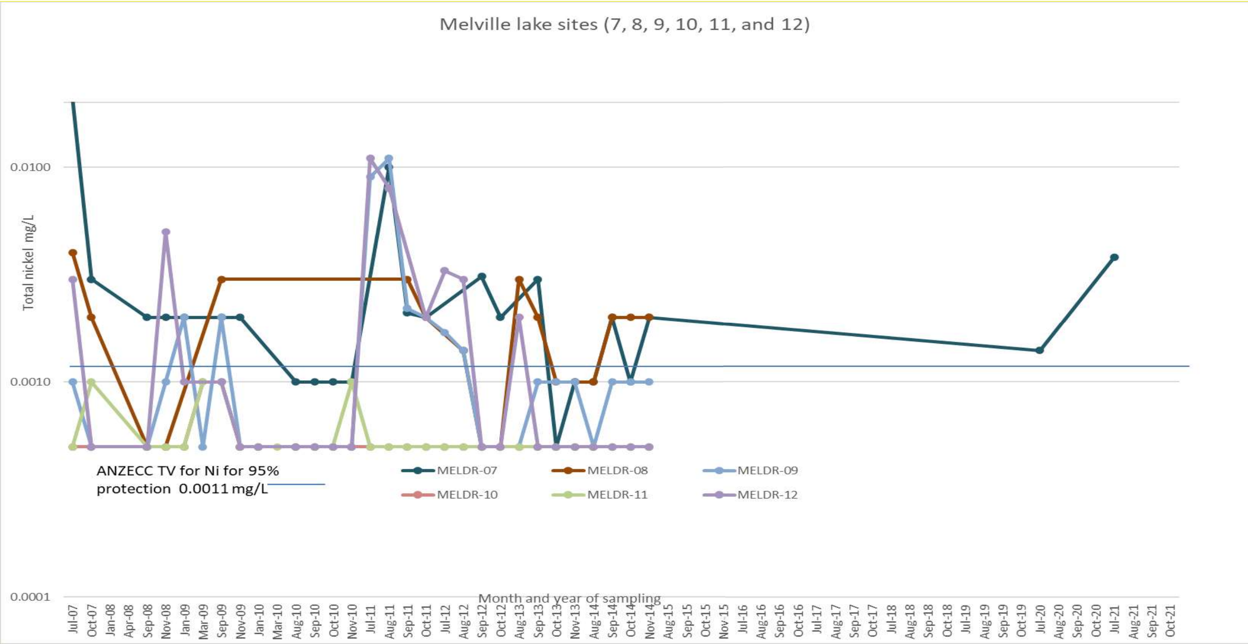


Figure 198. Total nickel at the Melville Lakes sites. Note: since 2015, nickel was only reliably analysed at two occasions at site 7, Booragoon Lake.

Time series

Between 2007 and 2014, most samples at Frederick Baldwin, Marmion Reserve and to an extent also Quenda Lake recorded values of or close to 0.0005 mg/L of total nickel (Figure 198) concentrations, which are below the NHMRC most recent recreational guideline of 0.1 mg/L and drinking water guideline of 0.02 mg/L at all Melville Lakes in all bar three samples; Booragoon Lake (July 2007 and August 2011), at Blue Gum Lake (July 2011) and Quenda Lake (August 2011 (Figure 198 and Table D-34 in Appendix D). Many samples were however, above the TV for 95% protection.

Metals in sediment

Below are box whisker plots of metals in sediments. The time series plots are managed as combined plots for each site.

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Aluminium

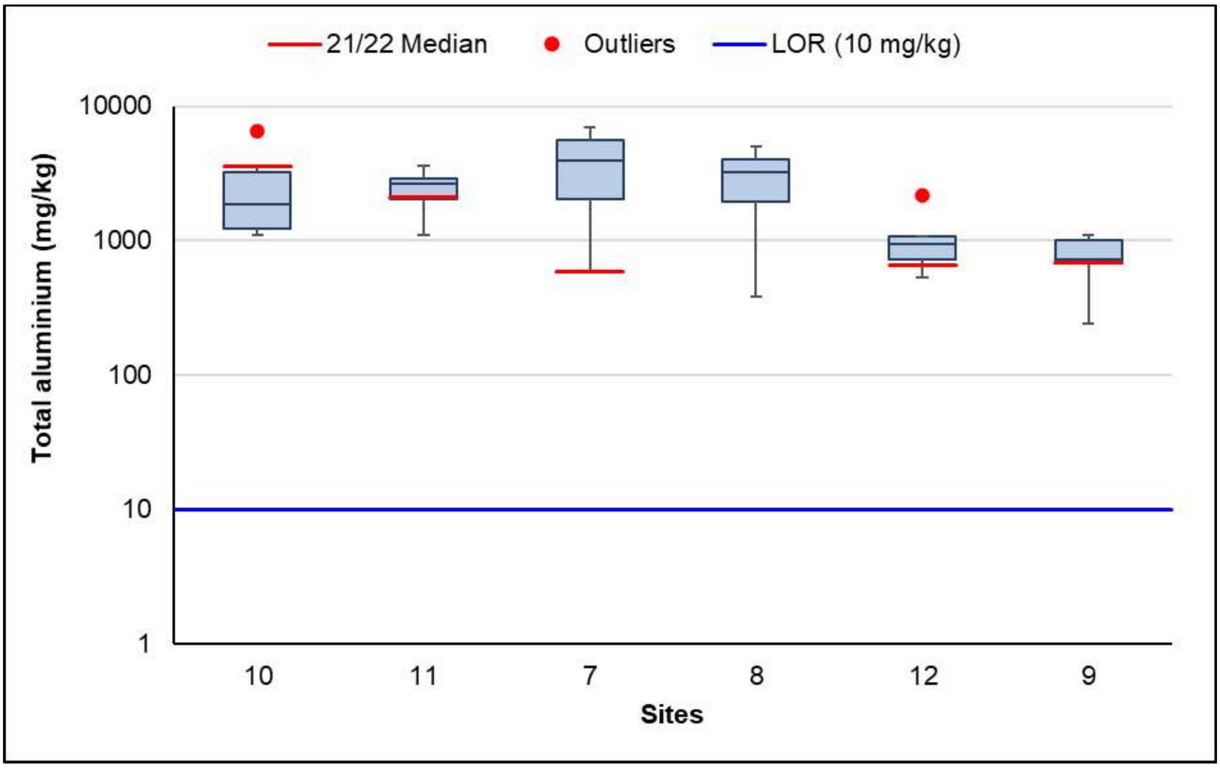


Figure 199. Box plots of total aluminium refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

Sediment total aluminium concentrations in 2021 varied across the Melville Lakes sites, with the highest concentration of 3580 mg/kg recorded at site 10 and the lowest concentration of 586 mg/kg recorded at site 7 (Figure 199 and Table D-36 in Appendix D).

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Total aluminium concentrations have varied greatly in sediment of the Melville Lakes sites (over the last eight years of monitoring) but with no strong patterns emerging (Table H-55 in Appendix H). It is notable that the very high result (1.500mg/kg) recorded at site 10 in 2016 is significantly higher than all other recorded concentrations, including those recorded in other years at site 10. Site 7 has more often than not recorded the highest concentration within the Melville Lakes sites.

Arsenic

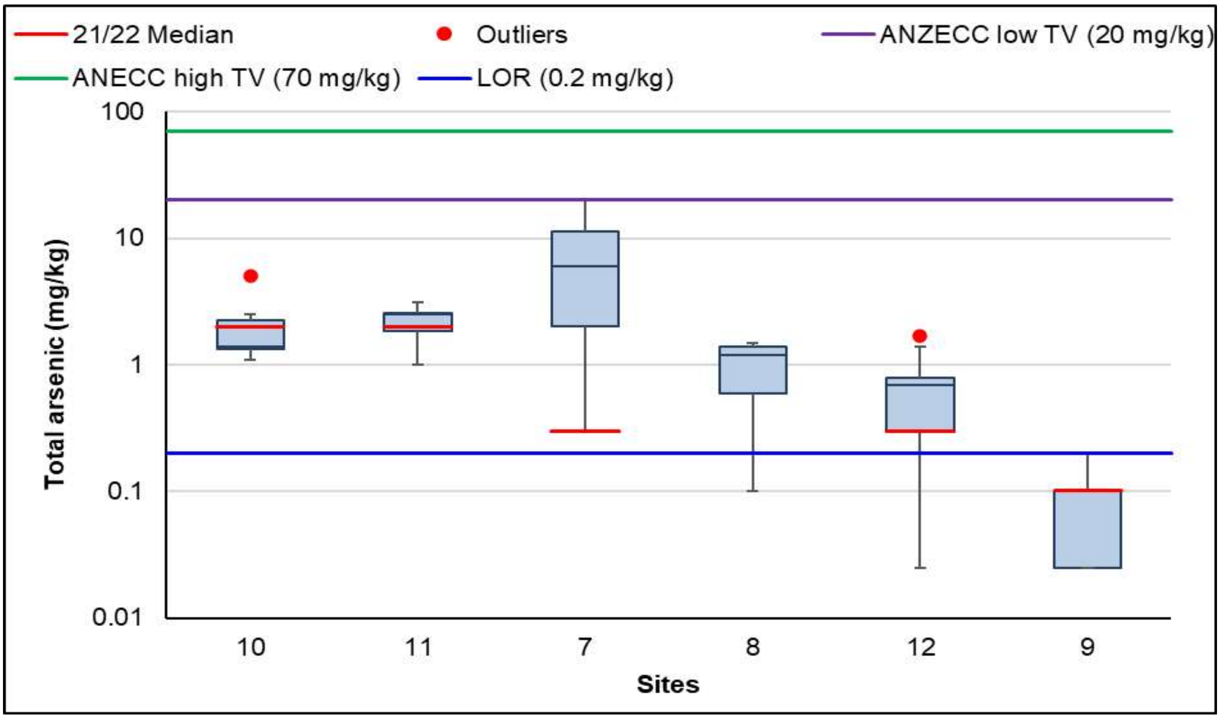


Figure 200. Box plots of total arsenic refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

Total arsenic concentrations in sediments in 2021 were all below the ANZECC low (20 mg/kg) and high (70 mg/kg) trigger values (Figure 200 and Table D-37 in Appendix D). The highest concentration of 2.0 mg/kg was recorded at site 10 and 11 in October 2021, followed by 0.3 mg/kg at site 7 and site 12 with the lowest concentration of 0.1mg/L was seen at site 9.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion

Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Total arsenic concentrations in sediment at Melville Lakes sites have generally been low throughout the ten years of monitoring (Table H55 in Appendix H).

Chromium

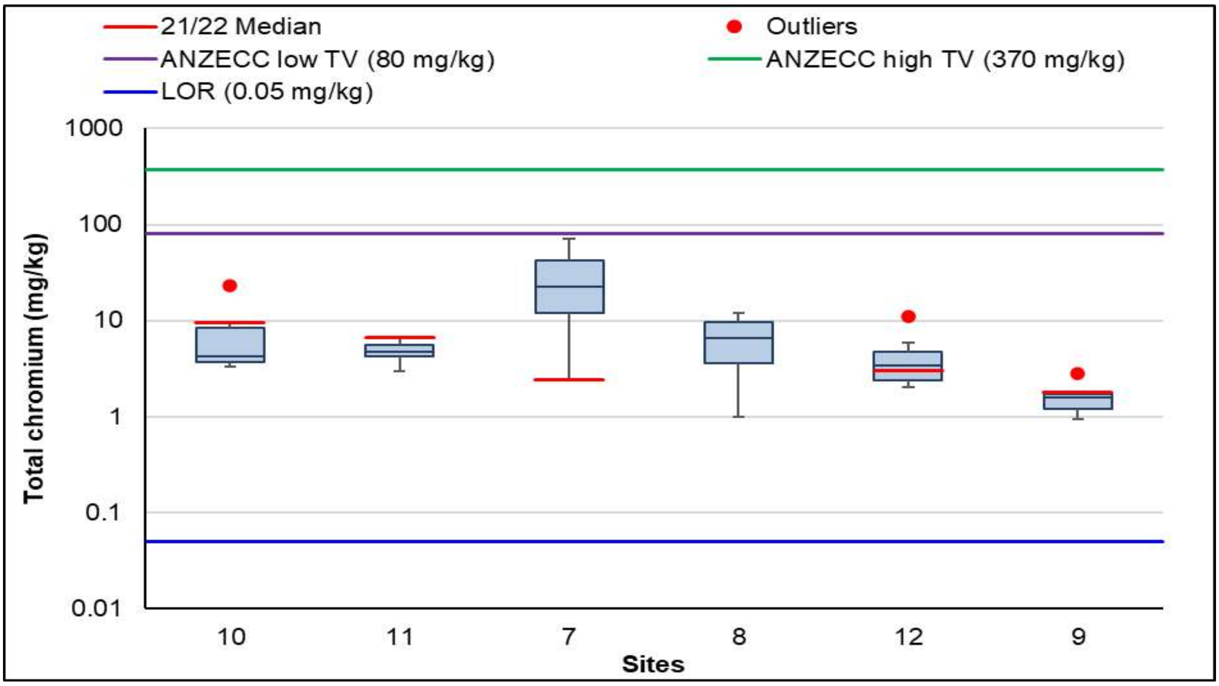


Figure 201. Box plots of total chromium refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

Total chromium (including Cr3+ and Cr6+) concentrations in sediment at all Melville Lakes sites were below ANZECC low (80 mg/kg) and high (370 mg/kg) trigger values in 2021 (Figure 201 and Table D-38 in Appendix D). The highest concentration in the Melville Lakes sites was 9.6 mg/kg was recorded at site 10 and the lowest concentration of 1.8 mg/kg was recorded at site 9.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Site 9 consecutively records the lowest concentrations of chromium within the Melville Lakes sites. The variability is higher at Booragoon Lake and Quenda Lake (sites 7 and 8) and very low at Marmion Reserve in particular. There are no overall trend with time.

Copper

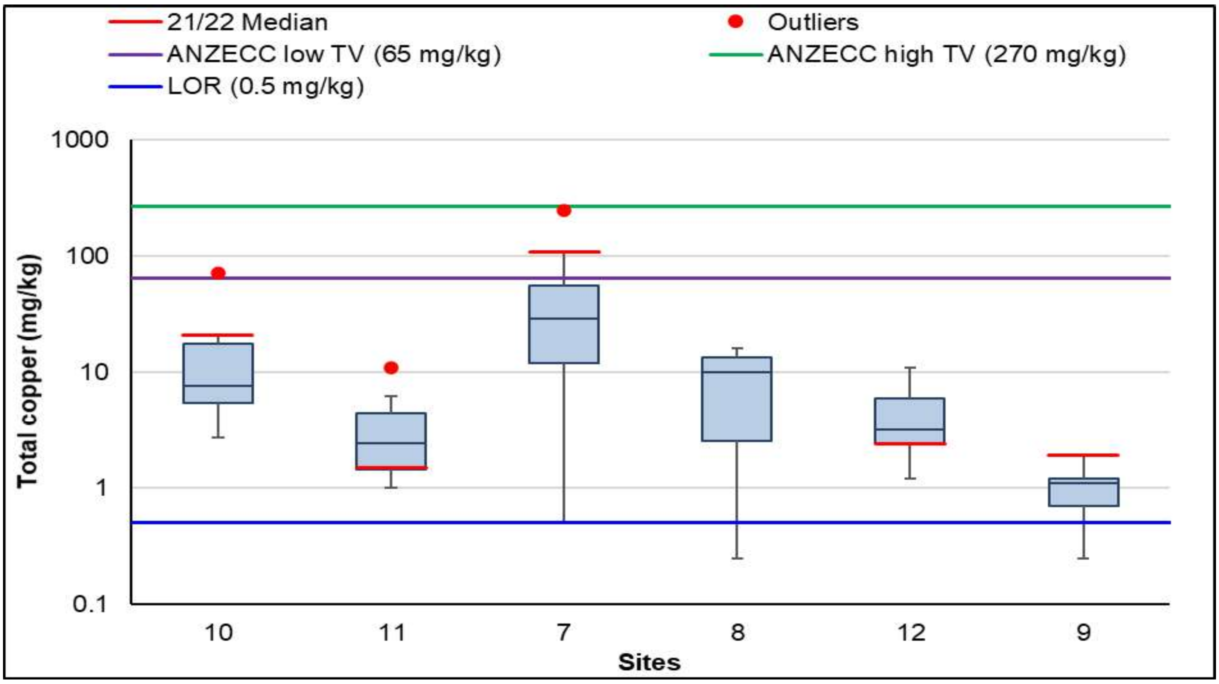


Figure 202. Box plots of total copper refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

Total copper concentrations in sediment collected from all but one of the samples collected from the Melville Lakes sites in 2021 were below ANZECC low (65 mg/kg) and high (270 mg/kg) trigger values (Figure 202 and Table D-39 in Appendix D). The highest concentration was 110 mg/kg recorded at site 7, this was the only exceedance above the ANZECC low (65 mg/kg) trigger value. Site 9 has consecutively recorded the lowest concentrations within the Melville Lakes sites, however this monitoring round, site 11 had the lowest concentration of 1.5mg/kg.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Total copper concentrations in sediment at Melville Lakes sites have been generally low in the previous ten years of monitoring (Table H-55 in Appendix H). Only site 7 and 10, have recorded exceedances of the low trigger value in the eight-year monitoring period. Concentrations at site 7 were significantly higher than other concentrations recorded at the other sites over the years.

Iron

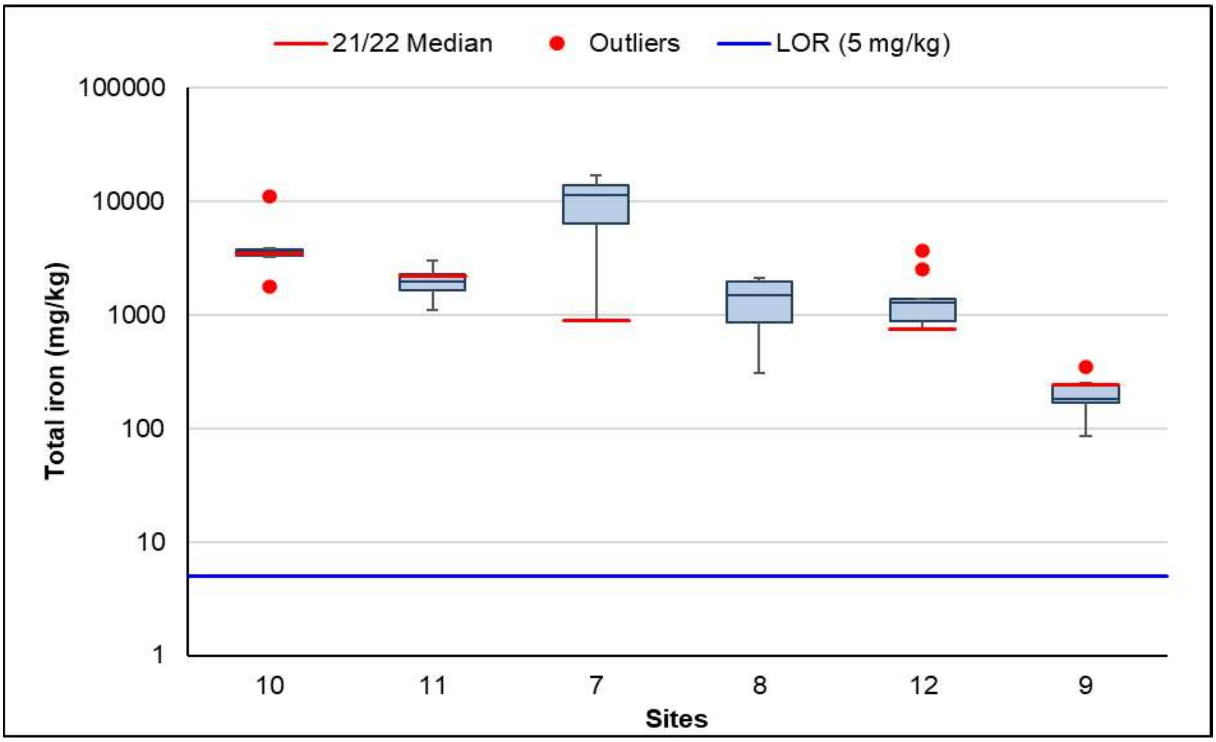


Figure 203. Box plots of total iron refer to the 2007-2020 historical median values and the red line indicates the median value in 2021.

Box whisker

No guideline currently exists for iron concentrations in sediment; therefore, it is difficult to gauge the severity of any potential impact arising from the concentrations recorded in the sediment collected from Melville Lakes sites. In 2021 total iron concentrations in sediment were varied (Figure 203 and Table D-40 in Appendix D). The highest concentration seen in the Melville Lakes sites was 3,500 mg/kg recorded at site 10 and the lowest concentration of 240 mg/kg was recorded at site 9.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

There is no indications of changes in trends in total iron with time at the Melville Lakes.

Lead

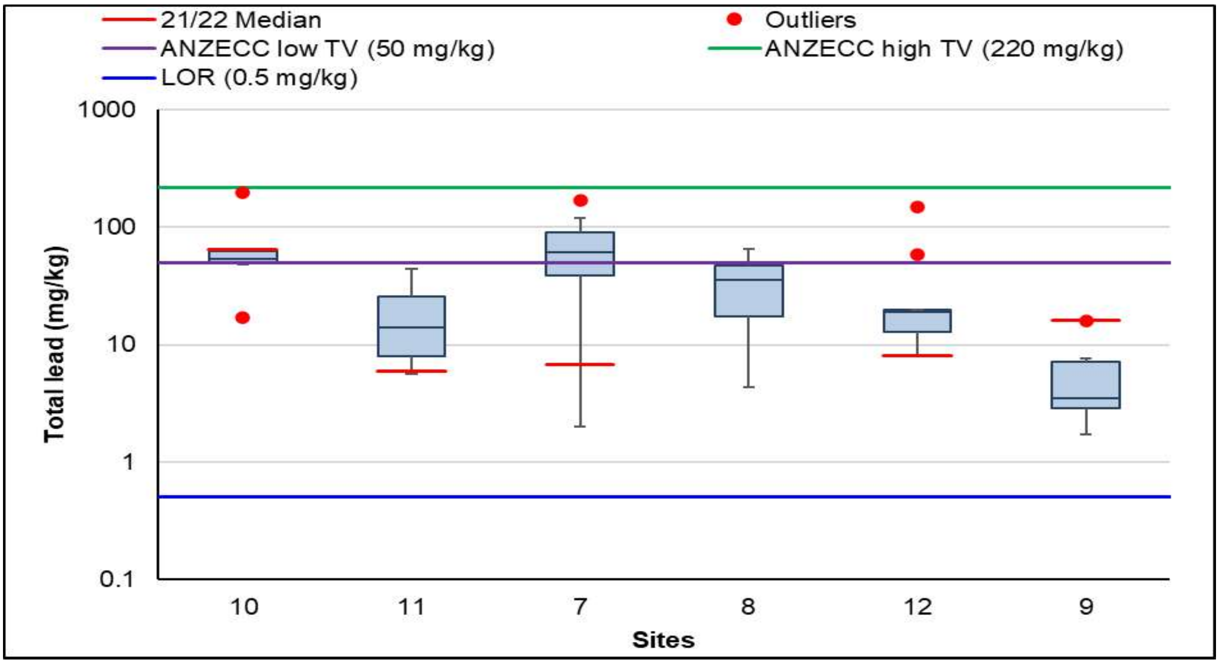


Figure 204. Box plot of total lead 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Five of the sites within the Melville Lakes sites recorded lead concentrations in sediments below the ANZECC low trigger value (50 mg/kg) in the sampling event of 2021. Site 10 recorded the highest concentration of 65 mg/kg, the second highest concentration was seen in site 9 at 16 mg/kg (Figure 204 and Table D-41 in Appendix D). No samples collected recorded an exceedance of the high trigger value (220 mg/kg). The lowest concentration of 6 mg/kg was recorded at site 11.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Total lead concentrations in sediment collected between from 2013 seem to have been decreasing in Piney Lakes (site 8) and Blue Gum Lake (site 12) and in Booragoon Lake since 2019. In 2019 through to 2021 there is a slight upwards trend in total lead in the sediments in Quenda Lake (site 9). Concentrations exceeding the low trigger value have been recorded in several samples from the Melville Lakes (sites 7, 9, 10 and 12) on at least one sampling occasion throughout the nine-year monitoring period. All other concentrations across Melville Lakes sites have been within acceptable limits.

Mercury

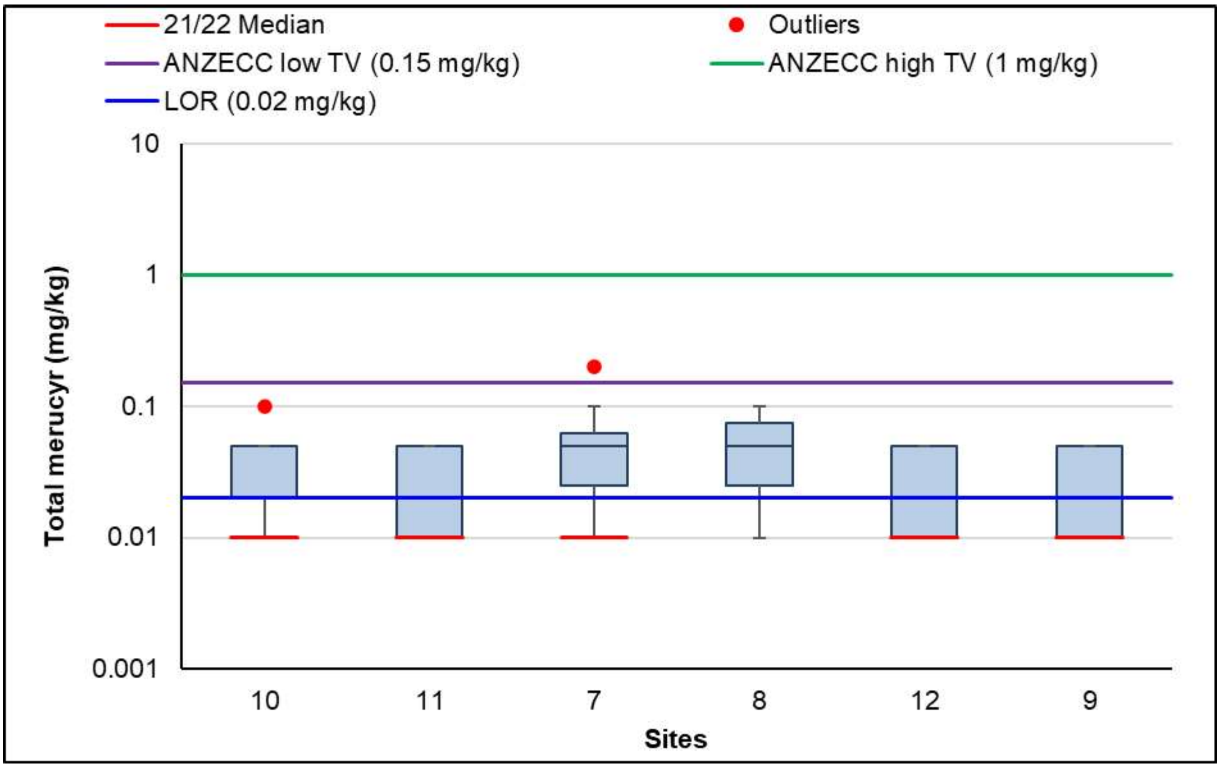


Figure 205. Box plots of total mercury refer to the 2007-2020 historical median values and the red line indicates the median value in 2021

Box whisker

Total mercury concentrations in sediment were all below the ANZECC low (0.15 mg/kg) and high (1.0 mg/kg) trigger values at all sites within the Melville Lakes sites in 2021 (Figure 205 and Table D-42 in Appendix D). There were no concentrations seen across the sampling events for site 7, 8, 9, 10, 11 and 12 that were greater than the LOR (0.02 mg/kg).

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Concentrations of total mercury in sediment of the Melville Lakes sites throughout the nine years of monitoring have generally been low and below the LORs (Table H-56 in Appendix H).

Nickel

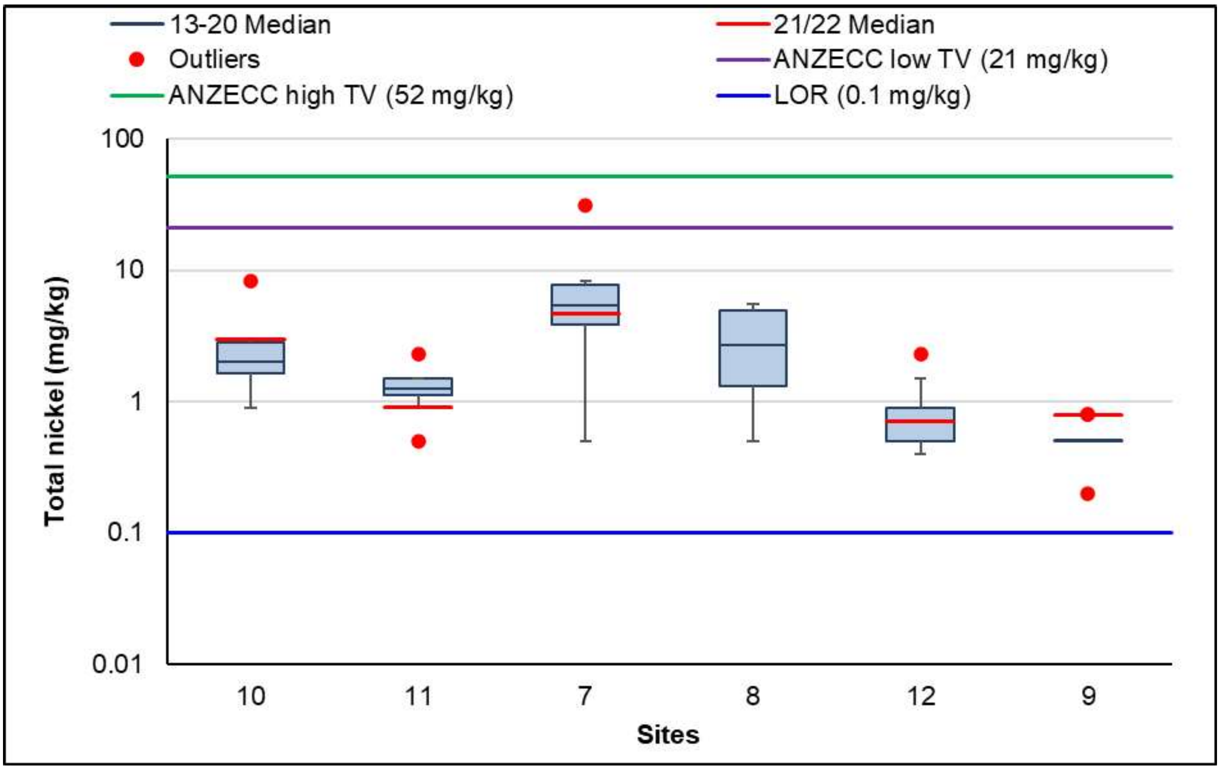


Figure 206. Box plot of total nickel 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Total nickel concentrations in sediment were all below the ANZECC low (21 mg/kg) and high (52 mg/kg) trigger values at Melville Lakes sites in 2021 (Figure 206 and Table D-43 in Appendix D). The highest total nickel concentration of 4.7 mg/kg was recorded at site 7, second highest was site 10 which had a nickel concentration of 3.0mg/kg, site 12 recorded the lowest concentration 0.7 mg/kg.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Concentrations of total nickel in sediment of the Melville Lakes sites over the past eight years of monitoring have generally been low (Table H-56 in Appendix H). The only exceedances of the ANZECC low trigger value recorded during this time have been at site 7 in 2015.

Selenium

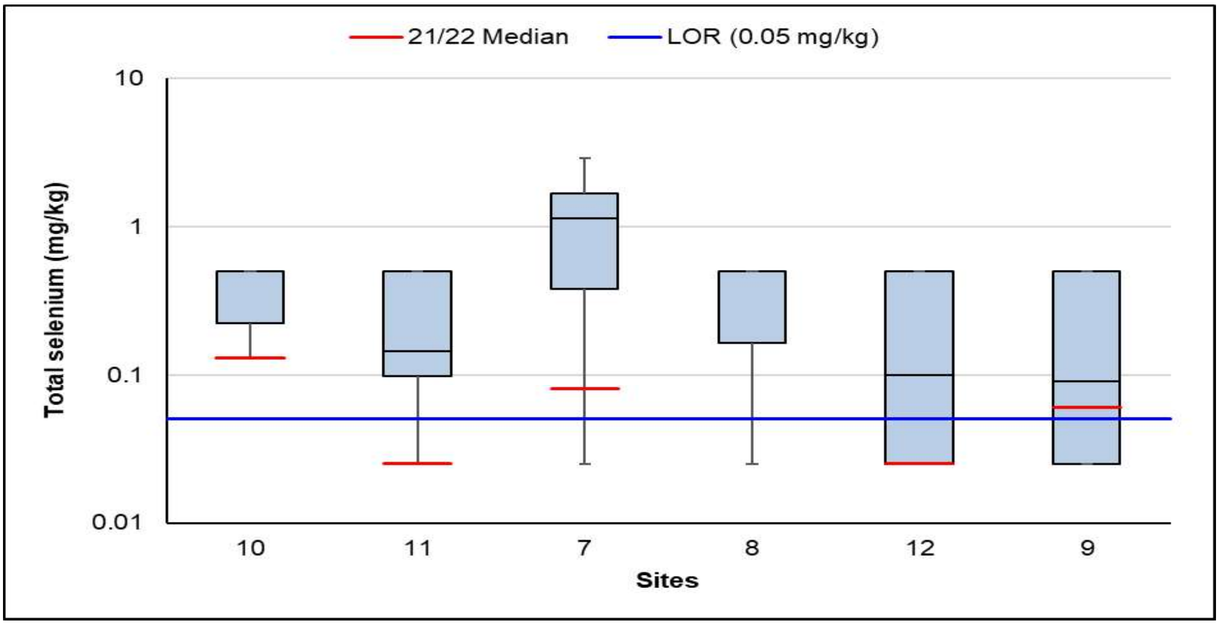


Figure 207. Box plot of total selenium 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

The highest selenium concentration (0.130 mg/kg) was recorded at site 10, sites 11 and 12 both recorded concentrations below the LOR (0.05 mg/kg) with concentrations of selenium seen to be at 0.025mg/L (Figure 207 and Table D-44 in Appendix D). Sediments can be a significant source of selenium in fish and invertebrates. Toxic effect threshold levels for selenium in freshwater sediment, for food chain organisms according to ANZECC & ARMCANZ 2000 criteria is 3 mg/kg and 4 mg/kg, respectively (Lemly, 1993).

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Total selenium concentrations recorded in 2021 are similar to those recorded in the preceding eight years (Table H-57 in Appendix H). Site 7 has regularly recorded the highest concentrations in the catchment, whereas sites 12 and 9 have regularly recorded the lowest.

Zinc

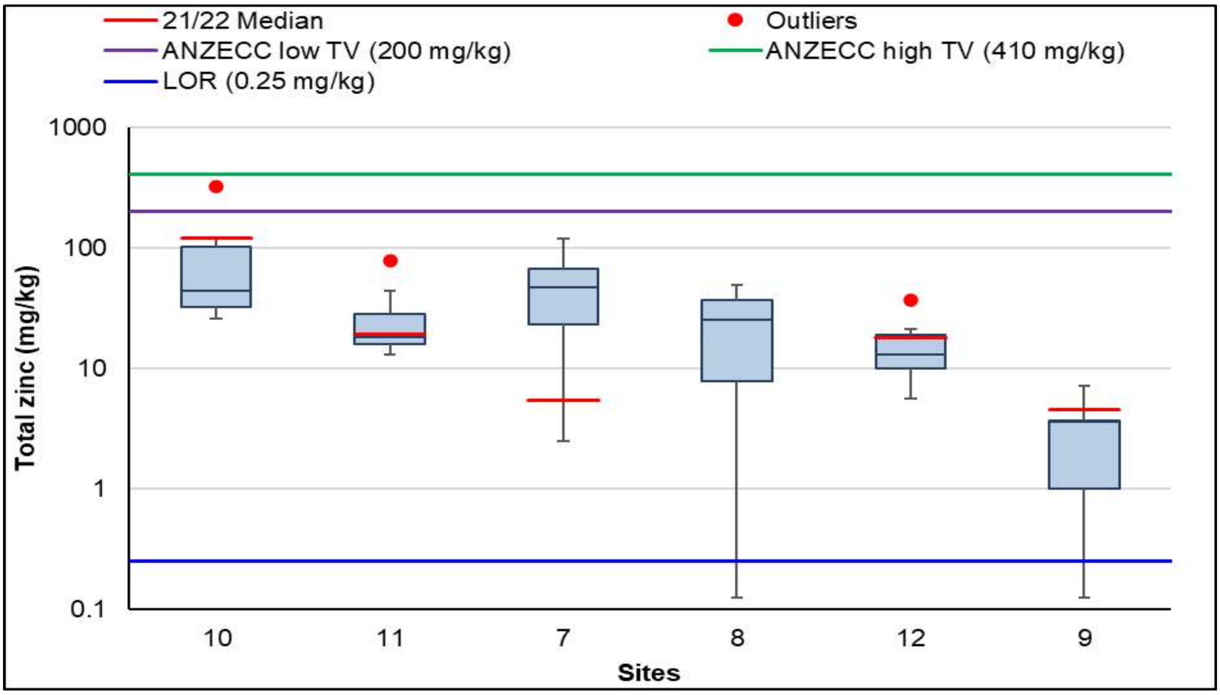


Figure 208. Box plot of total zinc 2007-2020 historical median values, with a red line indicating the median value in 2021.

Box whisker

Concentrations of total zinc in sediment throughout the Melville Lakes sites in 2021 were low, with all concentrations below ANZECC low (200 mg/kg) and high (410 mg/kg) trigger values (Figure 208 and Table D-45 in Appendix D). The highest concentration 120 mg/kg was recorded at site 10, followed by 19mg/L at site 11 and the lowest 4.6 mg/kg at site 9.

Time series

For plots, refer to Figure 209 for Fredrick Baldwin Reserve (site 10), Figure 210 for Booragoon Lake (site 7), Figure 211 for Piney Lakes (site 8), Figure 212 for Marmion Reserve (site 11), Figure 213 for Quenda Lake (site 9) and Figure 214 for Blue Gum Lake (site 12).

Concentrations of total zinc in sediment recorded in 2021 are similar to those recorded in the preceding eight years of monitoring (Table H-57 in Appendix H). During the nine years of monitoring, only sites 10 has recorded zinc concentrations in exceedance of the low trigger value, recording anomalously high concentrations in 2011 with a concentration of 320 mg/L.

Logarithmic plots of all metals in sediments

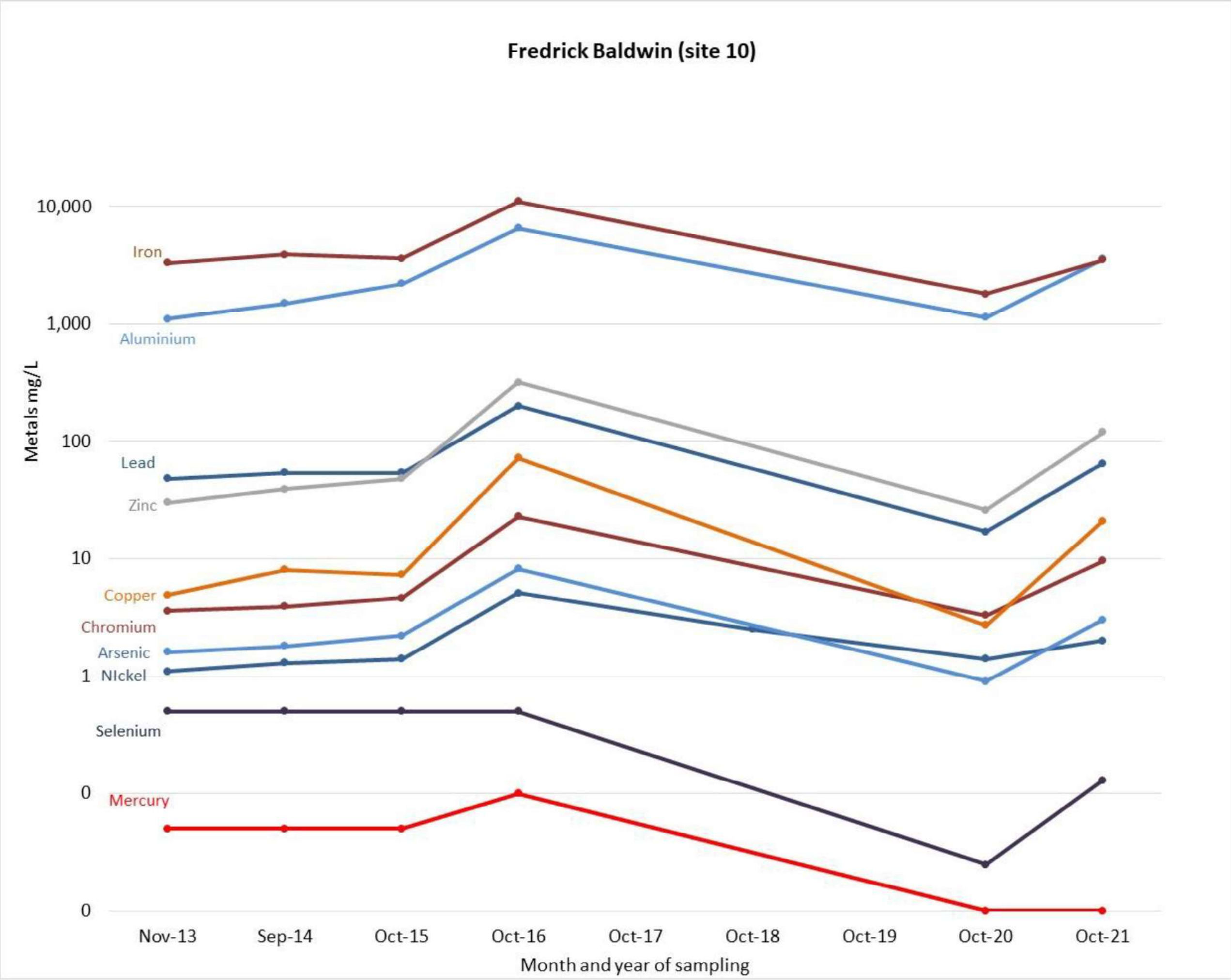


Figure 209. Logarithmic plot of combined metal records at Fredrick Baldwin.

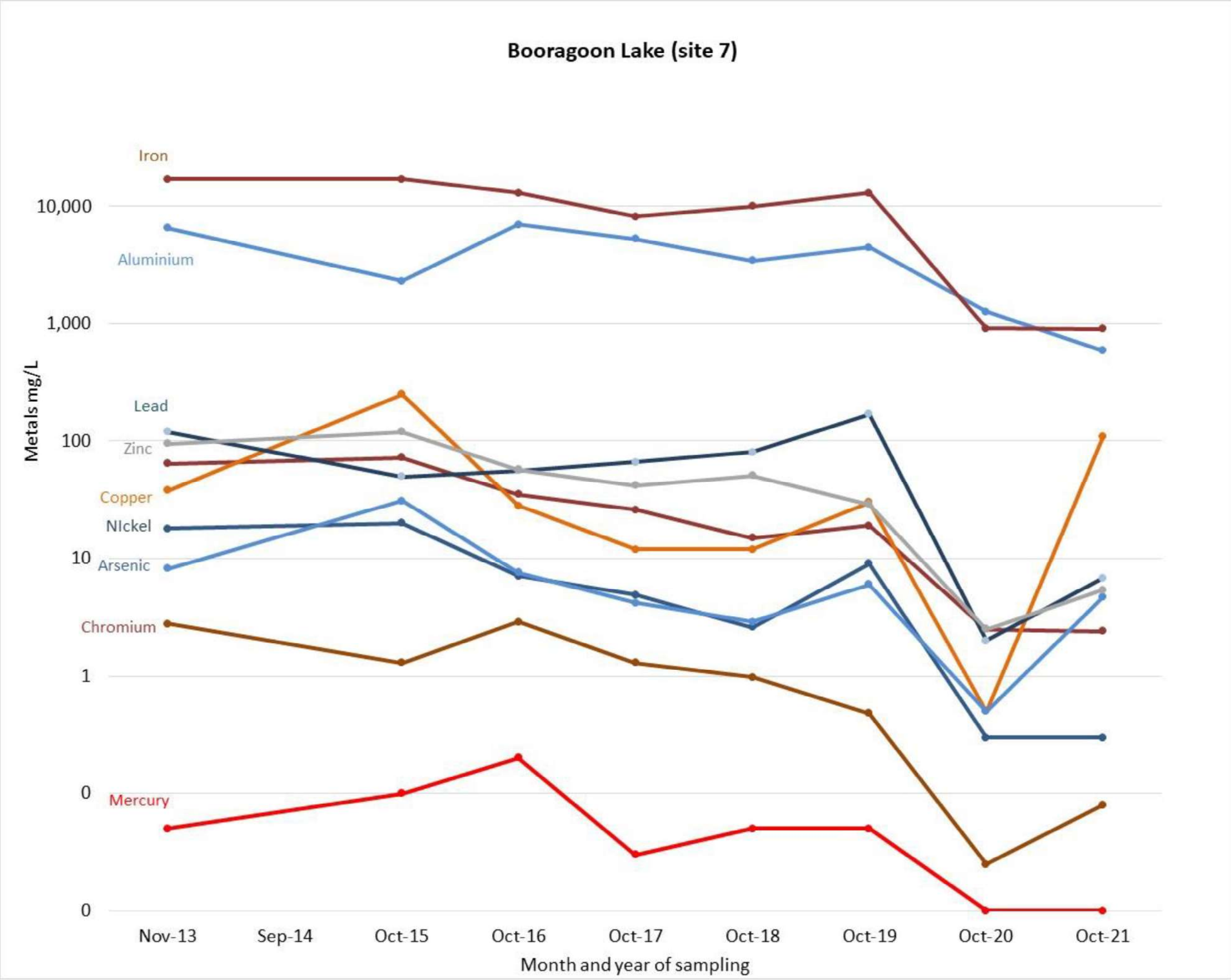


Figure 210. Logarithmic plot of combined metal records at Booragoon Lake.

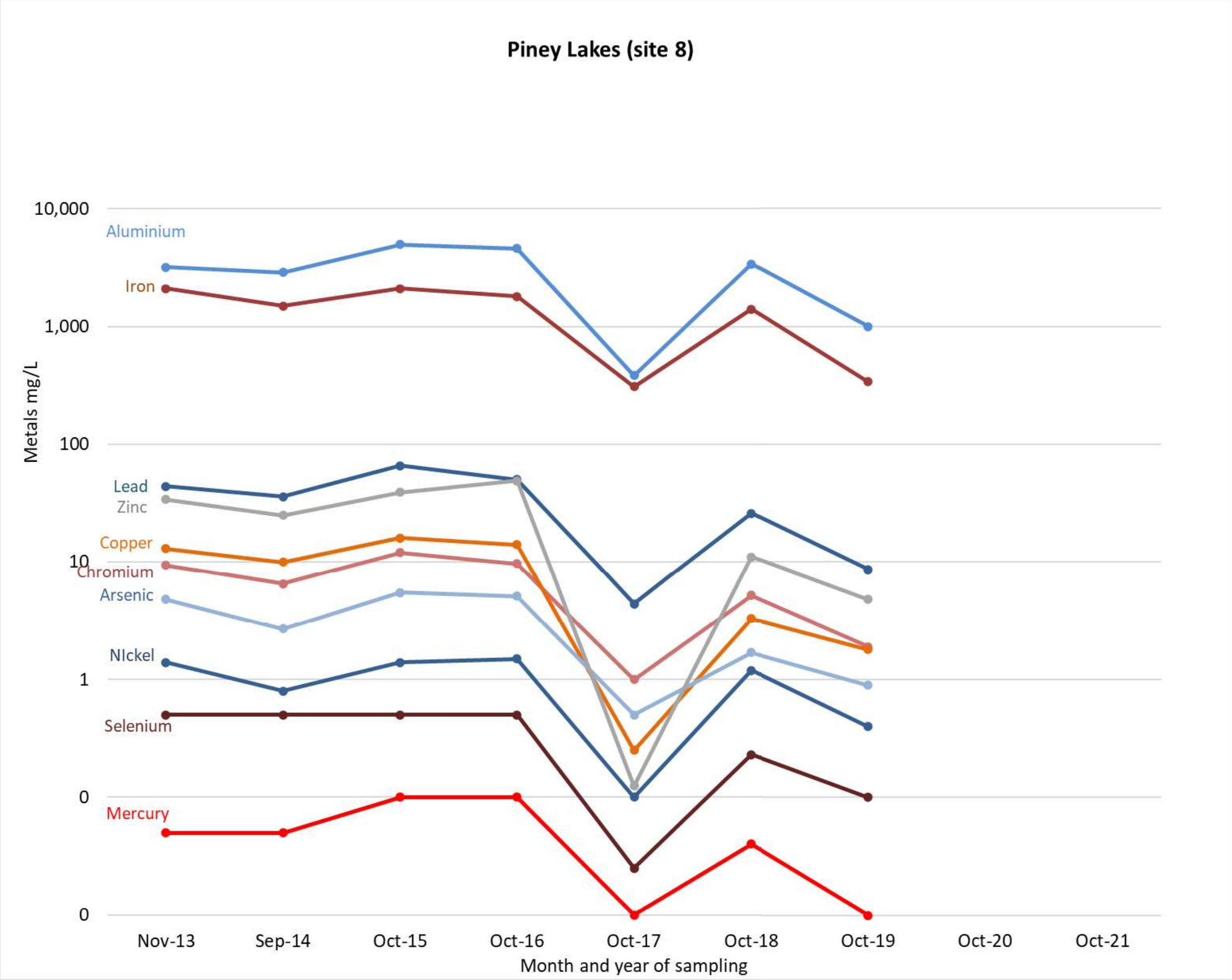


Figure 211. Logarithmic plot of combined metal records at Piney Lakes.

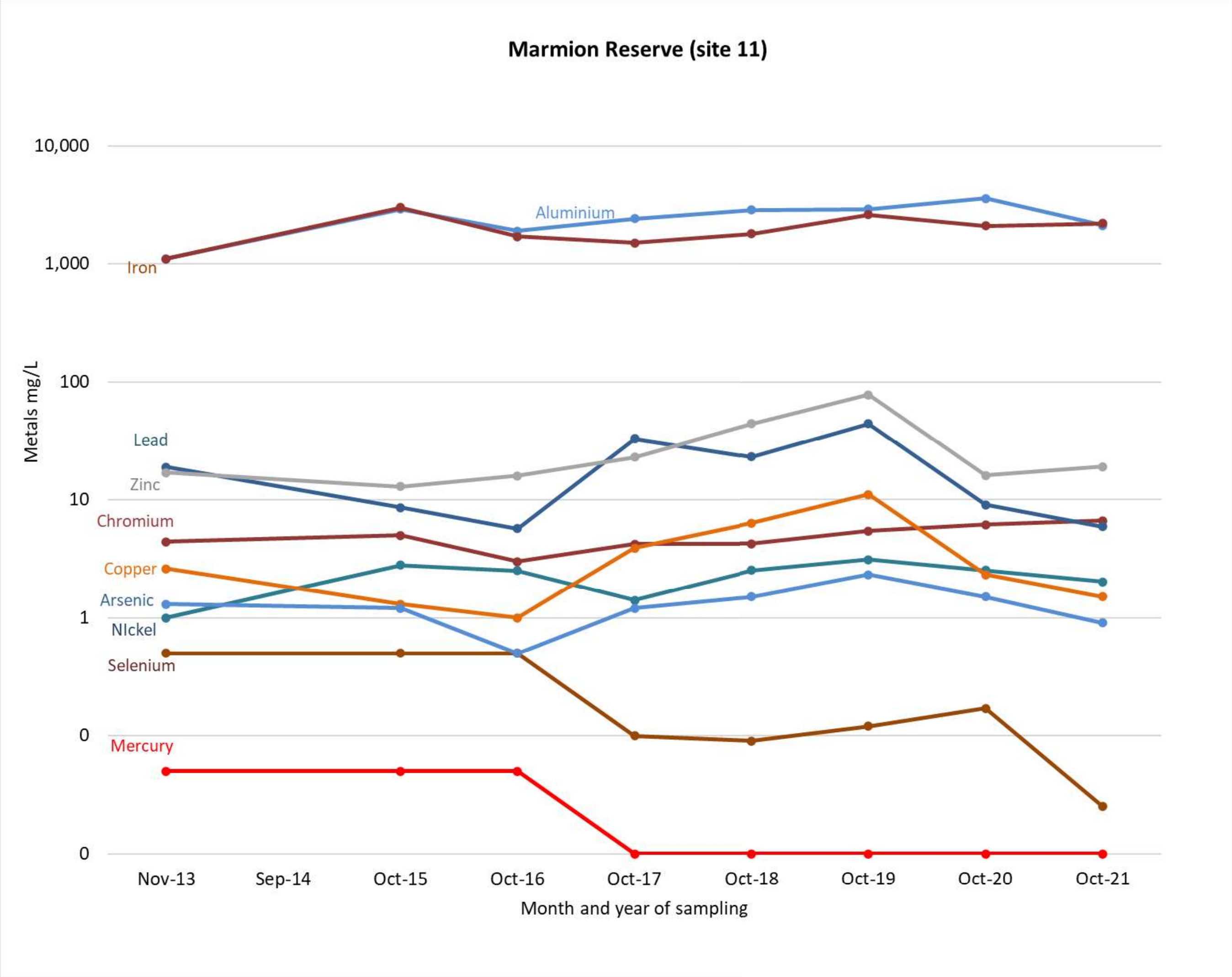


Figure 212. Logarithmic plot of combined metal records at Marmion Reserve.

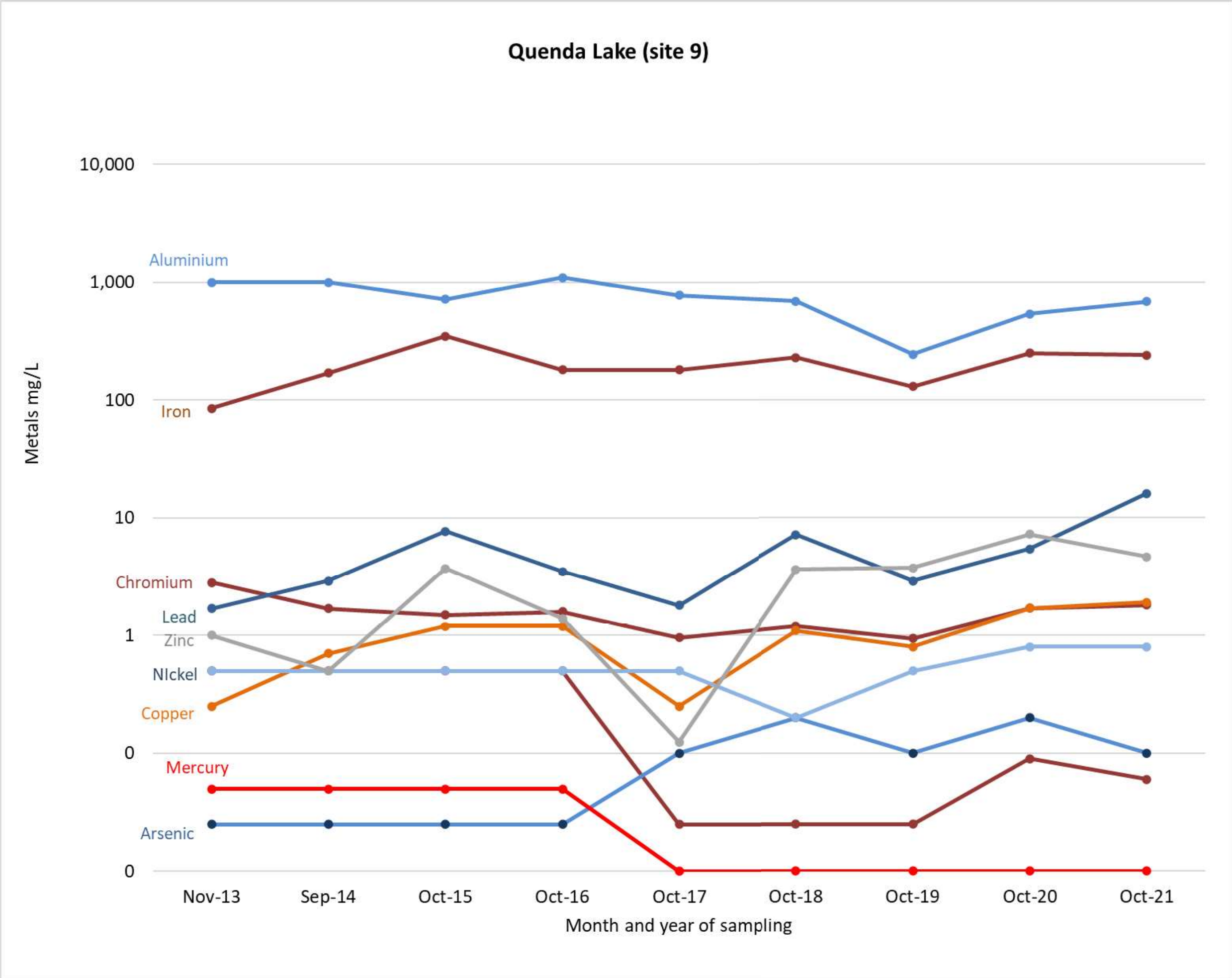


Figure 213. Logarithmic plot of combined metal records at Quenda Lake.

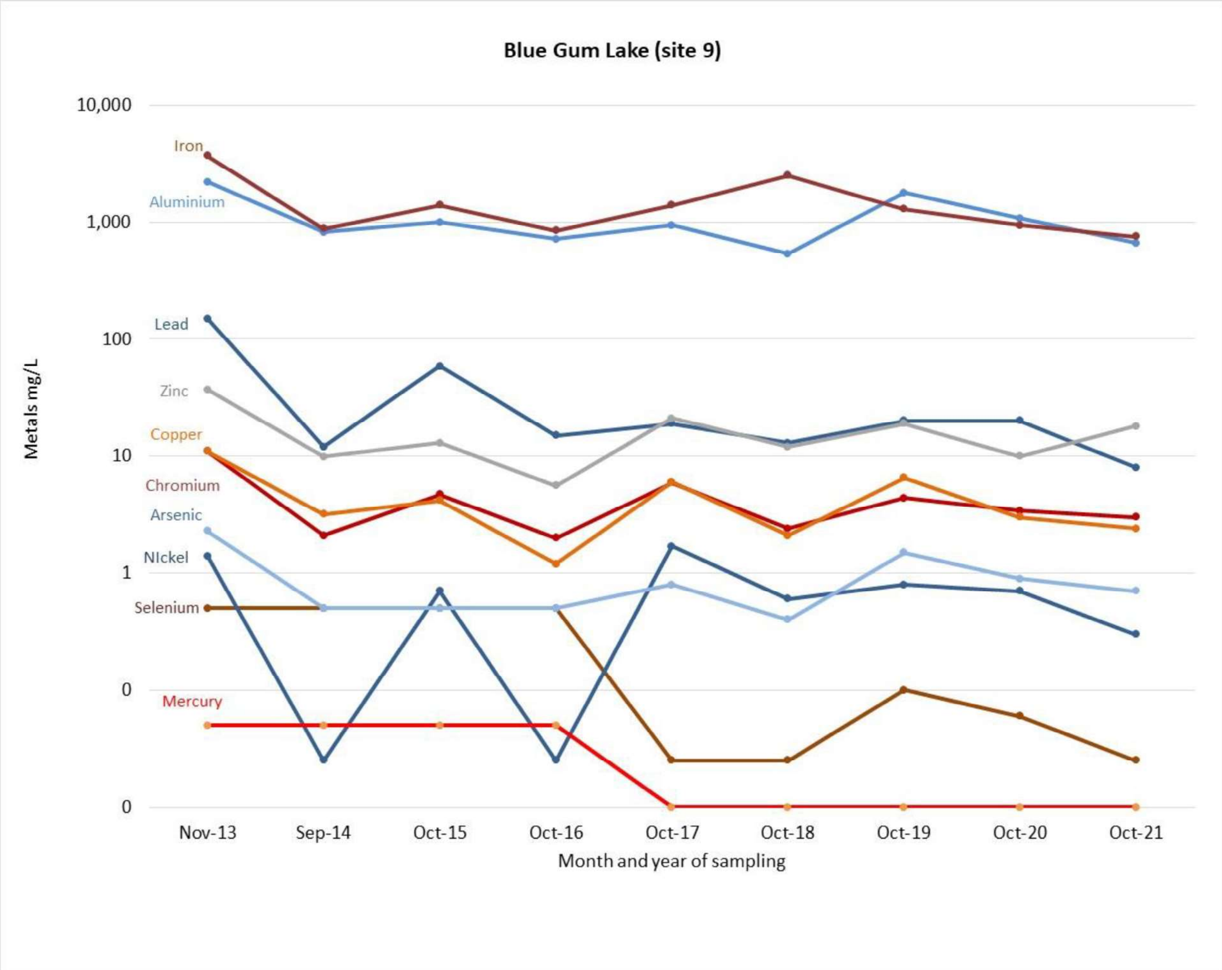


Figure 214. Logarithmic plot of combined metal records at Blue Gum Lake.

Summary of sediment metal results and combined metal plots

The total metals without adjustment for hardness were used to explore variations between metal concentrations of the sites. When the metals in sediments are examined with time for each site where sediment was sampled, the iron and aluminium levels remained highest of all metals, and there were some possible trends of decreasing and increasing levels of metals in some sites. But there were no overall trends, instead the metal at each site needs to be examined independently (Table 37).

Table 37. Summary of pH levels and metals in the sediments in sites 7, 8, 9, 10, 11, and 12.

Site	Mean and median pH (n) of water (ANZECC pH TV for lowland rivers = 1.5 – 8.0)	Metal trends in sediments
7 Booragoon Lake	5.90 and 1.52	Possible down wards trends of metals.
8 Piney Lake	5.82 and 5.73	Possible down wards trends of all metals. A lower value was recorded of all metals in October 2017.
9 Quenda Lake	6.84 and 6.82	Cr and Pb may be increasing and Se and Hg decreasing, but no clear trends exist.
10 Fredrick Baldwin	7.26 and 7.14	Highest Al and Fe. A higher value was recorded in October 2016 of most metals. No overall trends.
11 Marmion Reserve	8.28 and 8.17	While copper may be trending down at this site, the other metals may have increased between 2016 and 2019 but show no other trends.
12 Blue Gum Lake	6.61 and 6.90	Pb, Zn, Se and Hg may be decreasing, but no clear trends exist.

When the observations are considered together with the knowledge that a drop in pH is known to increase the solubility of metals, there is a slight trend that the drop in pH when comparing the overall results, may cause some of the metals to be released into the water. Effectively reducing the metals held in the sediments. The pH of the water at Booragoon Lake (site 7) was lowest of all sites on average, but since 2017 the pH at this lake has been tending to be within acceptable guidelines. This should logically result in an upwards trend of metals in sediments, but the opposite trend was observed. pH is therefore unlikely to be the main reason for differences in metal concentrations between or within the sites. It is notable however, that levels of iron and aluminium in Booragoon Lake (site 7, minimum concentrations of 1.3 mg/L total Fe and 0.22 mg/L total Al) was much higher than at the other sites (0.05 mg/L total Fe and 0.01 mg/L total Al). These results instead suggest one or more of the following is influencing metal levels in sediments;

- rivers bring metals downstream and these accumulate in sediments, in particular where flow is restricted
- wetlands near heavily trafficked roads are more likely to have inflows of metals
- wetlands closer to the river contain more metals in the sediments
- older and/or denser urban areas have contributed to accumulation of metals with time
- metals and the geochemistry of the metals in specific soils influence the retention of metals in sediments
- rehabilitation of wetlands may restrict flow and therefore removal of metals from wetlands
- other works done to reduce metal inflow and retention in wetlands are associated with these trends and observations.

There were also variations between sites in terms of the dominance of metals in the sediments. Overall, iron and aluminium were most abundant and tended to trend together. Then zinc, lead, chromium, copper, nickel, arsenic, selenium, and mercury in that order. While there appeared to be some clustering of lead and zinc as well of chromium, nickel and copper, these associations are not clear.

Particle size analysis

The average particle sizes at the Melville sites revealed that silt as well as clay tended to be more common in sites where water flow was lower, such as the lakes and where sediment may accumulate due to obstructions such as at the Bull Creek Main Drain (site 1) or John Creaney Park outlet (site 5). The amount of gravel recovered in samples (sites 5 to 6) is decreasing as the sites more downstream but is variable in the lakes (see also Appendix I).

Below is a reproduction of Table 4 detailing the sizes of particles.

Class	Size
Clay	<4 µm
Silt	4-62 µm
Fine sand	62-250 µm
Medium sand	250-500 µm
Coarse sand	500-2,000 µm
Gravel	>2,000 µm

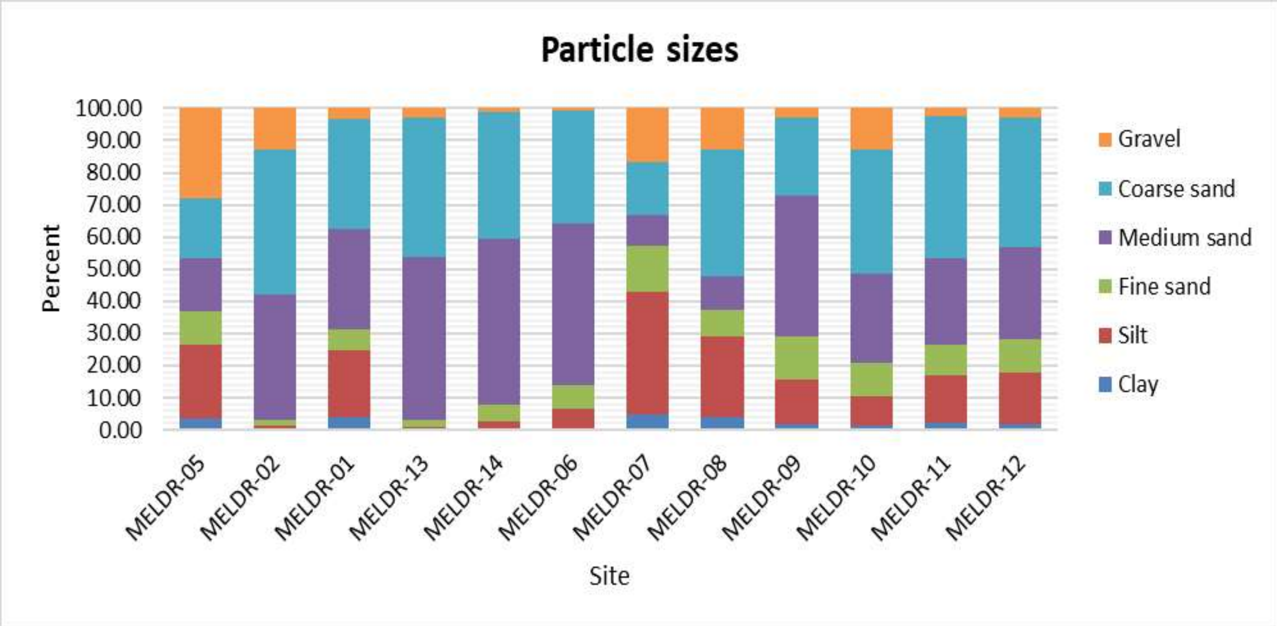


Figure 215. Average (mean) particle size analysis recorded at all Melvile sites between 2013 to 2021.

In addition to differences in particle sizes between sites, there have also been changes in particle sizes collected at different sites during different times. While some of these differences are no doubt due to differences in accuracy and precision associated with collecting such samples, some of these differences may reflect site specific ecological variations. These differences are plotted in Figures 215A, B, C and D and discussed below. Referring to Figure 215A that concerns three Bull Creek Main Drain sites the main observations are as follows per site;

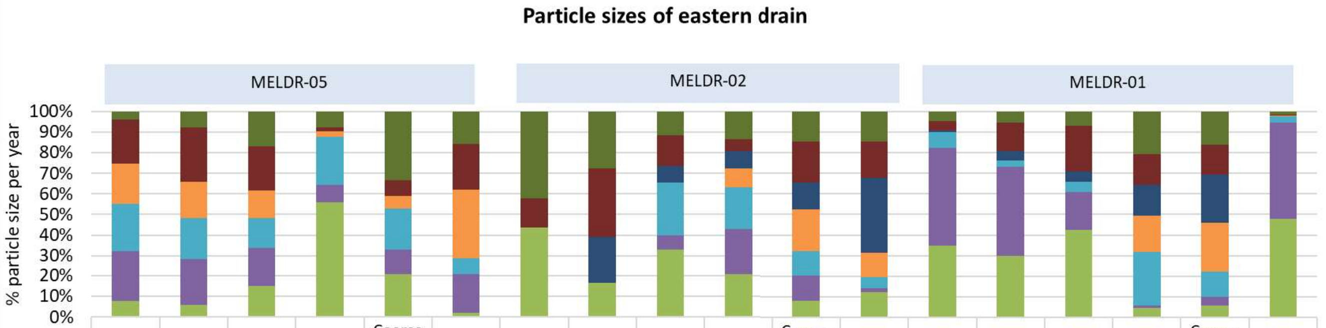
Site MELDR-05. At John Creaney Park, the proportion of gravel and coarse sands seem to have increased, while other particle sizes are reduced.

Site MELDR-02. At Brockman Park, the proportion of coarse sands has increased, medium sand and gravel have remained variable and more common, while clay, silt and fine sand has consistently made up smaller portions of the particle sizes.

Site MELDR-01. At Bull Creek Park Main Drain, the proportion of medium and coarse sands have increased, that of silt has reduced and gravel, clays and fine sand make up a smaller proportion.

These results suggest that sands, in particular medium and coarse sands, have increased within these sites, while gravel and finer particle sizes make up smaller proportions most of the time. The causes of this is unclear, but may be associated with changes to the intensity of stream flow or rehabilitation works at different years along this drain.

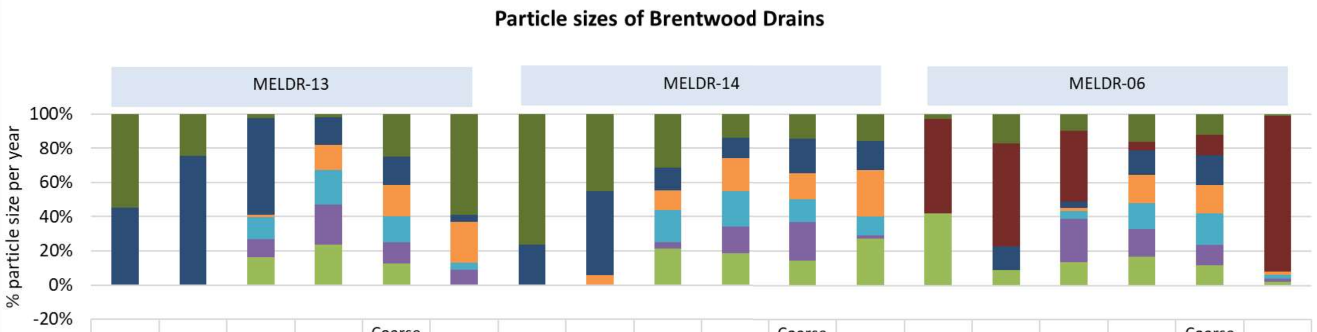
The differences in terms of particle sizes as the Brentwood Drains (Figure 215B) show that, for most years sampled, medium and coarse sands make up the largest proportion of the sediment particles. The interesting and possible exceptions to this occurred in site MELDR-06 (Bateman Park) where the proportions of silt, fine, medium and coarse sands were reasonably similar and in site 13 (Brentwood Drain), where coarse sand and gravel were common. It would be valuable to understand better why and how clays, silts and fine sands make up a larger proportion of the sediments at site 14 (RAAF Drain) in more recent years. Has water flow slowed down here?



	MELDR-05						MELDR-02						MELDR-01					
	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)
Oct-21	0.69	9.92	10.52	6.90	45.97	25.99	0.74	2.99	1.39	36.04	45.82	13.01	1.13	7.43	2.90	48.98	39.26	0.29
Oct-20	3.91	33.03	13.46	1.61	10.82	37.16	0.25	3.57	1.82	15.29	63.51	15.55	1.05	18.13	9.33	35.64	35.74	0.11
Oct-19							0.00	2.46	0.95	23.06	41.09	32.44	0.26	5.72	1.94	35.45	56.63	0.00
Oct-18	3.57	21.78	8.45	2.51	8.30	55.40	0.00	0.00	0.01	24.49	64.60	10.90	0.00	0.00	0.06	42.14	57.70	0.10
Oct-17	4.19	25.08	9.14	20.48	27.60	13.50	0.00	0.00	3.09	54.51	37.80	4.60	1.83	4.13	2.13	61.12	30.20	0.60
Oct-16	4.48	28.22	11.67	7.63	16.80	31.20	0.00	0.00	0.87	59.43	38.00	1.70	11.36	57.58	7.59	3.36	10.50	9.60
Oct-15	1.44	7.41	9.39	49.66	28.50	3.60	0.77	1.79	3.98	56.27	26.20	11.00	8.39	39.47	17.73	10.71	13.80	9.90

Oct-15 Oct-16 Oct-17 Oct-18 Oct-19 Oct-20 Oct-21

Figure 215A. Average (mean) particle sizes collected during several years at the eastern drainage sites.



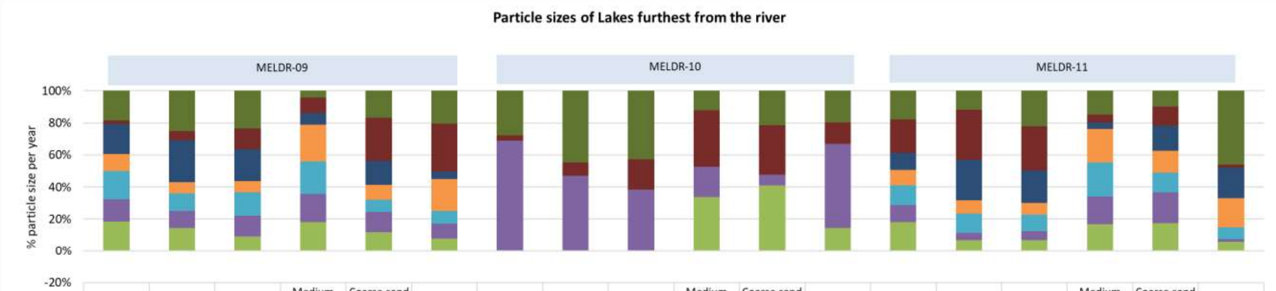
	MELDR-13						MELDR-14						MELDR-06					
	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)
Oct-21	0.15	1.69	0.24	5.41	72.43	20.09	1.02	10.43	12.25	42.25	33.20	0.85	0.08	7.47	4.88	58.74	28.77	0.06
Oct-20													1.56	26.03	20.88	18.12	28.97	4.44
Oct-19	0.13	5.17	5.16	41.08	47.16	1.31	0.31	11.37	5.14	35.86	46.38	0.94	0.00	5.93	1.97	50.96	41.14	0.00
Oct-18	0.00	0.00	0.13	38.27	53.50	8.10	0.00	1.31	4.43	57.56	35.20	1.50	0.00	0.00	0.92	59.88	39.10	0.10
Oct-17	0.00	0.00	1.19	53.41	44.00	1.40	0.00	0.00	7.39	61.41	30.60	0.60	0.00	0.00	2.31	53.29	44.30	0.10
Oct-16	0.00	0.00	0.94	60.26	35.80	3.00	0.00	0.00	1.32	46.58	52.00	0.10	0.00	0.00	12.68	58.82	28.40	0.10
Oct-15	0.00	0.00	1.52	61.98	36.40	0.10	0.00	0.00	8.34	56.56	33.60	1.50	1.19	3.87	6.89	59.95	28.00	0.10

Oct-15 Oct-16 Oct-17 Oct-18 Oct-19 Oct-20 Oct-21

Figure 215B. Average (mean) particle sizes collected during several years at the Brentwood Drain sites.

When exploring particle size changes over time in the lakes (Figures 215 C and D), the lakes have been split into two groups (to avoid clutter of plots, but also for geographical purposes). One group with lakes further form the river (MELDR-09 Quenda Lake, MELDR-10 Fredrick Baldwin Lake and MELDR-11 Marmion Reserve) (Figure 215C).

This figure shows that that while each lake is different, there are also similarities between lakes in terms of the proportions of particle sizes collected at different times. For example, Quenda Lake and Marmion Lake are similar in terms of the proportions of clay and sands collected at different times, but different in terms of silt and gravel. Fredrick Baldwin has not been samples as frequently, but have more clay, silt and gravel proportions than the other two lakes. These differences may be due to water flow at the sample sizes, where this may be faster at Quenda and Marmion Lakes, compared to that at Fredrick Baldwin. How has the extent and management of vegetation at Fredrick Baldwin resulted in stiller water and accumulation of finer particles?

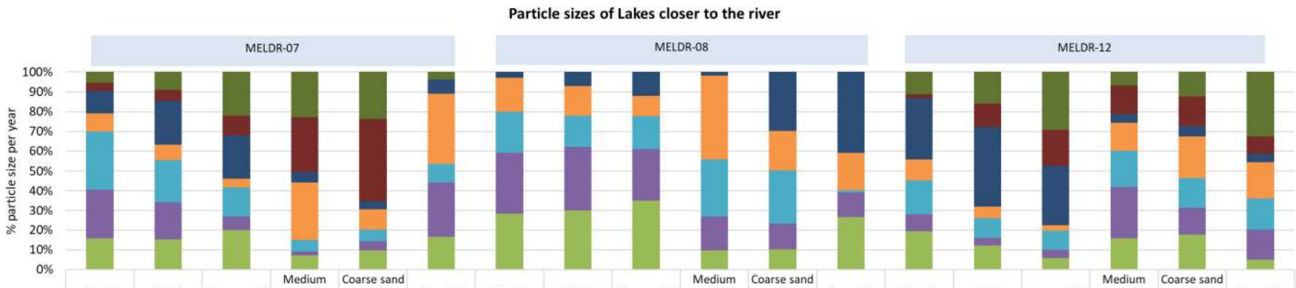


	MELDR-09						MELDR-10						MELDR-11					
	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)
Oct-21	2.35	27.42	25.02	11.44	29.31	4.46	1.37	22.53	23.48	11.48	31.82	9.33	2.79	11.87	15.97	28.13	28.61	12.63
Oct-20	0.28	6.30	13.85	26.02	46.93	6.63	0.16	4.21	10.30	32.93	46.05	6.34	3.24	31.08	20.23	9.70	35.22	0.53
Oct-19	2.36	28.87	21.00	20.47	26.32	0.98							1.68	25.09	14.74	7.73	45.62	5.14
Oct-18	1.37	7.68	7.30	63.35	15.90	4.40							1.49	8.34	5.32	39.75	40.10	5.00
Oct-17	2.25	11.87	15.68	55.01	13.50	1.70							1.92	11.97	7.50	40.51	36.10	2.00
Oct-16	1.77	11.78	13.64	48.91	21.80	2.10	3.41	23.67	20.97	17.76	9.50	24.70	1.65	4.48	4.01	33.16	56.20	0.50
Oct-15	2.34	15.98	9.91	49.37	20.70	1.70	0.00	0.00	0.18	31.82	61.10	6.90	2.84	6.99	5.01	32.06	51.50	1.60

Oct-15 Oct-16 Oct-17 Oct-18 Oct-19 Oct-20 Oct-21

Figure 215C. Average (mean) particle sizes collected during several years at the lakes furthest from the river.

The other three lakes, MELDR-07 (Booragoon Lake), MELRD-08 (Piney Lakes), and MELDR-12 (Blue Gum Lake) also show differences and similarities (Figure 215D). For example, Booragoon Lake and Blue Gum Lake are more similar to each other than they are to Piney Lakes. The proportion of silt and fine sands have increased slightly in Booragoon Lake and Blue Gum Lake, while clays has remained variable, but tends to have decreased in these lakes. In contrast, the proportion of coarse sands, but also to an extent medium sands, have increased in Piney Lakes, where clays, silts and fine sands have decreased. These differences can possible be attributed to differences in water flow and ecological features at sampling sites and at the lakes.



	MELDR-07						MELDR-08						MELDR-12					
	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)	Clay % (<4 µm)	Silt % (4-62 µm)	Fine sand % (62-250 µm)	Medium sand % (250-500 µm)	Coarse sand % (500-2,000 µm)	Gravel % (>2,000 µm)
Oct-21	1.67	22.84	24.05	17.17	30.28	3.99							1.20	18.80	25.45	12.59	33.99	7.96
Oct-20	1.29	13.52	11.25	20.73	53.20	0.00							0.21	13.76	15.87	26.16	41.89	2.11
Oct-19	3.61	55.74	23.90	3.97	5.44	7.34	0.55	8.74	5.12	1.01	58.80	25.78	3.34	47.01	26.23	8.02	14.40	1.01
Oct-18	2.87	19.37	4.99	22.08	13.70	37.00	3.20	18.90	4.25	22.05	39.60	12.00	1.13	7.38	2.40	26.08	58.50	4.50
Oct-17	9.16	53.34	16.17	4.24	7.20	9.90	3.91	19.77	7.01	15.01	53.60	0.70	1.82	11.68	8.47	33.33	40.80	3.90
Oct-16	7.72	47.91	7.71	1.45	6.30	28.90	5.74	40.27	11.01	8.99	26.00	8.00	0.95	4.32	3.70	48.52	38.80	3.70
Oct-15	4.94	38.19	21.86	5.40	12.20	17.40	5.36	37.93	14.76	5.04	20.10	16.80	2.08	14.37	4.98	28.67	48.70	1.20

Oct-15 Oct-16 Oct-17 Oct-18 Oct-19 Oct-20 Oct-21

Figure 215D. Average (mean) particle sizes collected during several years at the lakes closer to the river.

Discussion of results

Part 1. Comparing 2021 data to summated previous data

There were some differences when the statistical median values of parameters in the water and sediments collected since sampling began and up to 2020, are compared to that of samples collected in 2021. Summaries of where the most notable differences are presented below.

Bull Creek Main Drain and Bateman Park sites

- Site 15, John Creaney Park inlet - Recorded its first ever DO saturation reading within the ANZECC acceptable range in July. Previously and after this event, the DO saturation has generally remained approximately 45%. Recorded values below the ANZECC acceptable range for EC for the first time since sampling began at these sites in 2014.

- Site 5 John Creaney Park outlet - Recorded a value within the ANZECC acceptable range for EC for the first time since 2012. This year found site 5 (John Creaney Park outlet) recording the highest concentration in all total metals sampled for sediment.

- Site 16 Closed pipe downstream of Elizabeth Manion Park - Recorded values below the ANZECC acceptable range for EC for the first time since sampling began at these sites in 2014.

- Site 2 Brockman Park, confluence where pipe drain opens - Recorded exceedances in TSS in July and October; this has not occurred since March 2010.

- No obvious differences were observed at site 1, Bull Creek Main Drain, the culvert under Leach Highway or at the Bateman Park sites (13, 14 and 6).

Melville Lakes

- Site 7 Booragoon Lake - Recorded low pH values in 2021 similar to that experienced from 2007 to 2018. This differed from the increased pH values observed in 2019. After three years of high exceedances for TP and FRP at site 7 (Booragoon Lake, 2017, 2018, 2019), it appears that concentrations at this site may be reverting back to their pre-2017 values.

- Site 12 Blue Gum Lake - Although pH was below 5 on several occasions prior to 2014, the pH has increased since then to be within the ANZECC acceptable range for pH since then (including during the 2021 sampling season).

- Site 9 Quenda Lake outlet - Recorded unusually high exceedances of TSS on two sampling occasions. An exceedance of TSS has only occurred on one other occasion, in September 2008.

Part 2. Observations of long-term patterns – 2007 through to 2021

Monitoring of the water and sediment quality at several sites in the Melville Bull Creek catchment has occurred over 14 years (Tables 5 and 38). This has allowed for the creation of an excellent data base that not only can identify and investigate long term patterns, link patterns to events or management actions. Accordingly, management practices and actions can target sites and features more proactively.

The one parameter that stands out as possibly improving at all sites was pH, in particular as pH values seem to be less variable over time at most sites and stabilising between pH 6 and 8. In terms of other parameters, while rehabilitation has seen improvement in several indicators in the wetlands, these activities may also have inadvertently increased the amount of metal pollutants held in sediments. As pH increases metals are less soluble and can bind to sediments and are therefore not removed, and in some cases, the increased organic sediments and reduction in flow, may have resulted in these metals remaining in the sediments. This needs further examination.

Table 38. Summary of when sampling started at the different sites. Note: not all metals were sampled in the water at all sites after 2007 or 2014 – see also Appendix G.

Drain	Site	Physicochemical features	Nutrients	Metals in water	Sediments
Bull Creek Main Drain sites	15	2014	2014	2007	2013
	5	2007	2007	2014	2013
	16	2014	2014	2007	2013
	2	2007	2007	2007	2013
	1	2007	2007	2007	2013
Bateman Park drain sites	13	2013	2014	2014	2013
	14	2013	2014	2014	2013
	6	2007	2007	2007	2013
Melville lakes	7	2007	2007	2007	2013
	8	2007	2007	2007	2013
	9	2007	2007	2007	2013
	10	2007	2007	2007	2013
	11	2007	2007	2007	2013
	12	2007	2007	2007	2013

Bull Creek Main Drain sites 15, 5, 16, 2, and 1 - Overall summary

Upstream sites at John Creaney Park, are of the worse quality in terms of physical and nutrient parameters. While soluble metals were often also high at John Creaney Park, in particular at the inlet (site 15) soluble metals were often higher at Brockman Park (site 2) and Elizabeth Manion Park (site 16). Sediment metals, in particular iron and aluminium were however, highest at the most downriver site where Bull Creek Main Drain enters a culvert under Leach Highway (site 1). At this site however, metals in the sediment seems to have been decreasing since 2016. At John Creaney Park outlet (site 5) sediment metals may be increasing while at Bateman Park (site 2) they seem to remain stable. Unlike most physical and nutrient trends that have become more stable and often decreasing since 2014, metals in the water have however, become more variable with higher concentrations since 2014.

Oxygen

Low oxygen saturations have consistently been recorded in Bull Creek Main Drain sites over the 14 years of sampling the catchment, excepting for downstream Elizabeth Manion Park with three years in a row with all samples falling within the acceptable range for lowland rivers (2018, 2019 and 2020). Low oxygen saturations are a common finding with heavily piped catchments and/or wetlands with excessively high organic loads (either from animal waste or vegetation decomposition), however this is still a concerning issue as low oxygen saturations can be directly harmful to biota, result in increased toxicity of some metals to biota, and result in phosphorus release from sediment and subsequent eutrophication. Dissolved oxygen saturations are particularly low at site 5 (John Creaney Park), and much lower than at the inlet (site 15) to the lake. When sampled, the lake (site 5) at John Creaney Park always contains a large amount of leaf litter and organic debris, which may be contributing to high oxygen demand as this material decomposes. Groundwater, which is generally lower in oxygen than stormwater, is highly likely to also be filling this lake, in particular in late autumn and early winter.

Nitrogen

High total nitrogen concentrations, well in exceedance of the ANZECC trigger value for lowland rivers, have been recorded for several years at certain sites along the Bull Creek Main Drain since monitoring began in 2007. Total nitrogen was often high at sites along the two upstream branches of the Bull Creek Main Drain (for example at John Creaney Park outlet (site 5) and downstream Elizabeth Manion Park (site 16)). Additionally, a significant portion of nitrogen, predominantly as ammonia/ammonium, is being introduced to the drainage line between the convergence of these two branches and Brockman Park (site 2). This may be originating from groundwater, as high concentrations of ammonia have been recorded in the Jandakot Mound (Larsen, et al., 1998), and could possibly be even higher in this area as a result of the historical landfill at John Creaney Park (DWER 2017).

As water flows from Brockman Park (site 2) to the most downstream Bull Creek site (site 1), historically total nitrogen concentrations tend to become reduced by an average of approximately 55%. This may be due to uptake of nitrogen by macrophytes or dilution from the drainage branch coming from Rossmoyne Senior High School. This was unclear however, as the results in 2021 revealed that there was only a minimal reduction in TN from site 2 downstream to site 1. The remaining nitrogen at site 1, predominantly in the form of oxidised nitrogen rather than ammonia nitrogen, may be a result of slight oxygenation of the water occurring between these two sites. The high total nitrogen concentrations (exceeding ANZECC trigger values) consistently recorded at site 2 and site 1 are of concern, as this nitrogen contributes to eutrophication of the Canning River. Furthermore, the ammonia concentrations that exceeds the ANZECC freshwater protection trigger value at site 2 are concerning, as the portion of site 1 downstream of site 2 is known to support a variety of native fauna species including frogs, fish and macroinvertebrates (City of Melville, 2014).

While some concentrations of nitrogen fractions were above the trigger value at upstream sites (5, 16), the significantly higher concentration at site 2 (Brockman Park) suggest that there is a source of nitrogen between site 5 (John Creaney Park) and site 16 (downstream Elizabeth Manion Park) and site 2 (Brockman Park) which may come from the nearby large public open spaces/ovals.

Phosphorus

The often-high phosphorus concentrations at site 5 (John Creaney Park), while not resulting in high phosphorus concentrations in downstream site 1 (Bull Creek Main Drain sites), could, in conjunction with high nitrogen concentrations (which is often experienced at this site), result in algal and nuisance macrophyte growth in the lake. Filamentous algae have often been observed at this lake over the 14 years of sampling and may an indicator of the high phosphorus and high nitrogen levels records for this site.

Metals

Metals of concern include the high concentrations of iron and aluminium recorded at Bull Creek Main Drain sites. These metals, whose concentration is the Swan Coastal Plain is always high, can have negative effects on biota, in particular in acidic, soft hardness and/or warmer water conditions (ANZECC and ARMCANZ 2000). If pH is less than five, the waters can become toxic to fish.

The concentrations of these metals recorded at Bull Creek Main Drain were similar to those recorded across all Swan and Canning River drainage catchments (Nice, et al., 2009). Additionally, since monitoring began in 2014, high concentrations of total zinc at site 15 (John Creaney Park inlet) and site 16 (downstream Elizabeth Manion Park) and high total copper concentrations at site 16 (downstream Elizabeth Manion Park) have often been recorded. Soluble zinc and copper concentrations recorded at these sites (site 15 and 16) since 2017 indicate that a significant proportion of these total metals are likely to be soluble. The source of zinc is, however, unknown. Again however, high exceedances of the trigger values for these metals are common across Swan and Canning River drainage catchments (Nice, et al., 2009), and concentrations have generally been acceptable at downstream Bull Creek main drain sites (e.g., site 1).

Sediments

Sediment samples collected from site 5 (John Creaney Park) in 2021, together with historical records, show lead concentrations exceeding the ANZECC low trigger value at six out of seven sampling occasions. These high concentrations may be a legacy of previous contamination, possibly from a previous landfill at the site (Hirschberg, 1993) as lead is known to bind strongly to fine, organic sediment (ANZECC and ARMCANZ 2000) such as that found at this site. Although total lead concentrations in water samples from this site have only exceeded 95% freshwater protection hardness modified trigger values once in the 14 years of monitoring (in 2007), under certain conditions (e.g., low pH) it could, however, be released from the sediments and into the water column. This can result in toxic impacts on biota within the lake, as well as contribute to lead contamination downstream at site 1 (Bull Creek Main Drain) and the Canning River. There is also a possibility that the release of lead and uptake by biota could lead to bioaccumulation/biomagnification through the food chain at this, and other sites.

Brentwood Drain sites 13, 14 and 6 – overall summary

These sites show a progressive improvement upriver to downriver since sampling began, in particular since 2014 for several of the measured parameters. Most notable, nutrient composition of the drain, in particular at Bateman Park (site 6) indicate that plants that have been planted at this site since 2018, maybe using nutrients and hence reducing nutrient loads. Other factors may also be that fewer nutrients are flowing into this drain.

Nutrients

Concentrations of nitrogen as ammonia/ammonium, total and soluble iron and total aluminium have been declining over the 14 years of monitoring at site 6 (Bateman Park), the most downstream site sampled along the Brentwood Drain. Dissolved oxygen saturation has also generally been below the ANZECC acceptable range at site 13 (Brentwood drain) and site 6 (Bateman Park) and often within range at site 14 (RAAF drain).Although this is a potentially good outcome, it is however, too early to determine how or if the Brentwood Living Stream project has resulted in improvement of water quality at site 6 (Bateman Park), as this project was only completed in early 2018.

Although exceedances of total nitrogen had only been recorded once at site 6 (Bateman Park), the exceedances of total oxidised nitrogen and nitrogen as ammonia and ammonium (i.e., forms of nitrogen available for plant growth) generally recorded at site 6 could result in algal or nuisance macrophyte growth in areas of the drains where water is still. The 2021 sampling season results revealed fewer exceedances of total oxidised nitrogen and nitrogen as ammonia than recorded prior to 2020. As the record from site 6 only occurred once, it cannot be assumed to represent a new pattern for this site.

Metals

While some metals in the water (Fe, Al) are decreasing since sampling began, others, most notably Cu, Cr, and Zn, tend to be increasing, particularly at the upriver site, Brentwood Drain (site 13). While there are some seasonal variation, other metals in the water seem to be less variable.

Sediments

In terms of metals in the sediment, Brentwood Drain (site 13) had more metals in sediments than the other two sites. Additionally, at Brentwood Drain (site 13) in October 2016, and at Bateman Park (site 6) in October 2020, there were higher levels of most metals in the sediments compared to values at other times. These two peaks are more likely to be due to site specific activities rather than weather as they were not observed at these times at the other sites and weather was comparable to that of other years.

IN spite of these observations, these samples have however, (from 2013 at Brentwood Branch drain sites 13, 14 and 6) always recorded concentrations below the low trigger value for seven out of 10 metals. Of these metals, seven have trigger values available for assessment and the remaining three do not. The records reveal that, apart for site 13 (Brentwood drain), the other two sites recorded exceedances of low trigger values for five metals in the 2016 sampling (chromium, copper, lead, nickel and zinc). Selenium has only been detected above LOR once at site 13 (2018) and once at site 6 (2020) and the three sites had relatively low concentrations of aluminium and iron in these years, in contrast to recent years where these metal concentrations were relatively high. Selenium, aluminium and iron do not have ANZECC trigger values to compare results against. The absence of trigger values should however not suggest these metals are not of concern, in particularly as it is known that heavy metals and metalloids can affect biochemical, physiological and metabolic processes in plants (Srivastava, et. Al., 2017).

Melville Lake sites 7, 8, 9, 10, 11, and 12 – overall summary

These lakes could be divided into three types based on water and sediment quality. The most notable features are mentioned here as well as the compliance cards which contain more information.

Type 1. Best condition. Fredrick Baldwin (site 10) and Marmion Reserve (site 11).

Type 2. Intermediate condition.

- Site 8 Piney Lake while in overall good condition, samples from this lake have sometimes deviated from the normal levels for certain parameters at times. Hence this lake had been listed as between Type 1 and Type 3.
- Site 9 Quenda Lake. Dissolved oxygen saturation and pH values are lower, with total nitrogen (and dissolved organic nitrogen) and total aluminium concentrations higher from 2014 to 2020 when compared to 2007 to 2013.

Type 3. Worst condition. Booragoon Lake (site 7) and Blue Gum Lake (site 12).

- Site 7 Booragoon Lake. While still recording very high and variable concentrations of nitrogen, the overall maximum concentrations of total nitrogen between 2012 to 2020 was lower (except for a high maximum concentration recorded in 2017) than in previous years (between 2007 to 2011).
- Site 12 Blue Gum Lake. The yearly maximum concentrations of total nitrogen and total phosphorus was higher from 2012 to 2020, than in previous years, from 2007 to 2011. However, the maximum concentrations of these parameters recorded in 2018 were in the range of those recorded from 2007 to 2011. Dissolved oxygen saturations have also been lower at this site since 2013 than in the preceding years. Below are the most noteworthy long-term patterns observed in the catchment:

pH and oxygen

The pH values recorded in 2021 ranged from pH 5.10 to 8.43 and did not meet the ANZECC lower limit for wetlands on all four sampling occasions at Booragoon Lake (site 7), and at least once in Piney Lake, Quenda Lake and Blue Gum Lake (sites 8, 9, and 12). The pH values at sites 7 and 12 have often been particularly low (<5) in the years of monitoring prior to 2017 and remained this low at Quenda Lake. Low pH levels are of concern as low pH can increase the toxicity of some metals and can also have a direct negative effect on biota (ANZECC and ARMCANZ 2000). It is possible that the somewhat higher water levels observed at these lakes in winter and spring since 2017 may be resulting in less oxidation of acid sulfate soils in the lake beds and therefore less acidity entering the lake waters. Low pH can also be caused by the presence of high concentration of tannins in the water. Tannins are organic compounds derived from plant materials that give water a brown (often described as "tea coloured") hue and break down into humic and fulvic acids. The presence of excess plant material in the water is likely to result in the production of high concentrations of tannins. Tannin staining was noted in 2020 on various sampling occasions at sites 7. Pine needles are known to be a rich source of acidic tannins (Northup, et al., 1995) and the pine trees adjacent to the wetland at Piney Lakes reserve may be partly responsible for the low pH values at this site.

The pH at site 11 (Marmion Reserve) has often been high, particularly in late spring and summer months. This may be due to the high number of algae observed at the site in October, which would also explain the very high dissolved oxygen concentration observed. This algal growth has occurred despite total nitrogen concentrations being below ANZECC wetland guideline values and low nitrogen as ammonia/ammonium, although the site did record values exceeding the total phosphorous ANZECC wetland trigger values in September and October (0.084 mg/L and 0.099 mg/L).

Dissolved oxygen has generally been below the ANZECC acceptable range for wetlands at all Melville lakes sites throughout the past 14 years of monitoring, with particularly low median values at site 7 (Booragoon Lake outlet), site 8 (Piney Lakes outlet) and historically site 12 (Blue Gum Lake outlet). Low oxygen can occur in wetlands as a result of excessively high organic loads (either from animal waste or vegetation decomposition), or interaction with groundwater, which is generally comparatively low in oxygen. The lower oxygen at site 7 and site 8 (Booragoon Lake outlet and Piney Lakes outlet, respectively) in recent years could indicate an increase in oxygen demand at these sites. The low oxygen in these lakes is concerning issue as low oxygen saturations can be directly harmful to biota, result in increased toxicity of some metals to biota, and result in phosphorus release from sediments and subsequent eutrophication.

Nitrogen and phosphorus

Samples from sites 7 and 12 (Booragoon Lake and Blue Gum Lake) have usually recorded high total nitrogen (and ammonia) concentrations and almost always recorded high total phosphorus (and filterable reactive phosphorus) concentrations over the past 14 years of sampling. Concentrations of these nutrients recorded in the water column since 2007 have been highly variable between years, however often concentrations are higher in spring months than autumn months. This observation may be due to an accumulation of nutrients in the lakes over winter and the feces (rich in T and P) from the large waterbird populations observed using the lakes in spring (Hahn, 2007).

Total phosphorus and filterable reactive phosphorus at Site 7 (Booragoon Lake) had been increasing since 2017, although in 2021 the values were similar to lower values recorded in 2014. The combination of high soluble phosphorus and soluble nitrogen is likely to be a contributing factor to the algae growth often observed in these lakes, such as that of the blue-green algal bloom (*Microcystis aeruginosa*) seen in Blue Gum Lake on several sampling occasions in previous years. Algal blooms can also increase pH and therefore other water quality parameters. Thus, high nitrogen and phosphorous levels are of concern as these lakes have high conservation value and algal blooms can negatively impact upon both the biota and aesthetic value of the lakes.

Metals

With regards to metals, the high concentrations of iron and aluminium recorded at sites 13, 14 and 6, are representative of those recorded across all Swan and Canning River drainage catchments (Nice, et al., 2009) These results are however of concern, as these metals can have negative effects on biota. Total aluminium concentrations at site 9 (Quenda Lake) have been higher since 2014 (with concentrations often the highest of all the Melville Lakes) and pH values somewhat lower. It is possible that the lake could be receiving more nutrient rich runoff as a result of the surrounding development in the recent years (Fiona Stanley hospital and surrounding infrastructure). Natural Area Consulting (2016) noted that “stormwater drainage from the hospital car park to the east is causing erosion of the Water Corporation sewerage line embankment, with dislodged soil being washed across the limestone path and into the wetland”, which may be resulting in these changes to water quality.

Regular exceedances of soluble zinc have been recorded at site 10 (Frederick Baldwin Lake), partially as a result of the soft water at this site (on three of four sampling occasions in 2020). Exceedances of adjusted trigger values for zinc are reasonably common across the Swan and Canning River drainage catchments (Nice, et al., 2009). Metal speciation testing could determine the proportion of labile (not complexed) zinc complexed to organic material in water at this site, and thus its actual potential for toxicity (CSIRO, 2015).

Values recorded for each metal at site 7 (Booragoon Lake) were significantly lower than what has previously been recorded at this site from 2013 – 2019. Site 5 (John Creaney Park) had the highest values for each metal recorded out of all sites sampled for sediment in 2020 and had lower than usual amounts of metals recorded in the water samples on all occasions except for soluble iron recorded in August. This may be an indication that the sediment at site 5 is removing some of the metals from the water column and holding it within the soils at site 5.

The high concentrations of iron and aluminium recorded at many Melville lakes sites are concerning as these metals can have negative effects on biota, although the concentrations recorded at most Melville lakes sites are generally similar to those recorded across all Swan and Canning River drainage catchments (Nice, et al., 2009). Possibly as a result of acid sulfate soil oxidation (DER 2015), total iron concentrations at Booragoon Lake and Blue Gum Lake are particularly high and thus may be more likely to result in damage to biota and/or unsightly iron flocs that compromise water clarity. It is noted that comparatively high concentrations of aluminium and iron were also found at Booragoon Lake and Blue Gum Lake which could potentially be released into the water column in certain conditions.

Sediment

While at some of the lakes (in particular Booragoon Lake, site 7) metals in the sediment is trending down, at others, metals (in particular copper and zinc) seems to be trending upwards. Sediment lead concentrations have almost always exceeded the low trigger value at Booragoon Lake; however, lead concentrations in Booragoon Lake waters have always been below adjusted trigger values. This may be because the comparatively silty and fine sandy sediments at Booragoon Lake are effectively trapping lead within the sediments, so it is not easily released into the water column

Catchment wide recommendations to address key issues

Based on the results, it is considered that two lakes; Booragoon Lake and Blue Gum Lake as well as several of the Bull Creek Main Drain sites; John Creaney Park inlet, Brockman Park and the Bull Creek Main Drain site near Leach Highway, have the poorest water quality in the catchment. Management practices at the lakes is likely to be different to those at other sites where water is flowing through more effectively. In addition, improving the ecosystem qualities at sites that are associated with these sites noted above (such as John Creaney Park as well as Elizabeth Manion Park) can improve conditions downstream.

Based on results since sampling began, rehabilitation is likely to be assisting in stabilising and improving conditions in terms of physical, nutrient and metal characteristics. Ongoing activities should involve rehabilitation, ensuring water flow through the drains remains effective. In addition, management of drainage into these lakes should involve identification of sources of pollutants with follow up involving contracting land or business owners to reduce these inflows. Installation of filtering systems to remove pollutants into these lakes, in particular to those of intermediate to prevent further damage to these lakes, but also those of the worst quality. Maintaining the pH at above 6 is critical in order to prevent mobilisation of metals from sediments.

Catchment wide recommendations

Refer also to the Executive Summary of this document.

Existing plans

- Continue with the implementation of the Bull Creek Water Quality Improvement Plan (WQIP).
- Disseminate and consider the City of Melville Stormwater Management Guidelines (SERCUL, 2019) when making decision that may impact stormwater quality. These guidelines reference appropriate guidelines and regulations and prescribe ideal structural and non-structural practices for managing stormwater to ensure the best environmental outcomes for the City's waterbodies as well as the Swan Canning River system.
- As recommended in the Stormwater Management Manual for Western Australia (DoE, 2005), coordinate road sweeping with maintenance activities (i.e., road or construction works) and specific events (i.e., storm events or public major events). Best results can be achieved by focusing on 'hot spots' rather than routinely sweeping all streets.

Ongoing actions – research, monitoring and on-ground

- As proposed in the WQIP for the Bull Creek Catchment, review historical and current land use data, in particular contaminated and old tip sites, to identify potential sources of contaminants, prioritise areas requiring further investigation and identify management options.
- Continue monitoring the water and sediment quality at all sites in the catchment to generate more interpretable data about the condition of the catchment; determine

patterns and changes that may occur over time and to detect anomalies in the concentrations of parameters that may occur in response to events. Identifying causes will assist future management planning. Update GPS location data.
- Continue to regularly remove accumulated pollutants (e.g., sediment and gross pollutants) from nodes in the stormwater network, such as pits and infiltration sumps.
- Incorporate water sensitive urban design techniques into management practices when upgrading the catchment (e.g., permeable paving, bio-retention swales, pipe-less streets, and rain gardens).
- Continue to ensure the use of herbicides and insecticides on roadsides is undertaken as per manufacturer's recommendations and ensure maintenance staff use appropriate handling and application procedures for these materials.
- Continue to regularly conduct soil testing and leaf tissue analysis on turf areas before applying fertilisers.
- Continue to use native vegetation along roadsides, paths and in swales.
- Continue to revegetate natural areas and remove weeds to increase biodiversity.
- The following issues should be considered when formulating Acid Sulfate Soil (ASS) environmental management strategies:
    - The sensitivity and environmental values of the receiving environment. This includes the conservation, protected or other relevant status of the receiving environment (e.g., wetlands, Marine Parks, etc.).
    - Whether groundwater and/or surface water are likely to be directly or indirectly affected.
    - The heterogeneity, geochemical and textural properties of soils on site.
    - The management and planning strategies of local government and/or state government.
- The following examples of structural best management practices to be incorporated into management plans where appropriate:
    - onsite detention,
    - stormwater infiltration systems,
    - buffer strips,
    - pollutant traps,
    - grass or reed swale drains,
    - broken or flush kerbing,
    - pervious paving materials,
    - nutrient intervention installation,
    - native landscaping; and
    - ponds and wetlands including implementation of living streams with the involvement of the community to provide multiple positive effects by increasing public awareness and further improving water quality.
    - it is recommended that wherever possible open water inlets and if possible, outlets should flow over loosely arranged rocky substrate to provide some oxygenation during medium to high flow events. Low oxygen saturations within the wetlands, lakes and waterways of this catchment are common. This is a consistent finding with heavily piped catchments and/or wetlands with excessively high organic loads (either from animal waste or vegetation decomposition). Additionally, this implementation of rocky substrate may

increase surface area for bacteria to inhabit and assist with the nitrogen cycle and break down of other nutrients (Aczel, 2019). This, along with open water areas that allow wind driven oxygen transfer and appropriate wetland designs which allow for seasonal wetting/drying processes to assist microbial activity (breaking down organic matter) may provide a collective improvement in oxygenation over time.

Knowledge sharing

- It is understood that City of Melville parks and gardens staff have undertaken SERCUL's Fertilise Wise training in the past.
  See https://www.sercul.org.au/fertilisewise/
- It is recommended that all parks and gardens staff who have not previously attended this training (or a similar course) should do so. The best management practices taught as part of this training should be implemented when managing parks, including optimal timing of fertiliser application and calculation of optimal rates of fertiliser application.
- Continue to encourage schools in the City of Melville to participate in SERCUL's Phosphorus Awareness Project, which involves education of both primary and high school students about how actions undertaken in the home and garden can impact the environment (https://www.sercul.org.au/for-educators/incursions-and-excursions/).
- Continue to educate residents about appropriate plant species, fertiliser, and water use (Piney Lakes programs, brochures, mail outs and work with community groups).
- Industry - it is recommended that audits of industrial premises, consistent with the Light Industry Program (LIP), are continued to be conducted by trained City of Melville officers with the aim of reducing contaminants being released into groundwater and stormwater drainage.

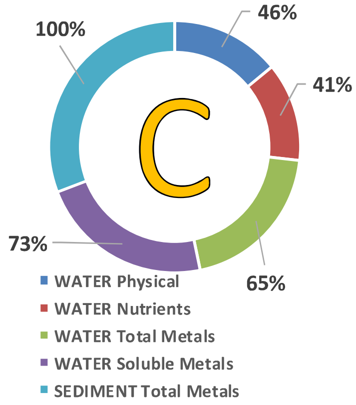
Compliance cards and site-specific recommendations

The water quality monitoring program implemented by SERCUL has proven to contribute extensively to ongoing data collection and validation to the Western Australian water quality database (Water Information Reporting - WIR database) the provided data is utilised in the management of the State's water resources. WIR database provides evidence to support the City of Melville's investment in water quality programs to promote water quality improvement within the local government's catchment is worthwhile. Therefore, SERCUL's recommendation is to continue monitoring the water and sediment quality at all sites within the catchment in order to collect and generate more interpretable data that contributes to determining the health and overall condition of the catchment. Having the ability to determine long term patterns and major changes that may occur over time and to detect anomalies and abnormalities in the concentrations of analytes and measured parameters that may occur in response to anthropogenic influences and environmental events.

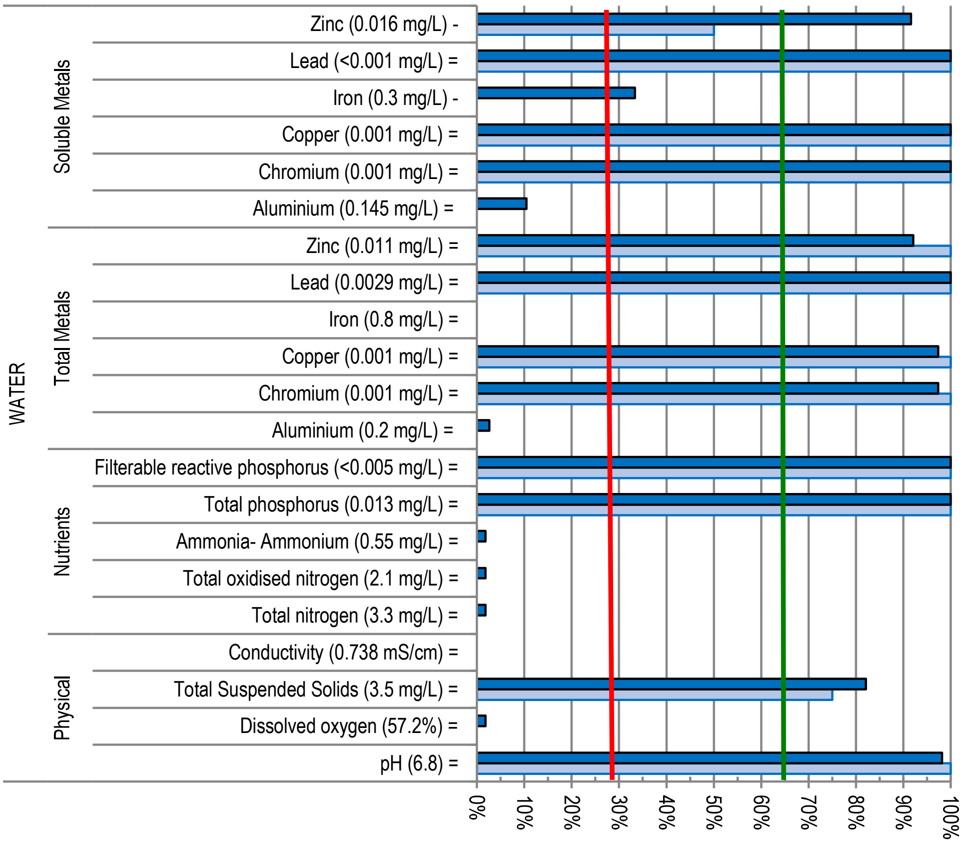
The continuation of the implementation of the Bull Creek Water Quality Improvement Plan (WQIP) is imperative to disseminate and consider the City Stormwater Management Guidelines (SERCUL 2019) when making decisions that may impact stormwater quality. The City Stormwater Management Guidelines (SERCUL 2019) reference appropriate criteria, regulations as well as prescribe ideal structural and non-structural practices for managing stormwater to ensure the best environmental outcomes for the City's waterbodies as well as the Swan Canning River system.

Note: site specific recommendations are not made following Compliance Cards for the following sites: Elizabeth Manion Park (MELDR16) and Quenda Lake (MELDR09). This occurred because the recommendations for these sites was to maintain existing activities.

Bull Creek Main Drain – MELDR-01 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-01 previously PSDTBCMD)	6162178	Bull Creek Park Main Drain	Culvert under Leach Hwy	392965.3	6453785.6



1025 samples, 66 new

- 2007-2020 Compliance (% of samples)
- Compliance 2021 (% of samples)

Water Quality Score		
Excellent	>80%	A
Good	66-80	B
Fair	50-66	C
Fail	<50	F

Fair

Notes:

= symbol indicates WQ did not change in 2021

+ symbol indicates WQ improved during 2021

- symbol indicates WQ degraded during 2021

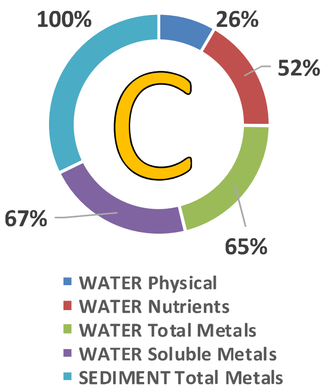
Bull Creek Main Drain (MELDR-01) recommendations

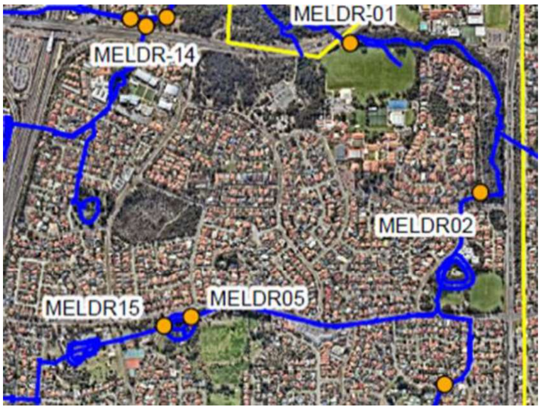
1. Continue to implement the current Bull Creek Reserves Strategic Management Plan: 2014-2019 (City of Melville 2014) until an up-to-date version is released, to ensure that the restoration of the foreshore is congruent with the long-term stability of the natural waterway's ecological and drainage functions.
2. Continue and extend the current floodplain restoration works throughout the Bull Creek reserve.
3. A macroinvertebrate assessment in the restored portion of Bull Creek Main Drain (starting at site 2 through to site 1) is recommended to assess ecological health of the waterway. Annual assessments would allow the effect of changes to the Creek (i.e., water quality changes and habitat development as plants become established) on macroinvertebrates to be assessed.
4. It is understood that riffles are to be installed along Bull Creek to improve dissolved oxygen levels and enhance nitrification (conversion of ammonia to nitrate) in the future. Hydrological studies would need to be conducted to inform riffle construction. Potential locations within the Creek at which these riffles could be installed (as shown in Figure 13-1) include:
    a. at the beginning of the Bull Creek Reserve at Brockman Park: This location is considered ideal as it easily accessible to plant and is visible to the public,
    b. at the point in the creek in line with the end of the cul-de-sac Forster Court; and
    c. near the amphitheatre of Rossmoyne Senior High School.
5. Riffles should be alternated with deeper pools with anoxic zones to allow denitrification (conversion of nitrate to nitrogen gas).
6. Invasive vegetation, in particular shrubs such as blackberry and various trees are prominent. Removal of these is a longer terms activity that needs to be gradual to prevent erosion.

Figure 216. Approximate location at which riffles could be installed in Bull Creek.

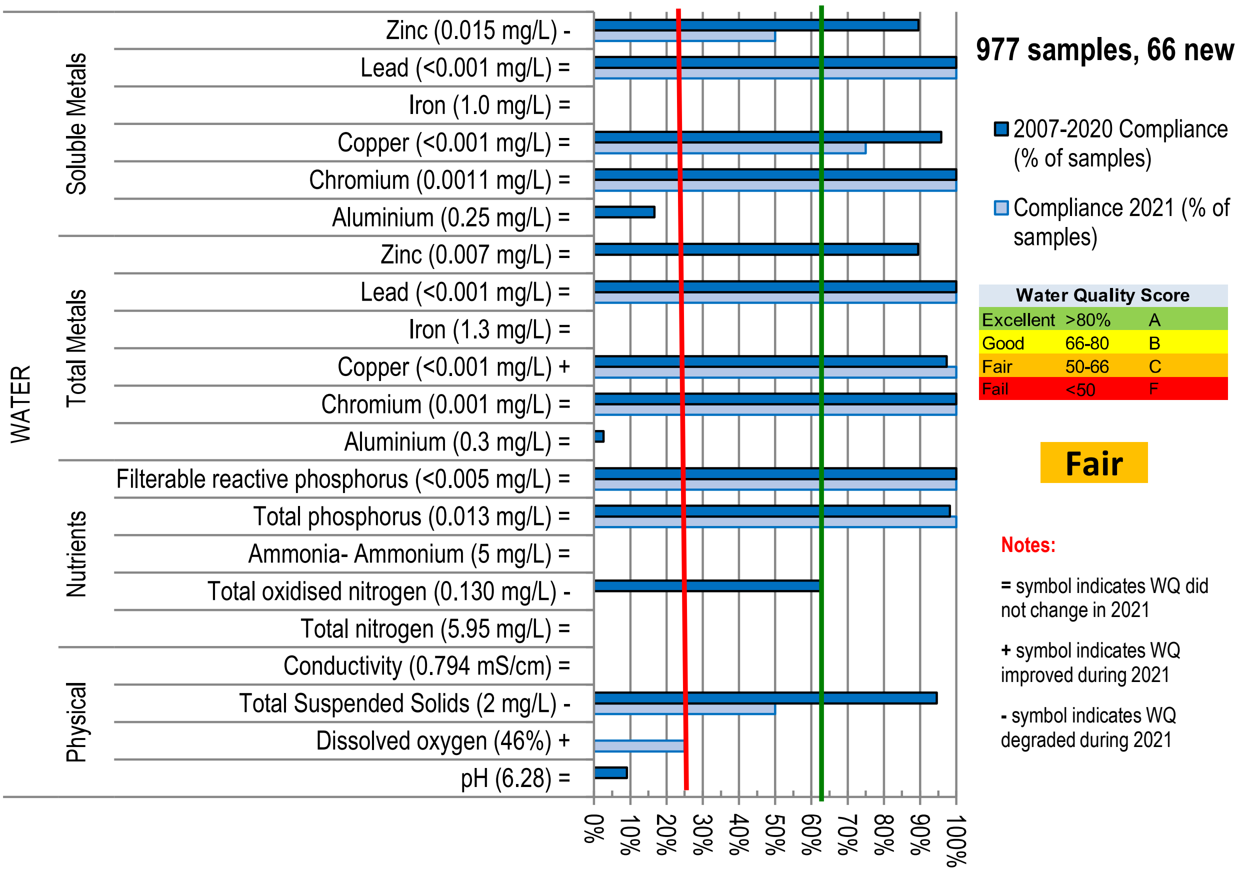
Figure 217. Location of MELDR-01 (PSDTBCMD). Culvert entry under Leach Highway. 14/07/22 Dolva

Brockman Park – MELDR-02 (2007 – 2021)





Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-02	6162370	Brockman Park	Where piped drain opens	393466.5	6453208.5

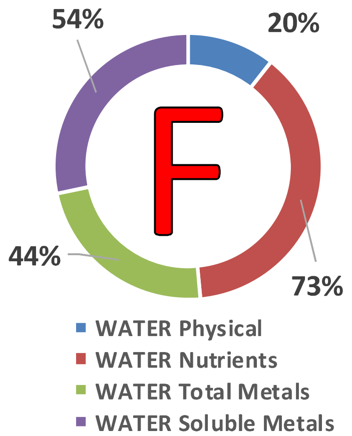


Brockman Park (MELDR-02) recommendations

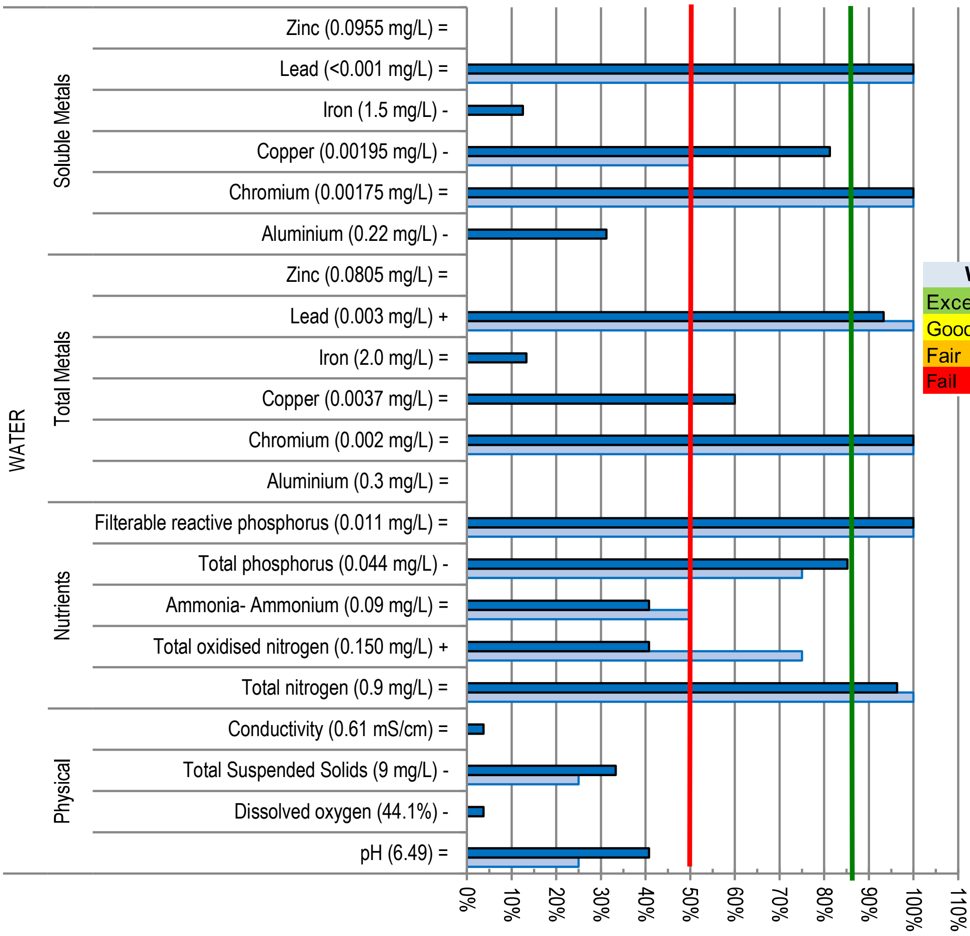
1. Continue to implement the current Bull Creek Reserves Strategic Management Plan: 2014-2019 (City of Melville 2014) until an up-to-date version is released, to ensure that the restoration of the foreshore is congruent with the long-term stability of the natural waterway's ecological and drainage functions.
2. Continue and extend the current floodplain restoration works throughout the Bull Creek reserve.
3. Further investigation to determine the source of the very high nitrogen as ammonia/ammonium concentrations at Brockman Park is recommended, as this ammonia/ammonium appears to be contributing a significant amount of the total nitrogen into Bull Creek. This could include the following:
    a. review of detailed stormwater drainage maps in the area,
    b. review of groundwater flow maps; and
    c. groundwater monitoring upstream of Brockman Park.
4. Primary physical treatment is required prior to the Brockman Park stormwater pipe inlet to prevent gross pollutants, particulate matter and sediment entering Bull Creek Park waterway and its foreshore. The existing inlet structure requires regular maintenance to remove gross pollutants and sediment. Maintenance should be conducted once a year at minimum, preferably in autumn and spring.
5. Continue investigation into the source of sediment deposition at the Brockman Park outlet structure into Bull Creek and develop appropriate management actions such as installation of sediment and gross pollutant trapping structure at nearby compensation basin.
6. Continue planting in Trevor Gribble basin to stabilise bare sand areas (see Figure 218 A) and thus prevent sediment runoff into the basin outlet and drain during storm events.

Figures 218. A) Sandy area in Trevor Gribble Park compensation basin where planting is recommended; B) grate in Trevor Gribble Park compensation basin with leaf litter and sediment sitting on top.

John Creaney Park Inlet – MELDR-15 (2014 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-15	6165331	John Creaney Park inlet	Approx. 5 m upstream of the main inlet into John Creaney Park, access via Water Corp drain utility access hole (lid lifting and bucket and rope required)	392256.48	6452699.35



429 samples, 66 new

- 2014-2020 Compliance (% of samples)
- Compliance 2021 (% of samples)

Water Quality Score		
Excellent	>80%	A
Good	66-80	B
Fair	50-66	C
Fail	<50	F

Fail

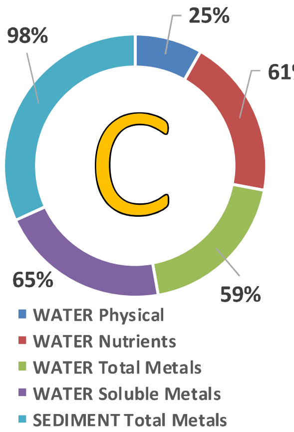
Notes:

= symbol indicates WQ did not change in 2021

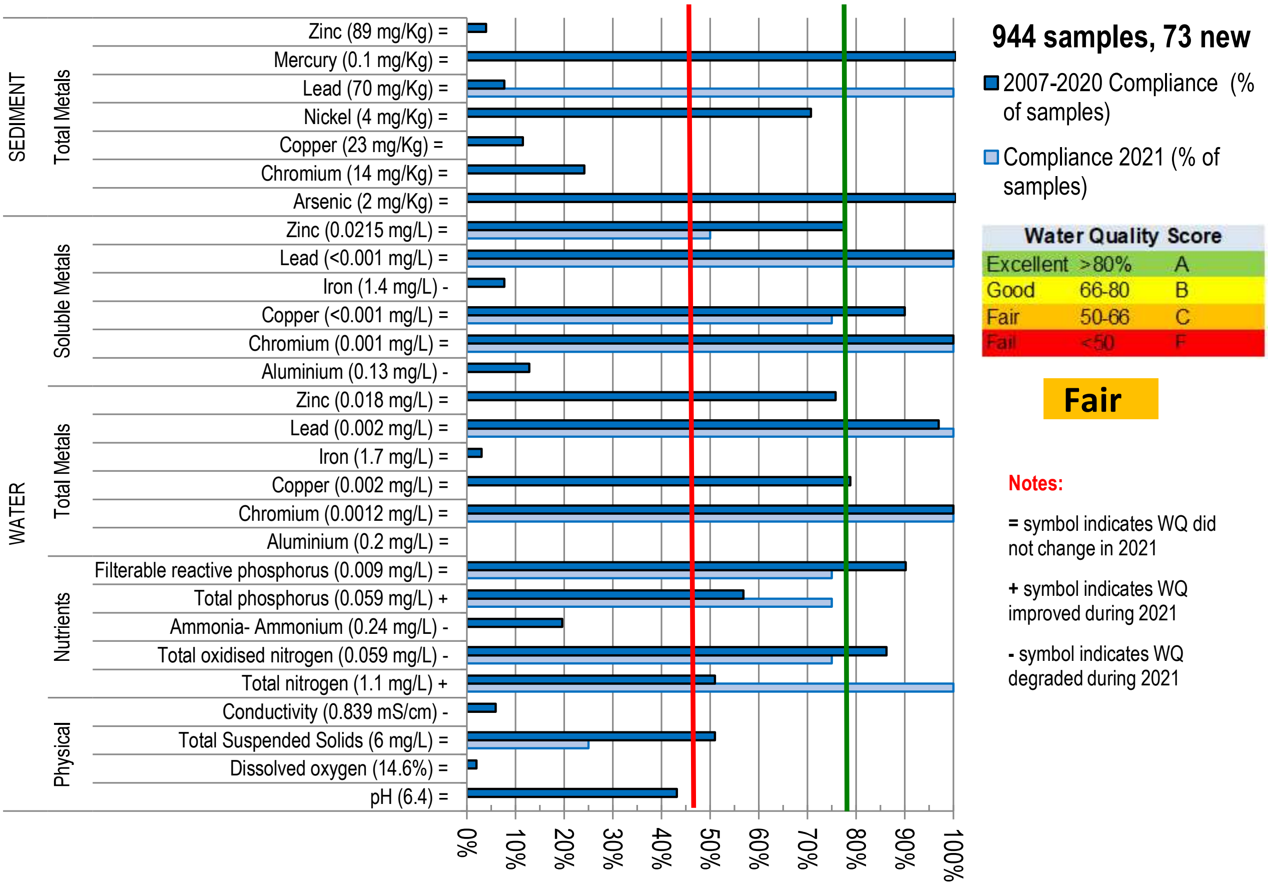
+ symbol indicates WQ improved during 2021

- symbol indicates WQ degraded during 2021

John Creaney Park Outlet – MELDR-05 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-05	6162373	John Creaney Park outlet	Compensation Basin Outlet	392359	6452734.7



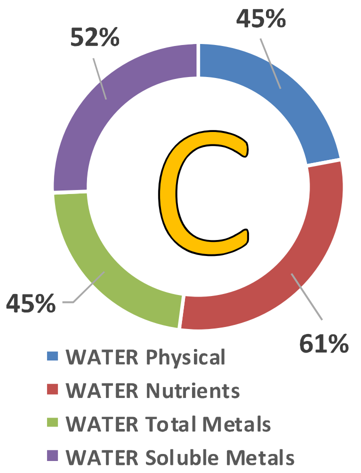
John Creaney Park inlet (MELDR-15) and outlet (MELDR-05) recommendations

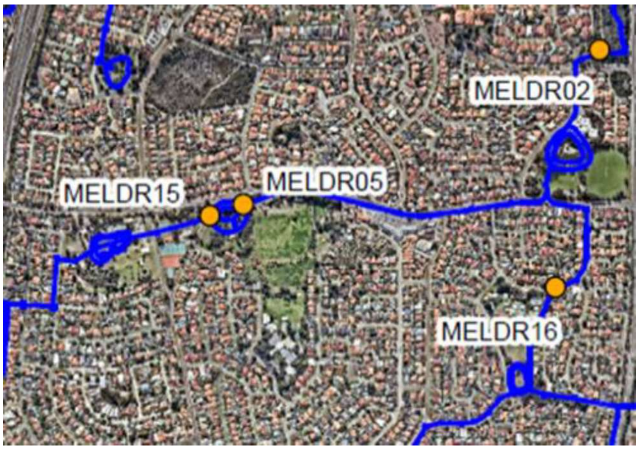
1. Redesign and/or restoration of the lake at John Creaney Park is recommended to improve its water quality, as well as that of the downstream receiving environment (Bull Creek Main Drain and the Canning River). This restoration could include:
    a. planting fringing in lakebed vegetation to take-up nutrients and metals;
    b. installation of a circulator or aerator to improve oxygenation;
    c. dredging and disposing of excess silty, organic sediment at this site; and
    d. creating a larger buffer between lawn and wetland area to reduce organic load entering the basin.
2. Conduct groundwater sampling at John Creaney Park to determine whether contaminated groundwater from the previous landfill at the site is the source of the often-high nutrients and poor sediment quality at the site. According to Australian Groundwater Map there are 16 existing groundwater wells within 500m of John Creaney Park, however access is unknown as they are registered with DWER for either water supply and irrigation or unknown uses. It is recommended new groundwater wells are installed for regular monitoring at around 8m deep in the direction of groundwater flow to the north as Perth Groundwater Map assumes depth to groundwater is between 5-6m.
3. Drain stencilling may be beneficial at sites along the drainage line such as Stockland's Shopping Centre and West Leeming Primary School to prevent discharge of contaminants into this drainage.

Figure 219. John Creaney Park Outlet (MELDR-05). The outlet is more open and surrounded by grassy areas. This location is likely to be influenced by fertilisers and urban wastes to a larger extent than more vegetated areas. Additional recommendations – revegetation and redesign drain to restore natural meanders. Dolva 140722

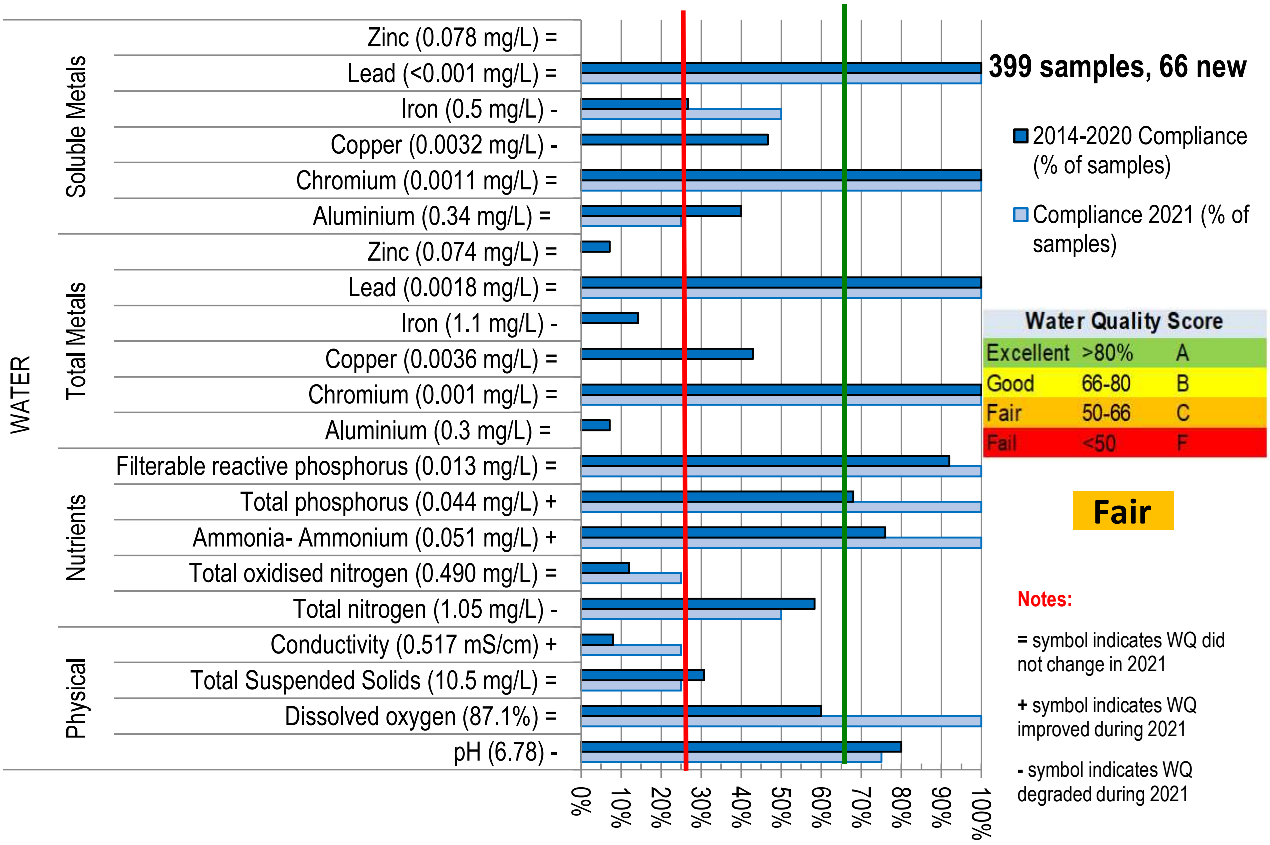
Figure 220. John Creaney Park Inlet (MELDR-15). The inlet is surrounded by native vegetation and deep litter layers. These features assist maintaining ecosystem integrity but contributes to organic litter entering the lake.

Downstream Elizabeth Manion Park – MELDR-16 (2014 – 2021)

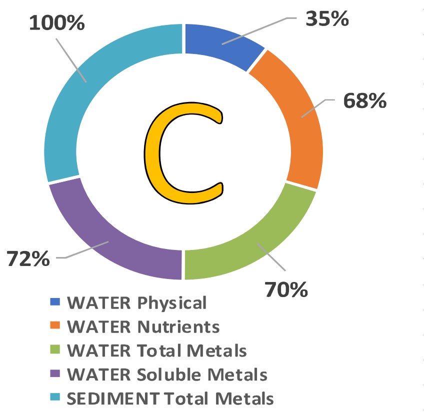


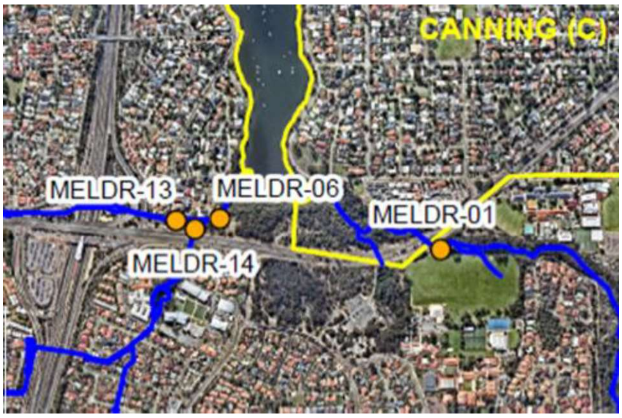


Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-16	6165332	Closed pipe Downstream Elizabeth Manion Park	On Nicholls Cres close to Hurley Way, in front of pathway, access via Water Corp utility access hole (lid lifting and bucket and rope required)	393327.76	6452478.47

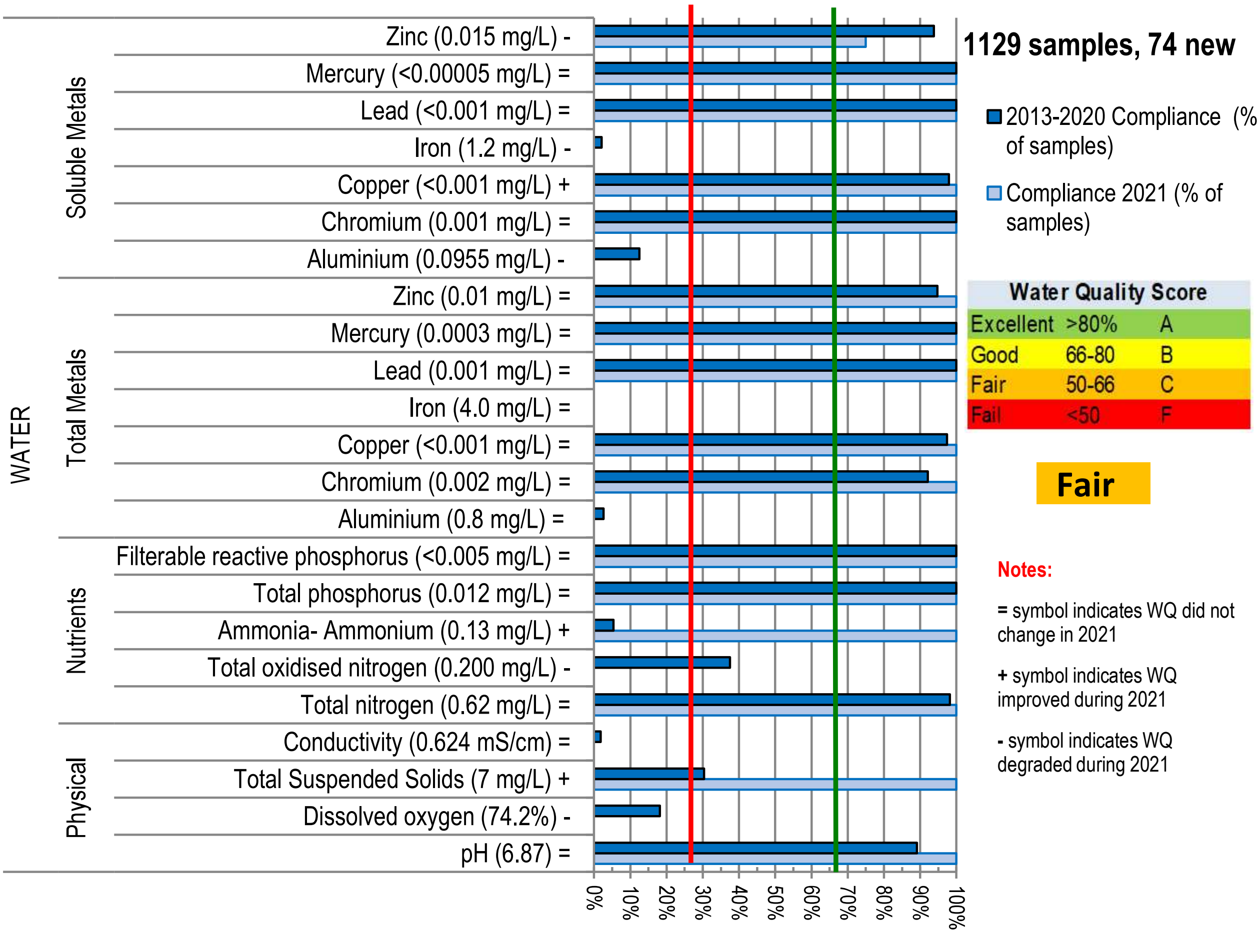


Bateman Park – MELDR-06 (2007 – 2021)

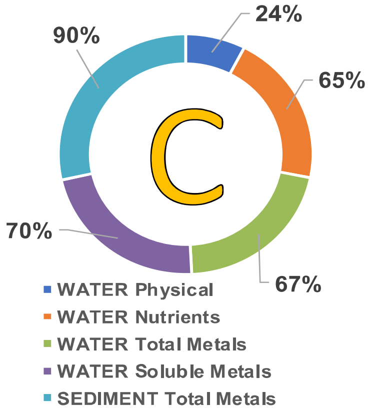




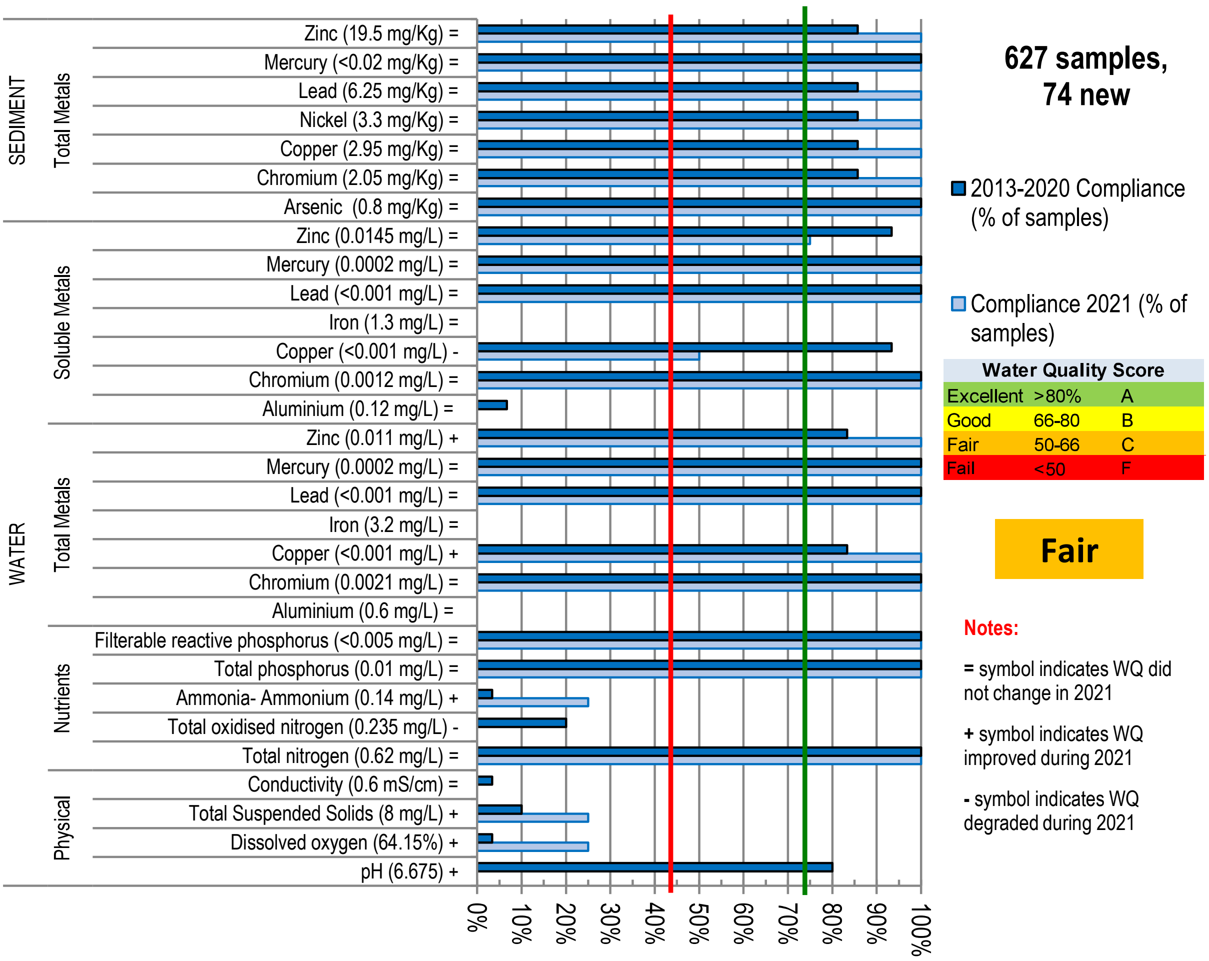
Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-06	6161691	Bateman Park	Downstream of the confluence of the two drains	392269.8	6453880.2



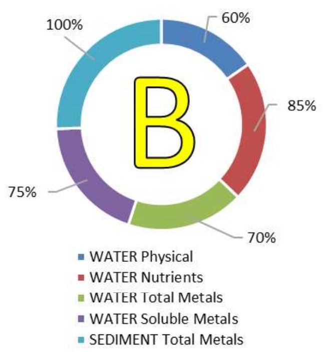
Brentwood Drain – MELDR-13 (2013 – 2021)



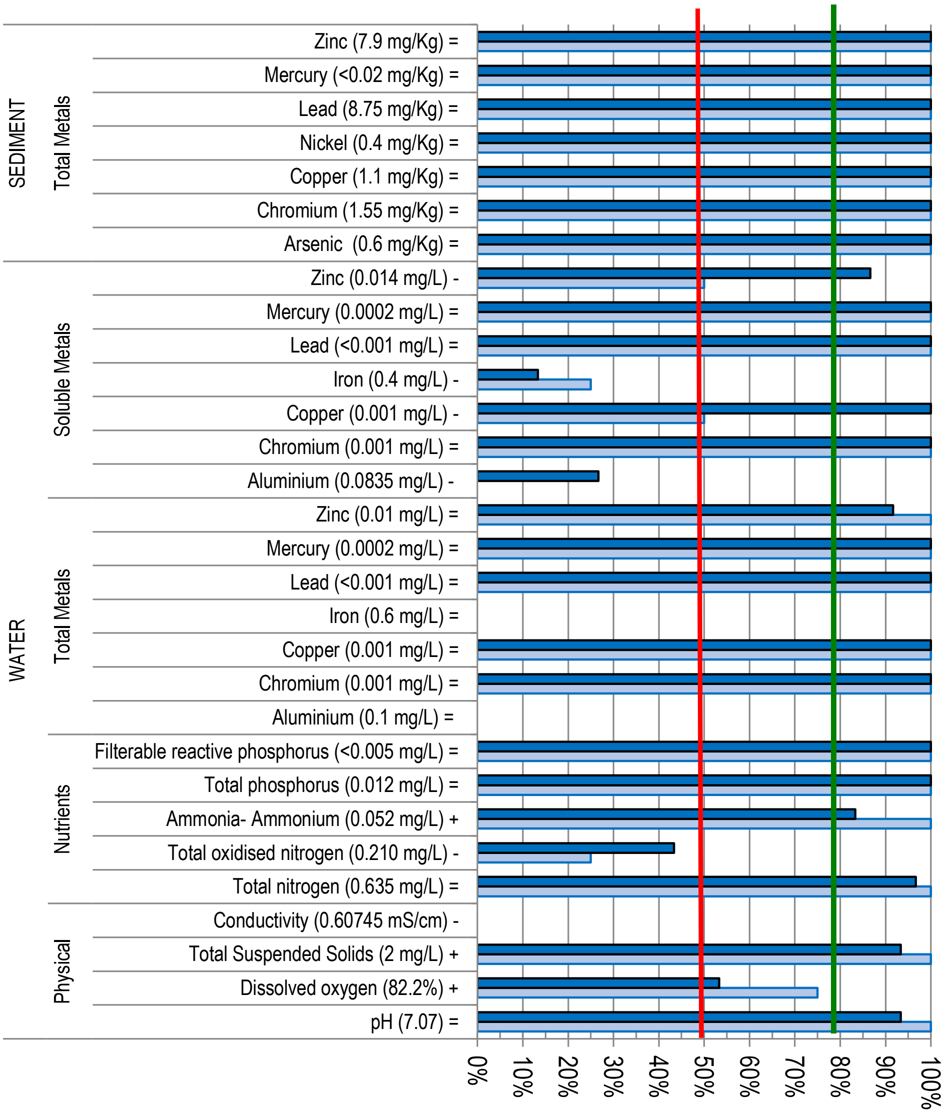
Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-13	6165324	Brentwood drain	Pulo Rd & Leach Highway, 10 m walking from Pulo Rd. Site moved at beginning of 2015-16 sampling due to construction works reshaping the drain.	392126.59	6453865.28



RAAF Drain – MELDR-14 (2013 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-14	6165325	RAAF drain	10 m down from pipe under Leach Highway	392195	6453841



627 samples, 74 new

- 2013-2020 Compliance (% of samples)
- Compliance 2021 (% of samples)

Water Quality Score		
Excellent	>80%	A
Good	66-80	B
Fair	50-66	C
Fail	<50	F

Good

Notes:

= symbol indicates WQ did not change in 2021

+ symbol indicates WQ improved during 2021

- symbol indicates WQ degraded during 2021

Bateman Park (MELDR-06), Brentwood Drain (MELDR- 13) and RAAF Drain (MELDR-14) recommendations

1. Continue to facilitate the maintenance of the Brentwood Living Stream restoration site: the rock riffles installed as part of the Brentwood Living stream project trap sediment that require routine removal by the Water Corporation.
2. Following construction of the Brentwood drain, it is especially important to continue monitoring this site for changes to the water quality to assess the impact/effectiveness of the restoration works. It may take several years before the Living Stream's capacity to improve water quality reaches full effectiveness. Furthermore, Water Corporation and Main Roads are in the planning stages for the reconstruction of the upstream Cloverleaf compensating basin (located at the off ramp of Leach Highway to Kwinana Freeway, Southward bound) to mitigate the poor water quality issues from the freeway runoff and subsequently reduce negative impacts in the Brentwood drain downstream. Water quality monitoring results at site 13 will allow for the assessment of the impact of these works on the overall outcome of the Brentwood Living Stream project.
3. It may of benefit to consider providing education materials to the grounds staff at the RAAF nursing home facility to ensure optimal management of the lake and so they continue to keep the nutrient contamination low there to reduce nitrogen entering this drainage line. This could include any of the strategies suggested on how to raise community awareness of the link between stormwater drains and natural waterways suggested in section 10 of *the City of Melville Stormwater Quality Management Guidelines* (SERCUL, 2019).

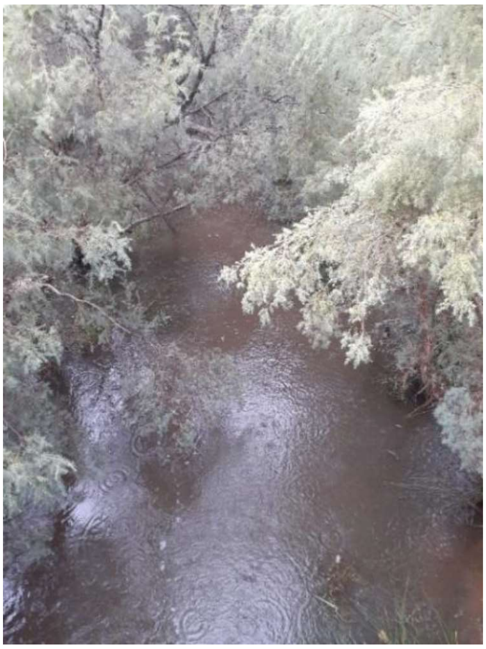


Figure 221. Bateman Park MELDR-06). Looking from bridge towards the confluence of the two drains. Well vegetated. Maintain monitoring and information for local community. 14/07/22 Dolva

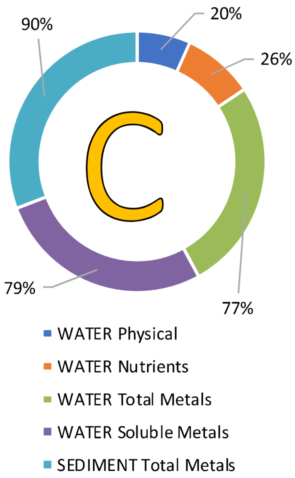
Figure 222. Brentwood Drain (MELDR13) near Pulo Road. 14/07/22 Dolva

Figure 223. Beside drain near Pulo Road. The limestone may contribute to higher pH and ameliorate acid waters from ASS. 14/07/22 Dolva

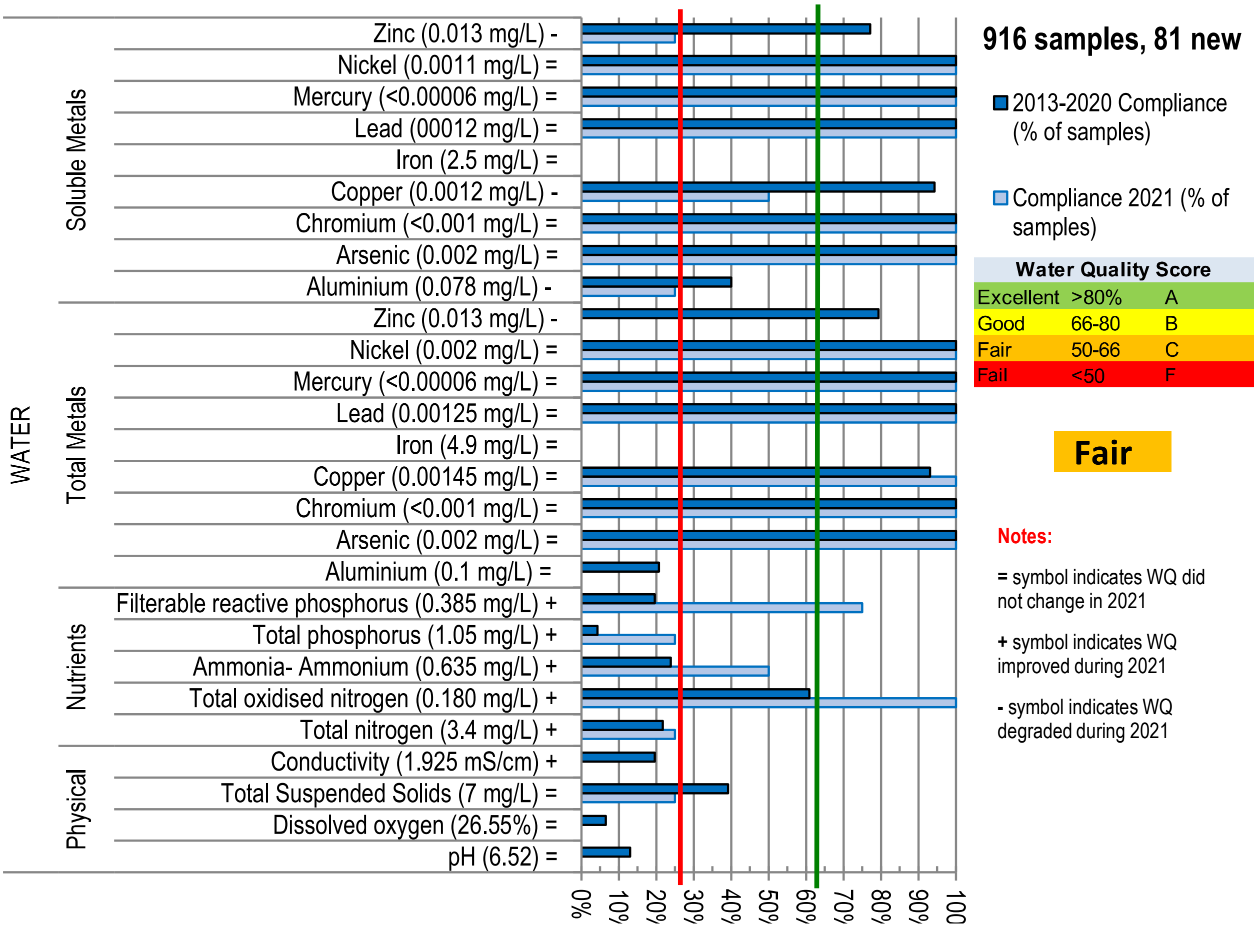
Figure 224. Showing the rifles looking towards the drain from the walkway. 14/07/22 Dolva

Figure 225. The entry of the RAAF drain into the creek is in the centre of this image. Surrounded by vegetation that filters contaminants. 14/07/22 Dolva. Additional recommendation – monitor contaminant inflow further upstream. Increase involvement with RAAF to extend the project.

Booragoon Lake Outlet – MELDR-07 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-07	6162375	Booragoon Lake	In the lake at the end of the boardwalk jetty	390734.68	6454164.09

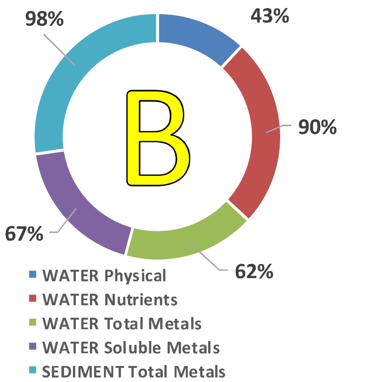


Booragoon Lake Outlet (MELDR-07) recommendations

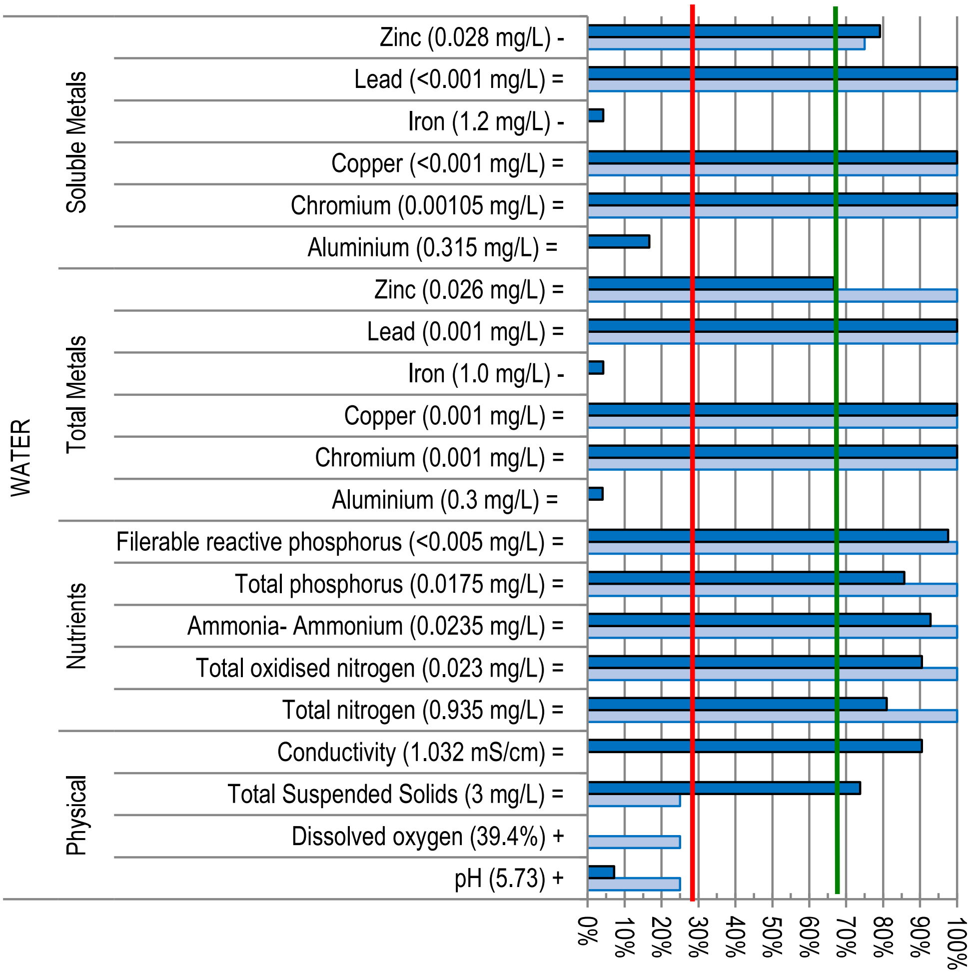
1. Continue to implement the current Booragoon Lake Reserve Strategic Management Plan (Melville 2019b) to ensure that the restoration of the Lake is congruent with the long-term stability of the lake's ecological and drainage functions.
2. Continue the replacement of grass surrounding the Lake with native species to prevent further ingress of grass into the Lake and help to filter runoff entering the lake from the surrounding area.
3. Continue the removal and control of other invasive species, which contribute to the large loads of organic material to the lake and prevent the growth of native understorey species, and replacement of these with native species.
4. It is recommended that all drainage outlets to the lake are revegetated in an equivalent manner to the recently redesigned outlets on the western side of the lake in an effort to improve gross pollution management.
5. Ensure that excess sediment and litter is periodically removed from the drainage basin in the north-east corner of the Lake, as necessary. This will decrease sediments (and associated nutrients and metals) entering the Lake body (DoE, 2005) or consider introducing rubbish traps to capture the litter before it enters the Lake.
6. Considering the excessively elevated levels of total and soluble phosphorus it is recommended to investigate possible treatment methods for the control/removal of phosphorus in a wetland environment such as an application program for Phoslock.
7. Continue monitoring pH levels in the Lake. After a year of recording pH values within the ANZECC acceptable range for wetlands (ranging from 7 – 7.11 between July and October 2019), pH values at this site have recorded values below the ANZECC acceptable range for wetlands in 2021 on three occasions (5.73 in July 6 in August and 5.36 in September) which has been typical for this site since sampling began in 2007. The increasing Lake pH may reduce mobilisation of metals from sediment, resulting in lower water concentrations of some metals. However, if pH lowers again in the future, it may be possible to neutralise acidity in the Lake originating from oxidation of acid sulphate soils with materials such as aglime, sodium bicarbonate, hydrated lime or quicklime as described by Department of Environment Regulation (2015).
8. Continue analysis of water samples for arsenic, mercury, and nickel, as exceedances of trigger values for these metals have been recorded in sediment collected from this site in previous years.
9. Consider speciation testing for zinc and copper to determine the labile (and therefore bioavailable) proportion of these metal concentrations, as a proportion of the metals present may be complexed with dissolved organic material and therefore may not be toxic.
10. Macroinvertebrate sampling is recommended to provide an indication of trophic status and species richness in this lake of high conservation value.

Figure 226. Collage showing the view across Booragoon Lake at the end of the walkway. Views of the edge towards the NE (top) and SW (bottom) are included to the right. 14/07/22 Dolva

Piney Lakes Outlet – MELDR-08 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-08	6162376	Piney Lakes	At the lake outlet	390151.59	6453473.10



717 samples, 66 new

- 2013-2020 Compliance (% of samples)
- Compliance 2021 (% of samples)

Water Quality Score		
Excellent	>80%	A
Good	66-80	B
Fair	50-66	C
Fail	<50	F

Good

Notes:

= symbol indicates WQ did not change in 2021

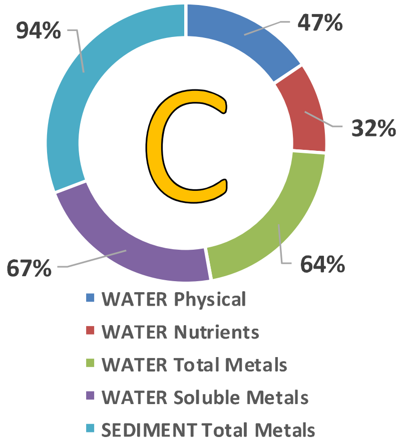
+ symbol indicates WQ improved during 2021

- symbol indicates WQ degraded during 2021

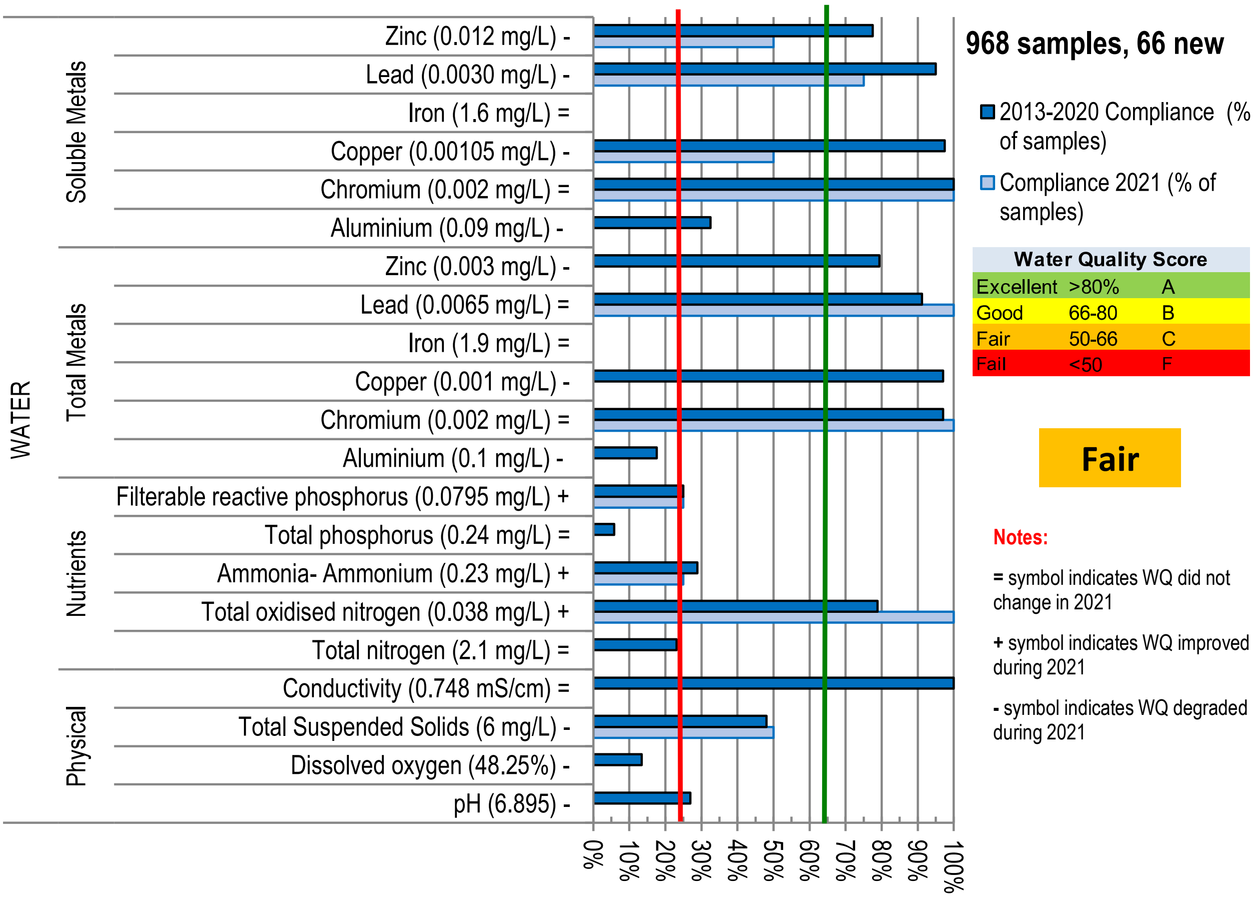
Piney Lakes Outlet (MELDR-08) recommendations

1. Investigation into ecological water requirements (EWRs) for this groundwater dependant wetland (which is also a Bush Forever Site 399) is required to determine the possible risk-of-impact of drawdown on the key elements of wetland ecosystem integrity (ecosystem processes, biodiversity, abundance and biomass of biota and quality of water and sediment) and allow for appropriate mitigation strategies to be devised.
2. Reducing the amount of grass and implementing hydrozoning of vegetation in parklands surrounding Piney Lakes will help to reduce groundwater abstraction and may help to increase maintain sufficient water levels at the Lakes.
3. As pH values have generally been below the lower acceptable limit for wetlands, consider conducting an acid sulphate soil investigation at the Lakes to determine whether this is the cause of low pH levels, and assess possible mitigation strategies. Particularly due to the site recording a pH value of 4.94 in July 2020 and a value of 5.19 in July 2021 – values this low have not been recorded at this site since 2012, and that the site is considered to have a high potential for acid sulfate soils (Landgate, 2016).

Blue Gum Lake Outlet – MELDR-12 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-12	6162379	Blue Gum Lake	In front of car park inlet	391282.81	6454886.75



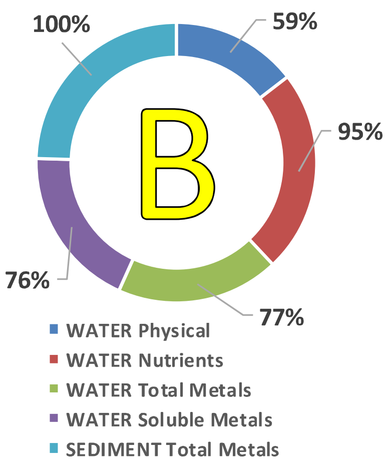
Blue Gum Lake Outlet (MELDR-12) recommendations

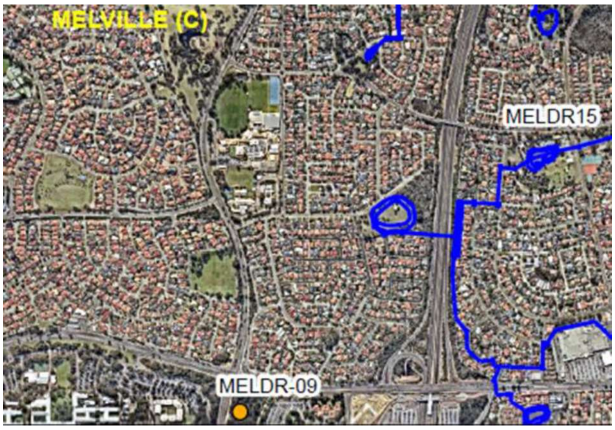
1. Continue to implement the Blue Gum Lake Reserve Strategic Management Plan (City of Melville 2019a) to ensure the stormwater objectives are met.
2. Continue restoration works on the foreshore of the lake with native species particularly with native sedges and wetland plants.
3. Continue the removal and control of other invasive species, which contribute to the large loads of organic material to the lake and prevent the growth of native understorey species, and replacement of these with native species.
4. Several outlets to the Lake have been redesigned in recent years to incorporate nutrient stripping plant species and rocky bases. Consider undertaking similar works in the remaining outlets to the Lake as outlined in the Blue Gum Lake Reserve Strategic Management Plan.
5. Reticulation and fertiliser application practices of upstream Karoonda Park should be reviewed to ensure that a minimum of nutrient enriched runoff is entering the lake from this park.
6. Considering the excessively elevated levels of total and soluble phosphorus it is recommended to investigate possible treatment methods for the control/removal of phosphorus in a wetland environment such as an application program for Phoslock.
7. Where this has not already been done, create a barrier between the foreshore and lawn verge to prevent encroachment of lawn grasses and weeds to facilitate a definite edge for more efficient park management.
8. Continue to regularly inspect the premises of the Tennis Club as per the Memorandum of Understanding (MOU) between the City and the Blue Gum Park Tennis Club in regard to fertiliser use and the storage of fertiliser within the precinct
9. Given the particularly low pH of waters previously recorded at the site (although less since 2017), consider conducting an acid sulfate soil investigation at the lake to determine the extent of acid sulfate soils and consider options for mitigation.
10. Consider speciation testing for aluminium, zinc, and copper to determine the labile (and therefore bioavailable) proportion of these metal concentrations, as some of the metals present may be complexed with dissolved organic material.
11. Macroinvertebrate sampling is recommended to provide an indication of trophic status and species richness in this lake of high conservation value.

Figure 227. Collage showing images of Blue Gum Lake. The main image shows a view to the North. The top right image shows the outlet closer to the lake and the bottom right the street drain that flows directly into the lake near the outlet.

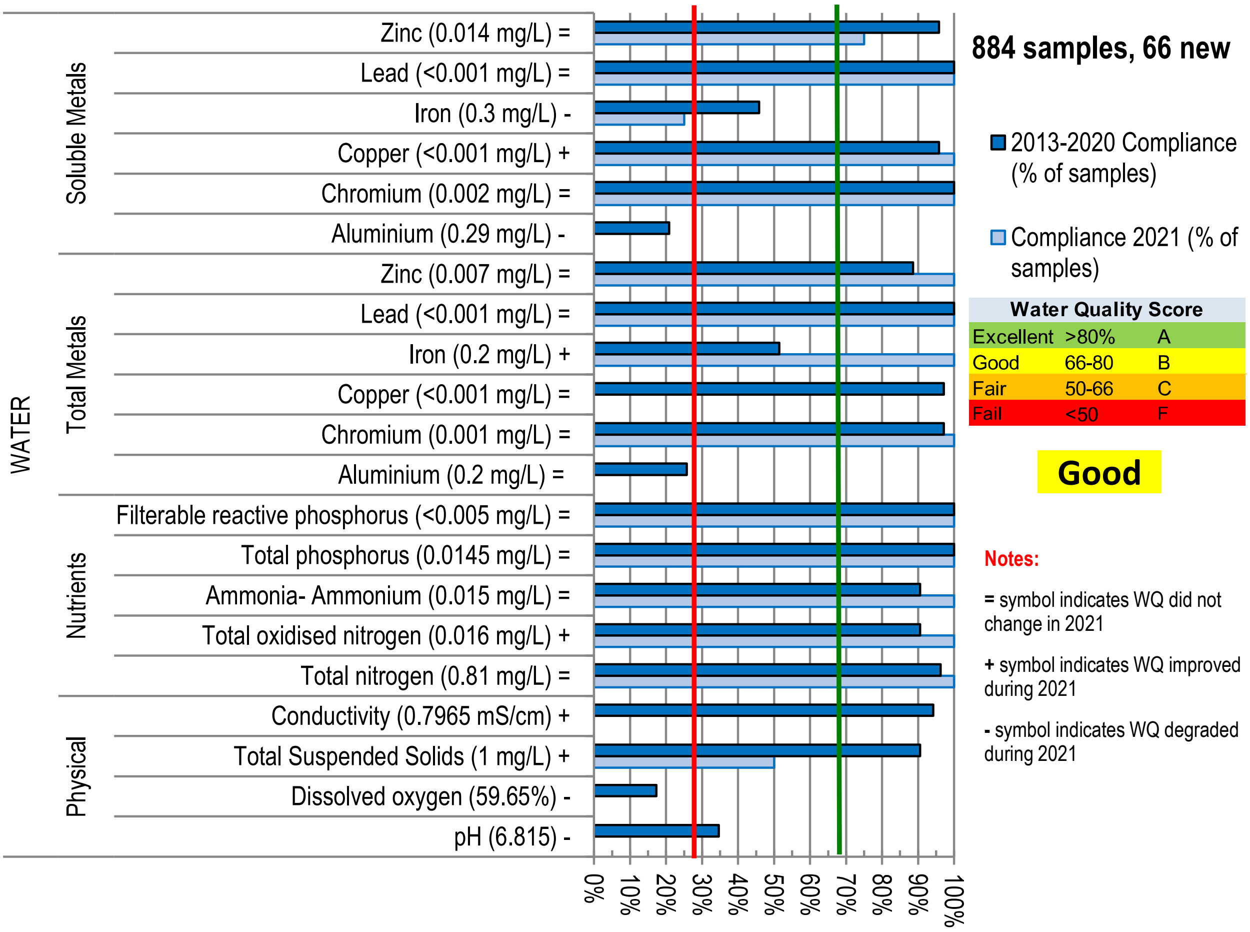
Additional recommendations **–** consider sediment trap at the above drain. This may reduce inflow of pollutants from the roads.

Quenda Lake Outlet – MELDR-09 (2007 – 2021)

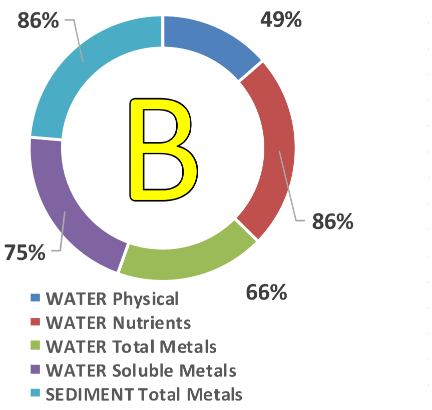




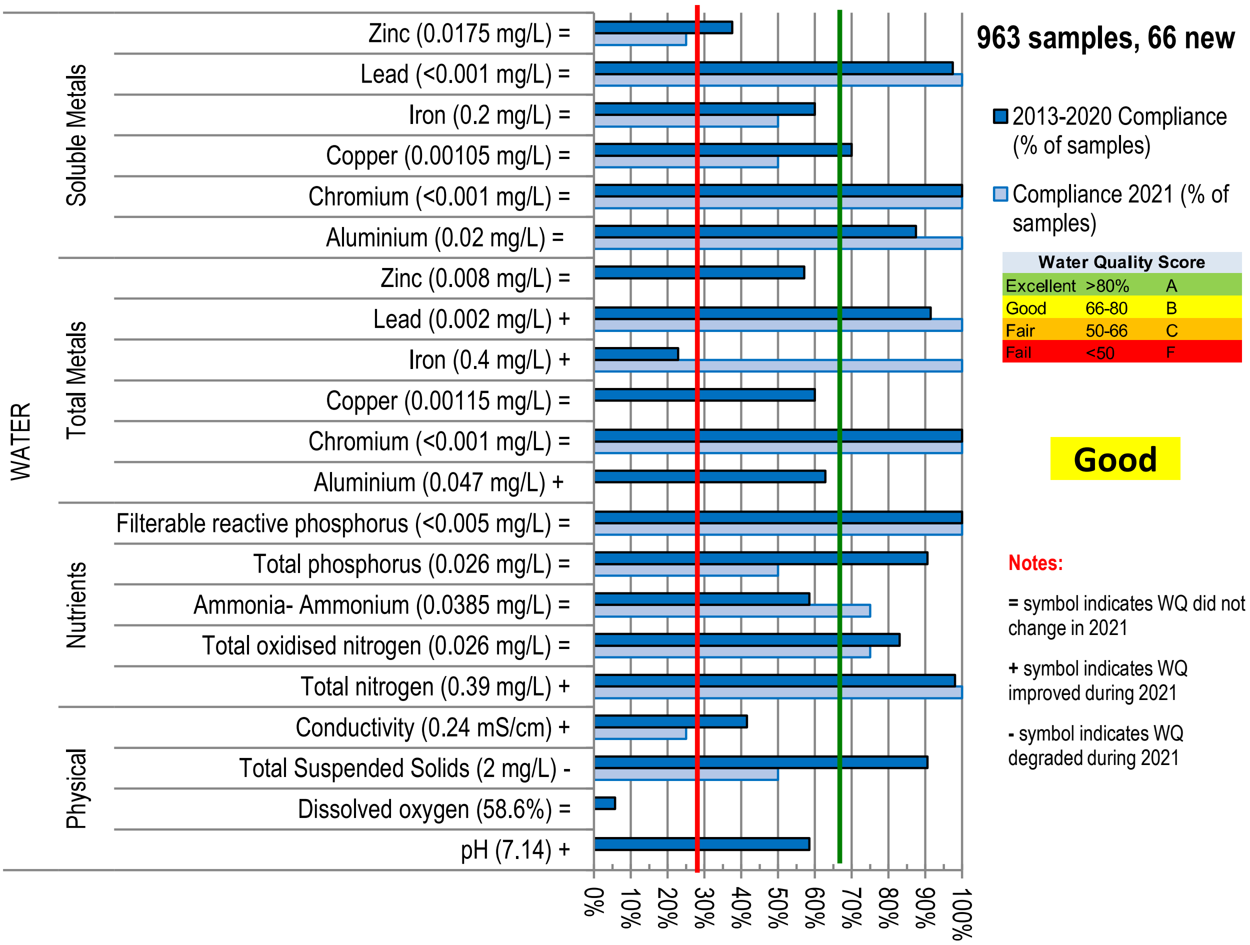
Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-09	6140831	Quenda Lake	At the lake outlet	390749.20	6451597.51



Fredrick Baldwin – MELDR-10 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-10	6162377	Frederick Baldwin	At the lake outlet	387989.87	6452295.91

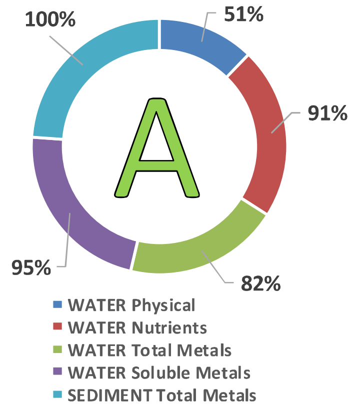


Frederick Baldwin (MELDR-10) recommendations

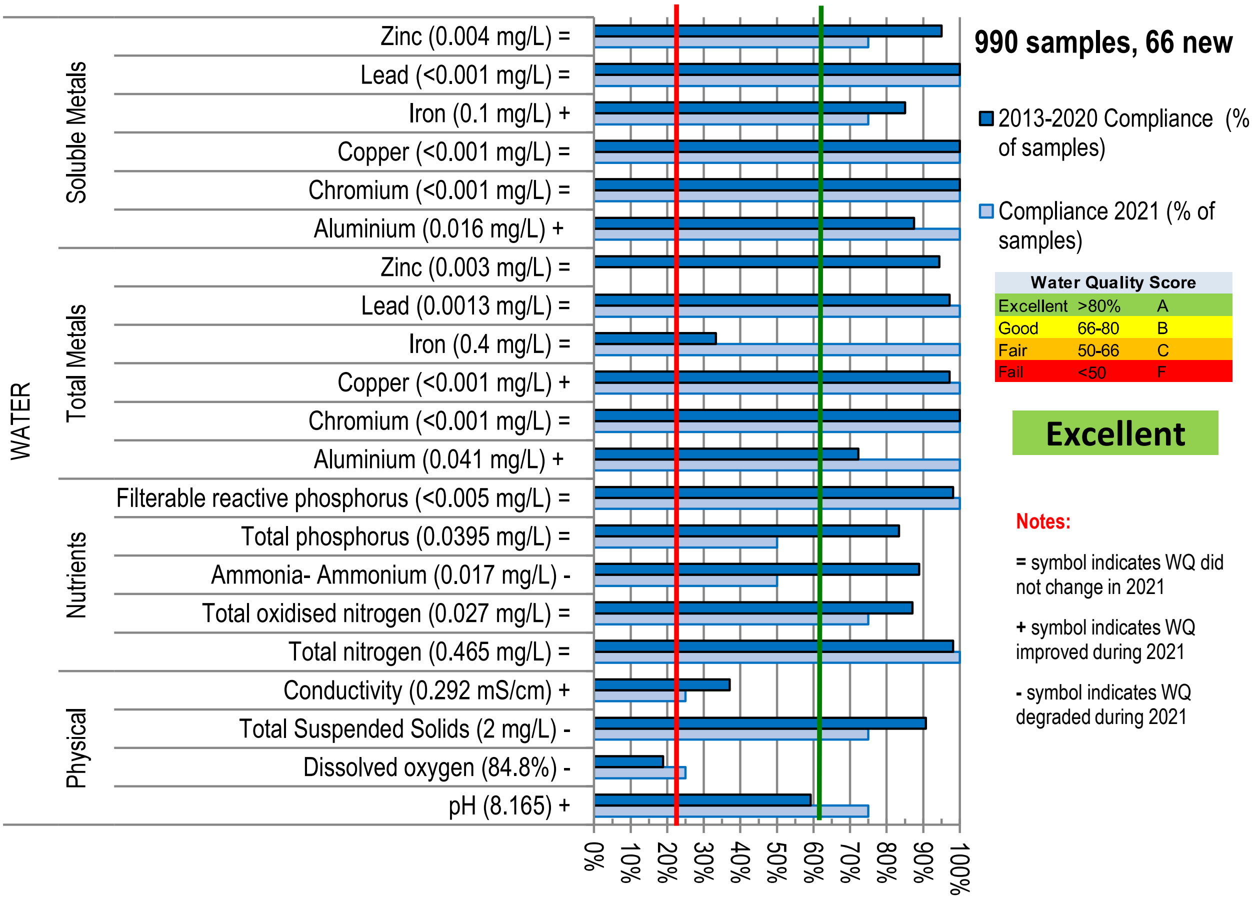
1. Continue consideration of the replacement of *Casuarina cunninghamiana* (Sydney she-oak) with local wetland tree species (*Melaleuca rhaphiophylla, Eucalyptus rudis*) in a staged fashion to reduce the weed seeding of downstream wetlands and waterways and increase nutrient uptake. Removing these trees will remove the needles which prevent the growth of understorey riparian vegetation.
2. Implement a foreshore revegetation program simultaneously with installation of bio-filtration sedge plantings to provide a buffer between the lawn recreational area and the lake foreshore. This will improve the aesthetics as well as improving the filtration of surface water entering the lake.
3. It is understood that signage at the lake had been developed to increase community awareness of where this lake's water comes from and where the lake water flows to encourage the community to consider responsible use of stormwater drainage.
4. Consider the placement of an aeration fountain to improve oxygen levels within the lake.

Figure 228. Collage of Frederick Baldwin Lake. Top – view to inlet. Left – another view to the inlet. Right – view at outlet. Bottom – showing floating monitoring station and outlet. 14/07/22 Dolva

Marmion Reserve – MELDR-11 (2007 – 2021)



Site No.	WIR site ref.	Drain section/ component	Sampling point location	Easting	Northing
MELDR-11	6162378	Marmion Reserve	At the lake outlet	387774.89	6454629.75



Marmion Reserve (MELDR-11) recommendations

1. The playground equipment was scheduled to be renewed in July 2020, use this opportunity to educate the community regarding how to protect the wetlands. If this has not been renewed due to Covid-19, then ensuring community education is still incorporated into the renewal of the playground equipment at this site when it occurs is strongly encouraged.
2. It may be of benefit to consider providing educational materials to the grounds staff at the adjacent retirement villages on the west side of Marmion Reserve to ensure gardening activities do not result in additional pollution to the lake. This could include the City's Protecting Your Wetlands brochure, which is understood to have been recently updated, or SERCUL's Phosphorus Awareness Project brochure (https://www.sercul.org.au/wp-content/uploads/2019/03/PAP2018Web.pdf).
3. Continue to maintain the City foreshore restoration project including planting with native tree species on the island and large areas surrounding the lake. It is understood that the City has removed collapsed and aging willows on the Lake island and from around the lake as well as older shrubs and weedy shrubs from around the lake and plans to replace this with native tree species. As willow trees are deciduous and known to produce large volumes of leaf litter (Latta, 1974), this should provide a positive benefit to lake water quality by reducing the leaf litter previously entering the lake.
4. As low water levels have been observed at this lake in previous years (although not in 2017 and 2018) consider monitoring of water levels throughout the year to allow for appropriate planning to occur.

Figure 229. Collage of images of Marmion Reserve. Top left – riffle inflow from a drain. Top right – view towards outlet. Bottom – submersed inflow pipe. 14/07/22 Dolva

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