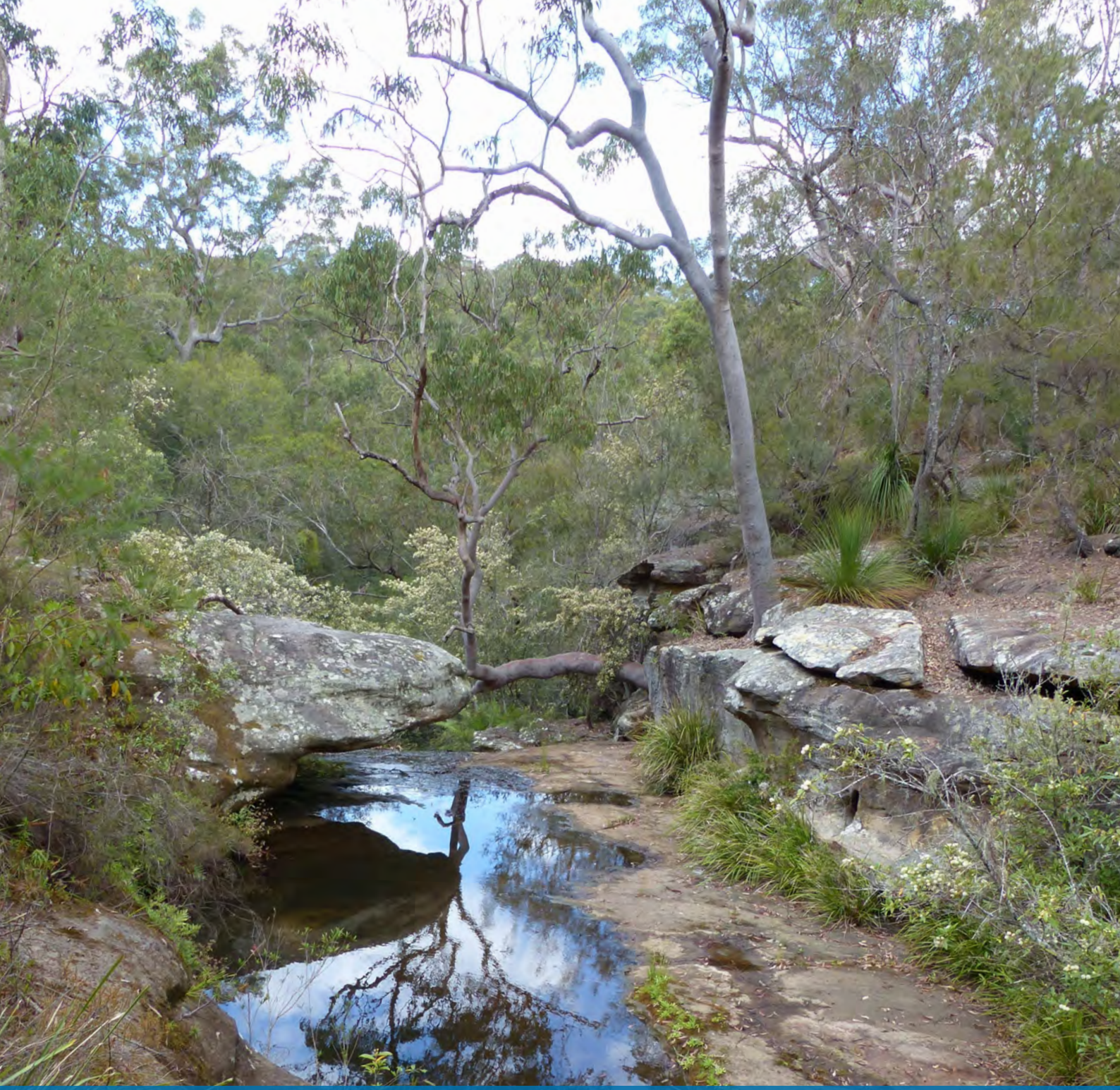

WATERWAY HEALTH REVIEW

(1995-2017)

HORNSBY SHIRE COUNCIL

Natural Resources Branch | Community and Environment Division

HORNSBY
SHIRE COUNCIL

Citation:

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Data used in this report was collected, analysed and reported on by Natural Resources staff at Hornsby Shire Council. The report was prepared by Kristy Guise and David Cummings and reviewed by Ana Rubio, David Bolton and Peter Coad. Laboratory analysis of water samples was carried out by NATA-accredited laboratories.

For further information contact:
Natural Resources Branch
Community and Environment Division
Hornsby Shire Council

EXECUTIVE SUMMARY

Healthy waterways are highly valued by the community of Hornsby Shire, therefore their protection and conservation is paramount. Long-term monitoring programs are fundamental to understanding the health of waterways. Ongoing monitoring will identify changes in the waterways that are caused by natural means or human pressures. Identifying these pressures is essential to natural resource managers to enable the protection of catchment and waterway health.

The Hornsby Local Government Area (LGA) contains a mix of land-uses which include natural bushland areas, urban, industrial and rural development. Activities within each of these land-uses place significant pressure on water quality in addition to major point sources of pollution such as Wastewater Treatment Plants (WWTP).

Hornsby Shire Council has monitored water quality to assess aquatic ecosystem health since 1994. This program is one of the most intensive monitoring programs undertaken by any Local Government in NSW. The information gathered from this program has been used to inform management, compliance and education activities, subsequently relieving pressures on local waterways and protecting community values. All management actions implemented through Council's Catchments Remediation Program aim to improve catchments and waterway health.

This Review describes the (relatively) long-term trends in water quality and how it conforms to guideline values at 35 sampling sites, which have been monitored monthly for up to 22 years (1995 to 2017). Data was compared to Hornsby Shire Council's freshwater and estuarine Regional Environmental Health Values (REHVs) which have been specifically developed to assess water quality in the region.

Overall, the water quality at the majority of long-term freshwater sampling sites has remained relatively stable despite an ever growing population and increasing development pressure. Waterways in urban areas are displaying symptoms of 'urban stream syndrome' consistent with other Australian and international urban areas (Vietz et al 2015). This involves significantly altered flow regimes and a slow alteration in water chemistry to more alkaline conditions. While some improvements, particularly in water clarity, are evident in urban creeks, the majority of water quality variables at these sites have been consistently poor through time.

Estuarine sites in the Hawkesbury River are exhibiting impacts from pressures that extend well beyond the Hornsby LGA, particularly with regards to increasing nutrient concentrations. Bacteria levels at estuarine sites are low and mostly compliant with the REHVs, however Marramarra Creek and Crosslands Reserve sites are close to the tidal limits and susceptible to freshwater catchment inputs. Except for the reference sites, Tunks Creek and Joe Crafts Creeks, bacteria results are highly variable at freshwater monitoring sites. While industrial areas exhibit persistently elevated bacteria levels, most sites generally comply with REHVs. The variability evident in the data suggests most sources of bacteria are associated with pulse, or intermittent, pollution events which are likely to be rainfall related.

More specific findings of this Review include:

- Water quality conditions at reference sites fluctuate naturally through time however the sites are quite stable with no strong significant long-term trends evident.
- The most significant long-term improvements in water quality have occurred downstream of the West Hornsby and Hornsby Heights WWTPs in Berowra and Calna Creeks respectively. Substantial reductions in total nitrogen and oxidised-nitrogen resulted from WWTP upgrades completed in 2003. Despite these operational improvements, there was no reduction in elevated phosphorus levels, and the nutrient concentrations in treated effluent currently discharged from the plants remains well above REHVs. Further improvements in water quality are not evident post-2003, hence a concerted collaborative effort is required to address this.

- Within the Hawkesbury River estuary, results indicate that total nitrogen concentrations are significantly increasing at all of the sampling sites located in the main arm of the Hawkesbury River. Significant increases in total phosphorus are of concern at sites located in Milsons Passage and south of Dangar Island. Whilst nutrient levels towards the mouth of the estuary are relatively low, sites further upstream already experience elevated nutrient levels that exceed the REHVs.
- Significant long-term reductions in total phosphorus have been achieved at two out of three industrial sites; Larool Creek in Thornleigh and Sams Creek in Mt Kuring-gai. Clarity in Larool Creek has also significantly improved, with reductions in total suspended solids and turbidity particularly evident post-2006. Despite this, industrial land-use continues to place a significant pressure on waterways with the majority of water quality variables remaining elevated and well above REHVs.
- Analysis of data collected between 2012 and 2017 showed significant improvements in both dissolved oxygen and nitrogen concentrations in Glenorie Creek. These more recent improvements are likely to be attributed to Glenorie town centre being connected to the Sydney Water sewerage network and a subsequent reduction in the number of on-site wastewater management systems (OWMS) operating in the catchment.
- Sites in Joe Crafts Creek and Tunks Creek demonstrate spatial variation in water quality with these sites exhibiting relatively good water quality compared to sites in closer proximity to urban and rural settlements higher in the catchments. These sites highlight the importance of the role that a vegetated catchment, intact riparian zone and natural instream processes play in improving water quality and protecting waterway health.

Overall, this Review has identified that long-term improvements in water quality have been achieved at many freshwater sites, particularly in relation to water clarity. However, persistently elevated nutrient concentrations, electrical conductivity and pH remain an issue. Similarly, amongst the estuarine sites, nutrient concentrations are of concern; particularly the ongoing elevated concentrations in Berowra Creek and the steadily increasing concentrations in the Hawkesbury River which may lead to an increase in algal blooms and impact on the recreational and commercial use of the estuary.

Wastewater management is an ongoing source of pressure on waterway health. Ageing infrastructure, managed by Sydney Water, causes pulse pollution events due to intermittent faults and releases of partially treated or untreated wastewater during high-flow conditions. Treated wastewater discharged during regular operation delivers a continuous source of nutrients to Berowra Creek. Continued collaboration between Hornsby Council and Sydney Water is essential to appropriately address these chronic issues.

The management of risks associated with water quality for swimming and other recreational activities continues to be an important focus of Council's Water Quality Monitoring Program. Following a comprehensive analysis of historical recreational monitoring data it has been found that bacteria levels exceeding public health thresholds are generally associated with wet-weather events. Council now uses real-time estuarine monitoring probes in conjunction with site-specific data analyses to assess the likelihood of bacteria being present at swimming sites. Daily advice on swimming conditions is available via a public web portal www.hornsby.nsw.gov.au/waterquality.

Analysis of the long-term data set for this Review has identified a range of management actions required to protect, mitigate or remediate catchments in order to protect local waterways and their associated community values. The proposed management recommendations are generalised into four categories: Monitoring; Research & Investigation; Education & Collaboration; and Planning & Compliance.

Monitoring:

- Monitor and assess bacteria levels to identify and manage risks associated with recreational waters,

- Daily updates of suitability for recreational use to be advised on Council's web-based swimming maps
- Ongoing (routine and response) monitoring to identify and manage risks associated with algal blooms
- Ongoing monitoring for catchment health assessments via the Ecohealth program incorporating water quality monitoring, riparian vegetation assessments, geomorphological condition and macroinvertebrate sampling
- Ongoing monitoring of local reference conditions in conjunction with further investigation of the influence of key south-east Australian climate drivers on these conditions
- Use of remote monitoring stations for the ongoing assessment of estuarine conditions

Research & Investigation

- Conduct further collaborative research specific to estuarine health and ecological responses, particularly with regards to algal bloom processes, estuarine infilling, freshwater inputs and environmental flows
- Investigate opportunities for additional catchment remediation devices and further Water Sensitive Urban Design (WSUD) in all catchments
- Investigate sources of pollutants in impacted catchments including modelling and on-ground assessments
- Investigate the influence of wet-weather events on data variability and associated local conditions

Education & Collaboration

- Collaborate with industry and relevant state government agencies to improve the management of industrial developments
- Collaborate with stakeholders, including neighbouring councils, state government agencies, community groups and research organisations to increase knowledge and improve management outcomes for waterway health
- Educate and collaborate with marina operators, boat users, riverside residents and holiday-park operators to minimise impacts from their associated activities
- Educate and collaborate with the community to increase catchment awareness, facilitate behavioural change and minimise risks associated with common urban and rural land-use activities
- Continue to collaborate with stakeholders for a coordinated approach to the management of risks to local aquaculture and commercial fishing operations
- Continue to collaborate with Sydney Water to improve the management of wastewater

Planning & Compliance

- Develop a whole-of-estuary Coastal Management Program in partnership with neighbouring councils to facilitate the coordinated management of the lower Hawkesbury River Estuary and associated tributaries
- Improve collaborative management of risks associated with legacy landfill sites, particularly at Foxglove Oval
- Maintain stringent sediment and erosion control standards within all catchments
- Protect the bushland and riparian zone in catchments to maintain their buffering capacity
- Review of waterways values and objectives for all monitoring sites
- Ensure the Water Quality Monitoring Program is aligned with the Water Sensitive Hornsby Transition Strategy

- Review current and develop new planning controls and prescriptive measures for the protection of estuarine and freshwater ecosystems to inform Local Strategic Planning Statements (LSPS), Local Environment Plans (LEP) and Development Control Plans (DCP)

With a growing population and continuously changing catchments, the pressures on water quality in Hornsby Shire will only increase. Climate stressors on waterways are also expected to intensify with climate change projections indicating the occurrence of more extreme weather events; longer drier droughts and more intense rainfall events against the backdrop of increasing temperatures. This Review provides a comprehensive understanding of the spatial and temporal variability and current conditions of our creek, estuary and river systems in combination with recommended management actions to protect Hornsby Shire's highly valued local waterways into the future.

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INTRODUCTION

Hornsby Shire Council's (HSC) Long-term Water Quality Monitoring Program (the Program) began in 1994, soon after a Statement of Joint Intent (SoJI) was signed by the (then) NSW Department of Planning, Environmental Protection Agency, Hawkesbury-Nepean Catchment Management Trust, Hornsby Shire Council and the Water Board. The SoJI was an agreement established in response to environmental issues which included the regular occurrence of algal blooms in Berowra Creek, increasing pressures of urban development and sewage discharge, and the recognition of the detrimental impacts of catchment activities on water quality.

The Program was designed to assess, through time, the impact of land-use on waterways within Hornsby Shire and to monitor the performance of Council's Catchments Remediation Rate (CRR) program. Council's water quality monitoring efforts have continually expanded to include aquatic ecosystem health monitoring, assessment of CRR initiatives, assessment of risks in recreational waters, detection of harmful algal blooms, assessment of wastewater treatment plant (WWTP) impacts and monitoring to support asset management and water conservation initiatives.

Data from the Program is used to influence and inform catchment management, modelling projects and education initiatives. HSC's Long-term Water Quality Monitoring Program is considered one of the most intensive and comprehensive water quality programs undertaken by Local Government in the state and has been carefully undertaken with stringent quality-assurance and quality-control measures (Appendix A) and water quality monitoring protocols.

In October 2017, HSC commenced a catchment health monitoring program called Ecohealth. This program incorporates the assessment of riparian condition, geomorphology, macroinvertebrate communities and water quality data to provide a measure of overall catchment health. In accordance with recommended weight-of-evidence (WOE) processes (ANZG, 2018), the results of this long-term water quality Review in conjunction with Ecohealth results will provide a more holistic approach to catchment assessment and management. With this approach, HSC is striving to deliver more targeted programs to protect, mitigate or rehabilitate waterways within Hornsby Shire.

Purpose of the study

Since 1994, HSC has monitored water quality at more than 180 sites. The purpose of this study is to analyse data collected from 35 long-term sites to identify significant temporal changes in water quality and assess environmental condition by comparing observed water quality data to Regional Environmental Health Values (REHVs), which are HSC's adopted guideline values for aquatic ecosystem health. Specific objectives of this study are to:

- Identify significant temporal trends in water quality monitored at freshwater and estuarine sites.
- Determine how water quality conforms against REHVs at freshwater and estuarine sites.
- Identify site-specific risks to water quality and recommend management options to achieve water quality objectives.
- Use knowledge gained from long-term water quality monitoring in association with established decision-making frameworks to guide HSC's monitoring program into the future.

Study area

Hornsby Shire Local Government Area (LGA) is situated approximately 25km north-west of Sydney and includes extensive areas of bushland and waterways. Hornsby Shire covers an area of 499km^2 of which over 60% of the area is bushland, with rural, industrial and urban land-uses constituting the remainder. The

main urban developments are concentrated in the southern half of the Shire on the plateau areas. The 35 long-term sites included in this report (Figure 1) were selected to spatially represent waterways across Hornsby Shire that receive input from natural, urban, rural and industrial land-uses, or areas impacted by point sources, such as WWTP. They also include estuarine sites selected to improve our understanding of estuarine health or sites of significance to the community. Individual site descriptions are included in Appendix B.

The study area also incorporates the estuarine section of the lower Hawkesbury River from Broken Bay to Wisemans Ferry. The estuarine/tidal limit of the Hawkesbury River extends further upstream to Yarramundi and the upper Hawkesbury River includes an extensive catchment that encompasses much of the northern and western sections of the Greater Sydney Basin.

Management issues

Freshwater

In the Hornsby LGA the upper catchments primarily include urban, industrial and rural land-uses. In urban areas, housing densities have increased, placing additional pressures on stormwater and wastewater infrastructure. Increasing and intensified development has meant an increase in impervious surfaces which, combined with the requirement to direct urban water through piping and culverts, has led to the impacts of magnified erosion and changes of urban water chemistry (Wright 2012).

Historically, industrial areas at Hornsby and Thornleigh, and to a lesser extent Mount Kuring-gai, have placed pressure on water quality in nearby waterways. Management to improve water quality in these areas has included enforcement of environmental compliance and installation of catchment remediation devices. However, industrial areas continue to be high risk sources of water pollution and stressors on water quality in parts of the upper catchment.

In addition to industrial areas, former landfill sites also require additional management to protect water quality in downstream waterways. The containment, treatment and monitoring of leachate, which is high in ammonium-nitrogen, is essential at these sites. At some former landfill sites, the establishment of treatment plants and regular monitoring of system performance has been an essential part of their management.

In the south-western section of the LGA, the further development of land within traditionally rural areas is occurring and predicted to continue with the growth of Greater Sydney. Intensified development at the perimeters of these areas, as well as the central village areas around Galston and Glenorie, has occurred. Currently, nurseries, market gardens, orchards and chicken farms are some of the main rural industries. An increase in hobby farms and sand mining operations has been notable.

The management of natural areas and their associated values is of considerable importance to the community within Hornsby Shire. The Hornsby LGA includes numerous National Parks and reserves that contribute to the large and extensive areas of bushland. Many of these areas are in the lower parts of the catchments and therefore exposed to pressures from development, infrastructure requirements, and land-use change in the upper catchment. These natural areas are places of significant cultural, spiritual, recreational and aesthetic value, thus, thorough management of water quality and riparian condition continues to be of great importance at these sites. The values provided by the natural environment are important contributing factors towards attracting people to live in Hornsby Shire.

Estuarine

The Hawkesbury River is a unique system providing the Greater Sydney community with a diverse range of opportunities. The extensive catchment that encompasses much of the northern and western sections of Greater Sydney has supported a rapidly increasing population. Consequently, the entire river system and the lower Hawkesbury River estuarine reaches are under increasing pressure from a vast range of activities, in particular, significant increases in urbanisation.

The lower Hawkesbury River supports recreational activities including swimming, fishing, water-skiing, kayaking, and boating, while the surrounding National Parks of Ku-ring-gai Chase, Berowra Valley, Marramarra, Brisbane Waters, Popran, Dharug and Muogamarra Nature Reserve, provide a unique landscape with extensive drowned river valleys and steep sandstone escarpments. In addition, the lower Hawkesbury River supports numerous river communities and industries, including important commercial fisheries and aquaculture enterprises. Commercial fisheries operating in the lower Hawkesbury include prawn trawling, estuary general fishery and oyster farming.

There are many pressures on water quality in the lower Hawkesbury River and associated tributaries, such as Berowra and Marramarra Creeks. These pressures include intensified urban development in the upper reaches, multiple wastewater discharge points and rural use of lands in both the upper catchment and areas of the flood plains along the river. In addition, future land-use change, such as an increasing need for extractive industries and the much larger widespread pressures of climate change and population growth present as major threats (Boon 2017). Concentrations of nutrients and sediment loads are predicted to increase as urbanisation of the Sydney Basin expands in upper catchments.

One of the major challenges to the management of this system is developing and implementing a whole system approach to such a geographically expansive system and catchment. In the estuarine reaches from the upstream tidal limit around Yarrumundi to the mouth at Broken Bay, the Hawkesbury River adjoins six local government areas, while numerous others occur within the Hawkesbury-Nepean Catchment, which extends south to Goulbourn and west to Lithgow. Collaboration across local government boundaries and alignment with recent coastal reforms will be key to the success of future management strategies.

Problematic algal blooms continue to occur in the estuarine reaches of the lower Hawkesbury River, and of particular note, in Berowra Creek (Haines et al., 2008; HSC, 2010, 2011, Boon 2017). Like in many estuaries, algal blooms occur naturally, however anthropogenically driven increases in nutrients can increase the occurrence and intensity of these events. If a bloom is dominated by a nuisance species of algae (i.e. toxic species) it could potentially be harmful to human health or result in significant environmental, social and economic impacts (DEH, 2001; Anderson et al., 2002).

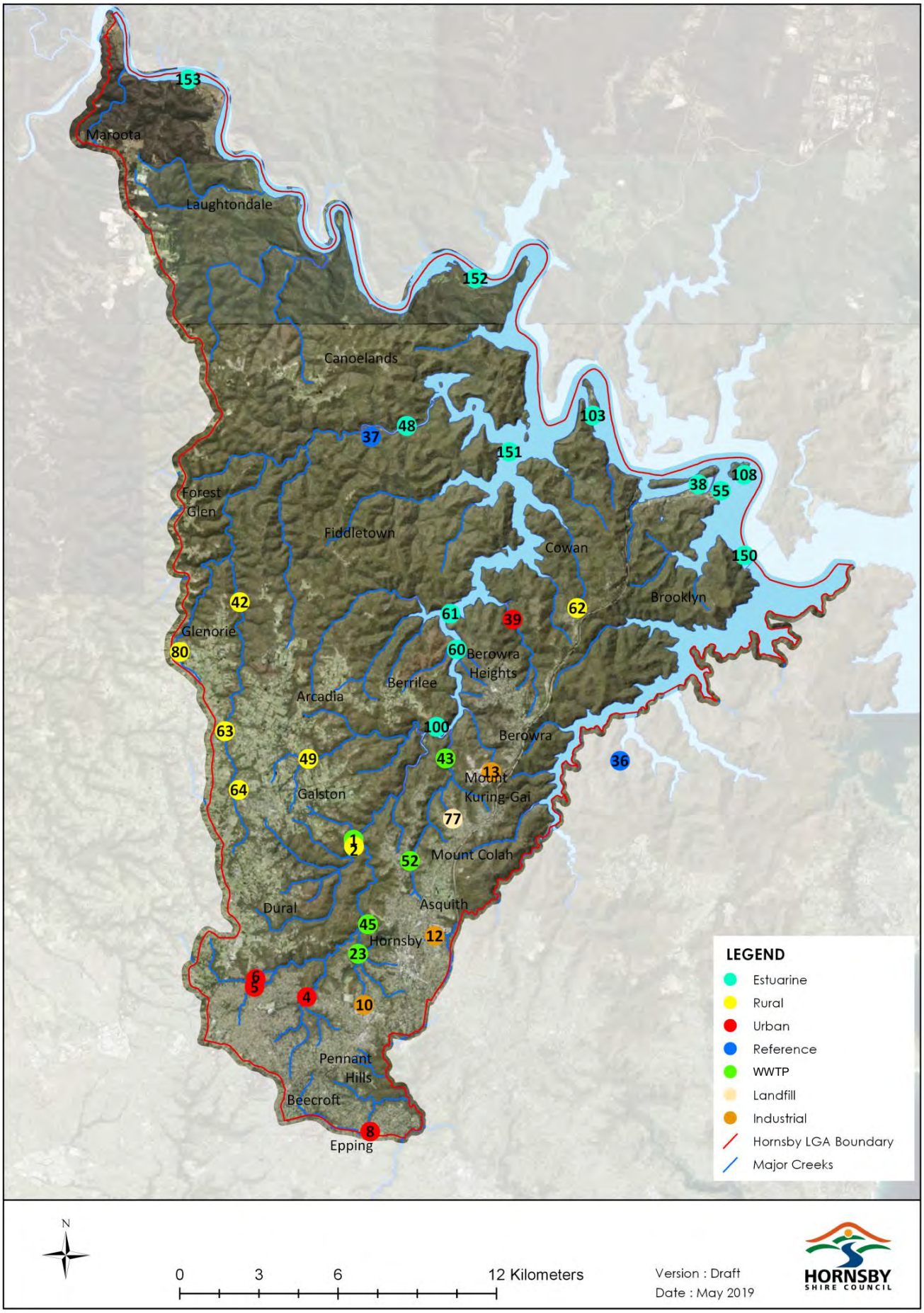


Figure 1 HSC long-term water quality monitoring sites and associated primary land-use

Overview of catchments

Water catchments in the Shire include Berowra Creek, Upper Lane Cove River, Cowan Creek and the Hawkesbury River (Figure 2).

Berowra (Creek) Catchment

Berowra Catchment is primarily contained in the Hornsby Shire LGA and is bounded to the south by Pennant Hills Road, to the west by Castle Hill Road and Old Northern Road, to the north by Canoelands Ridge, and to the east by the Pacific Highway. The Catchment includes a mix of land-uses including rural, developed and developing urban, light industrial and commercial. It also contains significant bushland areas such as Marramarra National Park, Muogamarra Nature Reserve and Berowra Valley National Park. Urban land-use dominates the south and south-eastern parts of the Catchment where the majority of residents live. Rural land-use is largely located in the north-western part of the Catchment within the Marramarra Creek sub-catchment. Marramarra Creek flows to lower Berowra Creek near to its confluence with the main arm of the Hawkesbury River.

Berowra Creek is 26km long and runs generally south to north. Its lower half forms a characteristic drowned-river valley estuary of the Hawkesbury Sandstone system and its upper reaches drain the plateau. Berowra Creek is freshwater above Rocky Fall Rapids located about 3km downstream from Galston Gorge. Below Rocky Fall Rapids the creek becomes more saline and influenced by the tides. Berowra Creek has several tributary creeks including: Pyes, Georges, Waitara, Larool, Calna, Gleeson, Sams, Joe Crafts, Kimmerikong, Still, Tunks, Calabash, Glenorie, Colah, Smugglers and Marramarra.

There are two large WWTPs located within the Berowra Creek Catchment, one at West Hornsby (discharging into Waitara Creek) and another at Hornsby Heights (discharging into Calna Creek). Waitara Creek and Calna Creek are both tributaries of Berowra Creek. Major upgrade works (undertaken between 2001 and 2003) led to these WWTPs providing a tertiary level of treatment to sewage with additional nitrogen and phosphorus removal and disinfection. The works focused on reducing total nitrogen levels to assist in protecting the downstream Berowra Creek estuary from eutrophication and algal blooms. Upgrades and improvements have also been made to wastewater management in the western part of the Catchment. The Galston & Glenorie Wastewater Scheme (completed in 2015) delivered wastewater services to over 600 properties in the Glenorie and Galston areas. These areas are located in the headwaters of Glenorie and Colah Creeks which are both tributaries of Marramarra Creek.

The major pressures on water quality in Berowra Creek are: discharges of tertiary treated sewage from the West Hornsby and Hornsby Heights WWTPs (into Waitara and Calna Creeks respectively); stormwater runoff from the urban and industrial land-use areas located in the south and south-eastern parts of the Catchment; and runoff that enters Berowra, Tunks, Still, Colah and Fiddletown Creeks from the rural and peri-rural areas in the southern and western parts of the Catchment.

Water quality monitoring site locations include:

- Upper Berowra Creek Catchment (above the West Hornsby WWTP); Pyes Creek (005), Georges Creek (006), Waitara Creek (023), Larool Creek (010) and upper Berowra Creek (004)
- Lower freshwater reaches of Berowra Creek (below the West Hornsby WWTP); Fishponds (045) and Galston Gorge (001)
- Tributary creeks flowing from south-eastern part of the catchment; Calna Creek (043 and 052) and Gleeson Creek (077)
- Tributary creeks flowing from north-eastern part of the catchment; Sams Creek (013), Joe Crafts Creek (039) and Kimmerikong Creek (062)

- Tributary creeks flowing from the south-western part of the catchment; Still Creek (049) and Tunks Creek (002)
- Berowra Creek Estuary; Calabash Point (061), Berowra Waters (060) and Crosslands Reserve (100) of which the latter is located close to the extent of tidal influence.
- Marramarra Creek Catchment; Unnamed Creek, Galston (064), Glenorie Creek (080), Colah Creek (042 and 063), Marramarra Creek (048) and Smugglers Creek (037).

Cowan (Creek) Catchment

The Cowan Catchment includes three LGAs (namely Hornsby Shire, Ku-ring-gai and Northern Beaches Councils). The western boundary of the Catchment is defined by the Pacific Highway ridgetop which lies within Hornsby Shire. Cockle and Cowan Creeks respectively form the southern and easternmost boundaries of the Catchment areas located within Hornsby Shire.

Land-uses in the southern part of the Catchment include extensive light industrial areas, large commercial shopping centres and developed urban areas. The bushland of Ku-ring-gai Chase National Park covers a large part of the Catchment.

Water quality monitoring site locations include:

- Hornsby Creek (012) and Murray Anderson Creek (036).

Lane Cove (River) Catchment

The Lane Cove Catchment includes seven Local Government Areas and only the upper reaches (in particular the Devlins Creek sub-catchment) are located within Hornsby Shire. Devlins Creek flows in part adjacent to the M2 motorway corridor. The Catchment is highly developed and dominated by urban land-use with some commercial use and includes bushland of Lane Cove National Park. This Catchment is Hornsby Shire's only area that drains to downstream Sydney Harbour rather than the Hawkesbury River.

Water quality monitoring is limited to one site:

- Devlins Creek (008).

Lower Hawkesbury (Estuary) Catchment

The Lower Hawkesbury Catchment includes those areas within Hornsby Shire that drain directly into the lower Hawkesbury River estuarine reaches. Broadly, it includes areas westwards and eastwards from where Berowra Creek enters the Hawkesbury River. Areas to the west include Wiseman's Ferry, Laughtondale and Courangra Point and those to the east include Bar Point, Milsons Island, Brooklyn, Dangar Island and Gunyah Point.

Land-uses in these areas include riverside settlements, small farming ventures, market gardening, marinas, boat ramps, aquaculture and fishing industries (commercial and recreational). A WWTP that services Brooklyn, Dangar Island, Mooney Mooney and Cheero Point discharges tertiary-treated effluent beneath Peats Ferry Bridge (on the Old Pacific Highway) into an area of strong tidal current. The Brooklyn WWTP was commissioned in 2007.

Water quality monitoring site locations include:

- Estuarine sites in the western part of the Catchment; Laughtondale (153) and Courangra Point (152).
- Estuarine sites in the eastern part of the Catchment; Marramarra Creek (151), Milsons Passage (103), Dangar Island (108), Brooklyn (038, 055), and Gunyah Point (150).

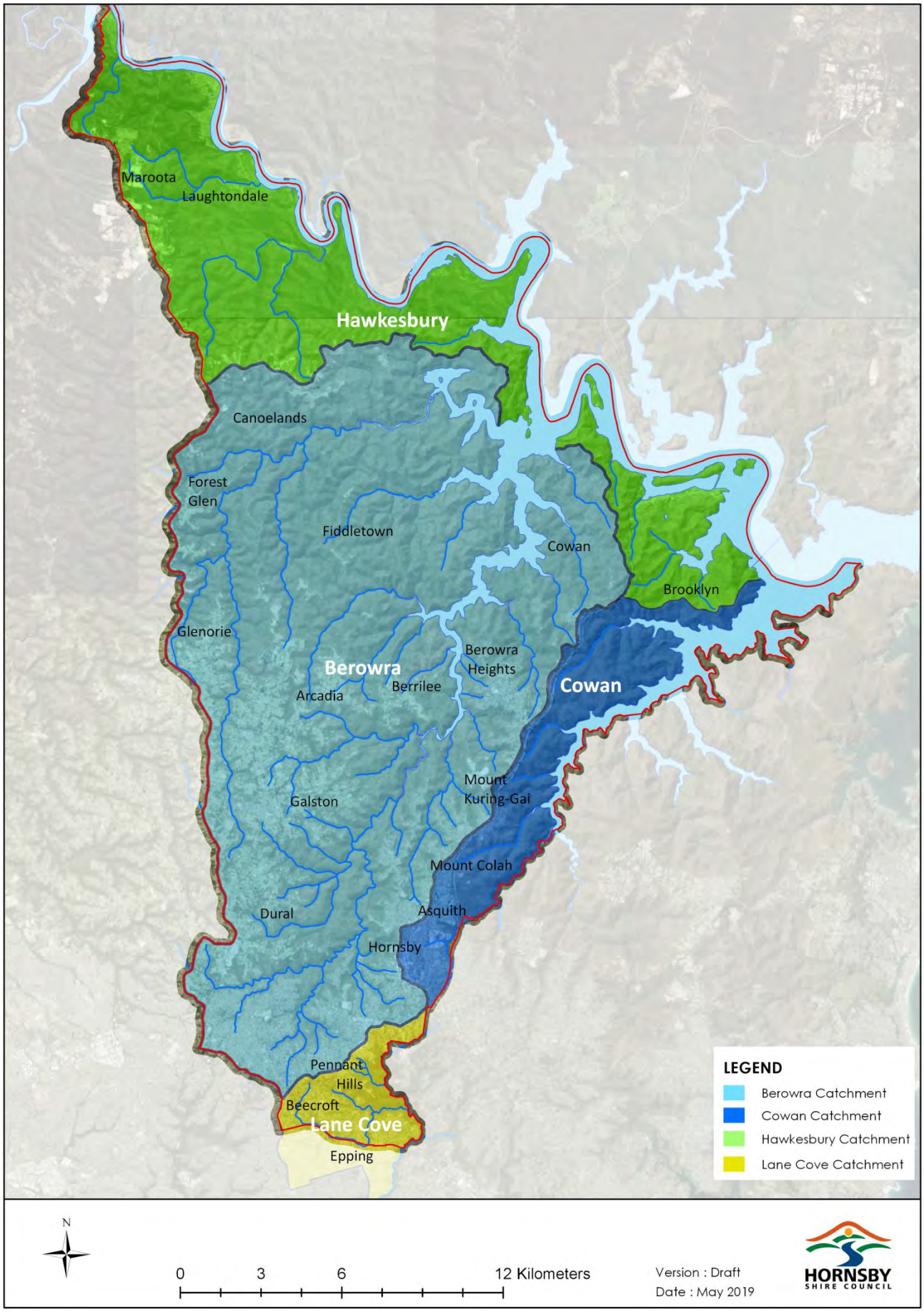


Figure 2 Major water catchments in Hornsby Local Government Area

METHODOLOGY

This report presents information on temporal and spatial variability and significant changes in water quality at 35 sites monitored as part of HSC's Long-term Water Quality Monitoring Program. These sites were monitored over a period of up to 22 years (1995 to 2017) with data (primarily) collected on a monthly basis in both wet and dry conditions.

Many of the sampling sites have been monitored since 1995, however this analysis also includes several sampling sites that haven't been monitored for as long but are considered of value in understanding long-term changes of water quality. Likewise, the analysis also includes some individual water quality variables that have been monitored at long-term sites but for less time. Site specific details on sampling duration and variables are provided in individual site summary reports presented in the Results section.

A total of 11 physical and chemical (phys-chem) and four (4) biological (stressor) variables were analysed as part of this report. For reporting purposes, the variables have been grouped according to Table 1:

Table 1 Grouping of water quality parameters for reporting

Group	Parameter
Phys-chem	Temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC)#, Salinity*
Clarity	Turbidity, Total Suspended Solids (TSS)
Biological	Chlorophyll-a (Chl-a)*
Nutrients	Total Nitrogen (TN), Total Phosphorus (TP), Ammonia Nitrogen (NH_3-N), Oxidised Nitrogen (NO_x-N)
Bacteria	Faecal coliforms (F.cols), *Escherichia coli* (E.Coli), Enterococci (entero)

** Estuarine sites only*
 # Freshwater sites only

Temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), salinity and turbidity data were collected in situ using Yeokal Portable Water Quality Analysers. Total suspended solids (TSS), nutrients, bacteria and chlorophyll-a (Chl-a) data are results of laboratory analysis of grab samples. Additional descriptive information has been provided where available for Soluble Reactive Phosphorus (SRP) at estuarine sites. Detailed field sampling and testing methods are documented in Council's Water Quality Monitoring Annual Reports (HSC 2016).

Quality Assurance/Quality Control

Given the large effort to maintain an intensive water quality monitoring program in HSC, stringent quality assurance and quality control (QA/QC) procedures have been implemented to ensure the integrity of the data. These procedures were in place for sampling collection and handling, sample transport, laboratory analysis and data handling. An extract of QA/QC procedures from the 2015/16 Water Quality Annual Report (HSC 2016) is provided in Appendix A. In summary, QA/QC processes included:

- Calibration of the water quality meter each day before and after sampling;
- The collection and analysis of both duplicate and blank samples; and
- Transport of samples to NATA accredited laboratories with Chain of Custody documentation.

Regional Environmental Health Values

Guideline trigger values are set for water quality variables to indicate the limit at which there is a risk of impact, and if exceeded, should 'trigger' some management response. The ANZECC/ARMCANZ Guidelines (2000) list default trigger values for water quality assessments but recommend that more appropriate

guideline trigger values be developed based on local or regional information obtained from long-term monitoring of local reference sites.

In 2012 Regional Environmental Health Values (REHVs) were developed specifically for Hornsby LGA using data from the Long-term Water Quality Monitoring Program (Table 2). These REHVs have been adopted as the guideline values for this analysis. For freshwater sites the REHVs are derived from two local reference sites located in undeveloped bushland catchments. All estuarine areas in or near the Hornsby LGA are in some way impacted by stormwater or wastewater from parts of the catchment. As such, it was not possible to incorporate an estuarine reference site in the Program. REHVs for estuarine water are derived from a combination of the ANZECC/ARMCANZ Guidelines (2000), Guidelines for Managing Risks in Recreational Water (NHMRC 2008) and NSW State Authority recommendations. Detailed information on the development of the REHVs is documented in Council's Companion Technical Report (HSC 2012).

Table 2 Regional Environmental Health Values

Parameter	Units	Freshwater REHVs		Estuarine REHVs
Dissolved Oxygen(DO)	% sat	Lower	75	80
Dissolved Oxygen (DO)	% sat	Upper	118	110
pH	unit	Lower	4.8	7
pH	unit	Upper	7	8.5
Turbidity	NTU		8	10
Total Suspended Solids (TSS)	mg/L		7	6
Electrical Conductivity (EC)[#]	mS/cm		0.32	NA
Chlorophyll *a* (Chl-a)*	µg/L		NA	4
Total Nitrogen (TN)	mg/L		0.32	0.3
Total Phosphorus (TP)	mg/L		0.01	0.03
Ammonia Nitrogen (NH_3-N)	mg/L		0.02	0.015
Oxidised Nitrogen (NO_x-N)	mg/L		0.05	0.015
Faecal Coliforms (F.cols)	CFU/100 mL	Median	150	150
Faecal Coliforms (F.cols)	CFU/100 mL	80th percentile	600	600
Enterococci (Entero)*	CFU/100 mL	95th percentile	NA	40

**Estuarine sites only*

[#] *Freshwater sites only*

Data analysis

Data in this report was analysed using the following three approaches:

- Descriptive statistics
- Percent non-conformance (%NC)
- Trend analysis

Data for individual parameters were removed from the analysis where only one sample was collected or reported on within any given year. Data were analysed over a range of timeframes. In all instances long-term data analysis was undertaken using the longest period of data available for a given site. To assist in deriving management priorities based on current conditions, additional analysis was undertaken for the last five years of data (October 2012 to September 2017). Where less than 10 years of data was available,

additional analysis over the most recent five years was not undertaken. In addition, analysis was re-run for sites immediately downstream of WWTPs (freshwater sites 001, 043 and 045 and estuarine sites 060 and 061). Data in this analysis was limited to that collected post completion of the WWTP upgrades (2004 onwards).

Descriptive statistics

The statistical software package Statistica by Stat Soft® was used to calculate descriptive statistics. Descriptive statistics were calculated for all the data available since 1994 for each individual site. The descriptive statistics calculated included; sample size (valid n), Mean, Median, Minimum, Maximum, 20th Percentile, 80th Percentile and Standard Deviation (Std Dev).

Percent non-conformance

Measures of non-conformance were based on the REHVs provided in Table 2. The non-conformance were expressed as a percentage of times a reading was above or outside REHVs over the timeframe assessed e.g. long-term, post-WWTP upgrades or 2012-2017. It should be noted that guideline values for bacteria have been developed to access risk to public health and should be compared against a median and the 80th percentile for faecal coliforms and the 95th percentile for enterococci. For the specific purpose of reporting on temporal trends (not risk), the %NCs for faecal coliforms and enterococci have been calculated using individual data points against the REHV values, not a calculated 80th or 95th percentile value against the REHV.

Trend analysis

The significance of trends in water quality variables was tested using Statistica to perform a non-parametric *Kendall tau* test, which produces a rank correlation coefficient (Cox and Moss, 1999). This is useful in datasets that contain many outliers and those that may not be normally distributed. The test was applied to determine at the 5% significance level if the trend is significantly different from zero. The test also calculates a statistic constant called *tau* which measures the strength and direction of the trend. *Tau* ranges from values of -1 to +1 where the sign indicates the direction of the trend (i.e. decrease or increase respectively) and the value indicates the strength of the trend (slope steepness). A value of 0.4 or greater is generally regarded as important and a value close to zero indicates no major trend (Cox and Moss, 1999). The assumptions of this test are that the trends are monotonic and that observations are independent of each other. Results of the trend analysis are provided in Appendix C.

Graphical presentation

Trends in the long-term data and results of the data analysis are presented graphically. For each variable at each site annual boxplots were created with whiskers representing the 5th and 95th percentiles, the box representing the 20th and 80th percentiles and a median dot point. Where data was considered in relation to a REHV, the REHV value is plotted on the graph as a broken red line (Figure 3).

To summarize how sites performed colour-coded summary tables were prepared. The median values provided for each parameter were representative of the overall median for the timeframe considered. Non-conformance was presented as percentage (%NCs) of times that a parameter of question was above (or outside) the REHV at the site. Trends were presented as either non-significant (NS), significantly increasing (↑) or significantly decreasing (↓) based on the *Kendall tau* values. See Table 3 for the categorisation of the colours. For parameters where a REHV was not available or there was insufficient data to complete the analysis, cells were depicted in the colour grey. Additional spatial interpretation of non-conformance and trend analysis results was performed using ArcGIS Software (Appendix D).

Table 3 Colour based categorisation of analysis results

Median	%Non-Conformance (%NCs)
Within (upper and lower values), or below (upper value only) REHVs	<25% non-conformance with REHV
Equal to REHVs	25% to 75% non-conformance with REHV
Outisde (upper and lower values), or above (upper value only)	>75% non-conformance with REHV

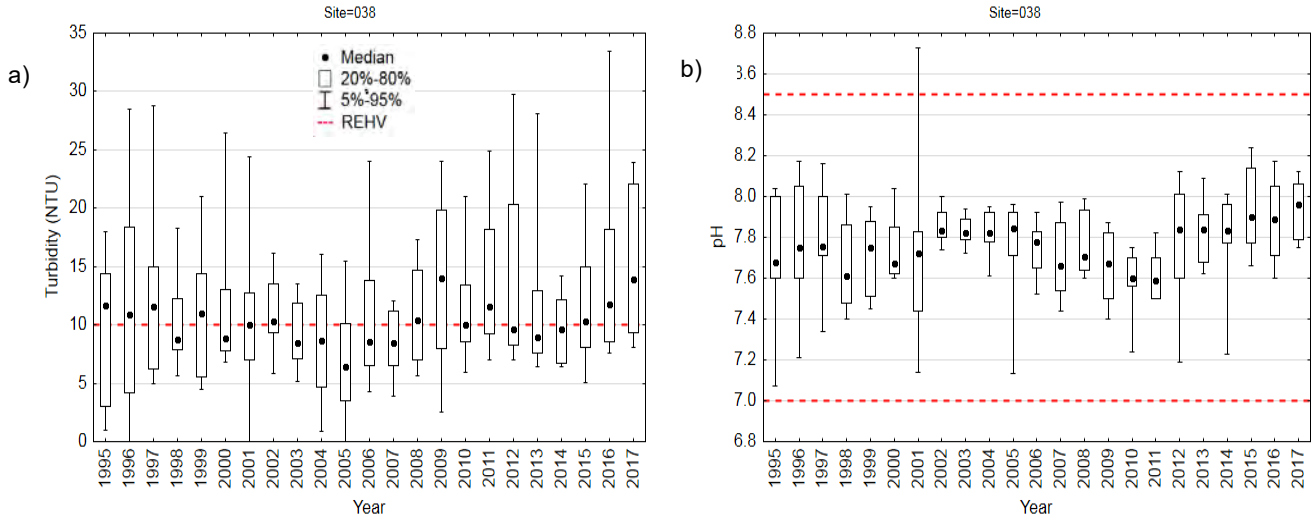


Figure 3 Graphical representations of data with a) an upper limit REHV and b) an upper and lower limit REHV

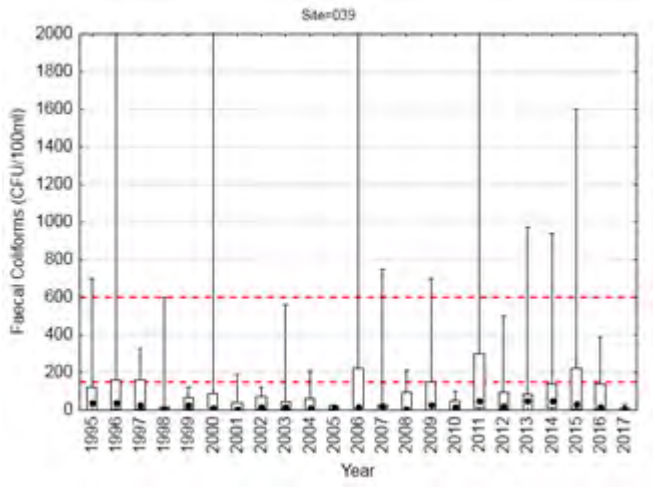


Figure 4 Graphical representation of faecal coliform data which has 2 REHV values; median and 80th percentile

RESULTS – INDIVIDUAL SITE SUMMARIES

Results of the long-term data analysis are presented as individual site summaries for each of the 35 sites. Each site summary presents the following information:

- Associated program name/s (details in Appendix E)
- Monitoring program timelines
- Key findings and recommendations
- Site photos
- Results of data analysis
- Boxplots showing the annual variability for each variable measured

Whilst these site summaries have been designed so that they can be used as standalone documents, interpretations of results and management decisions should only be made in the context of the overall Review.

Table 4 Page references for individual site summaries grouped by primary land-use / influence

Primary Site Influence	Major Catchment	Freshwater or Estuarine	Site No	Site Location	Page No.
Estuarine	Hawkesbury River	Estuarine	038	Sandbrook Inlet	61
Estuarine	Hawkesbury River	Estuarine	048	Marramarra Creek	81
Estuarine	Hawkesbury River	Estuarine	103	Milsons Passage	129
Estuarine	Hawkesbury River	Estuarine	108	Bradleys Beach, Dangar Island	133
Estuarine	Hawkesbury River	Estuarine	150	Gunyah Point	137
Estuarine	Hawkesbury River	Estuarine	151	Bar Island	141
Estuarine	Hawkesbury River	Estuarine	152	Courangra Point	145
Estuarine	Hawkesbury River	Estuarine	153	Laughtondale	149
Industrial	Berowra	Freshwater	010	Larool Creek	37
Industrial	Berowra	Freshwater	013	Sams Creek	45
Industrial	Cowan	Freshwater	012	Hornsby Creek	41
Recreational	Berowra	Estuarine	100	Crosslands Reserve	125
Recreational	Hawkesbury River	Estuarine	055	Brooklyn Baths	93
Reference	Berowra	Freshwater	037	Smugglers Creek	57
Reference	Cowan	Freshwater	036	Murray Anderson Creek	53
Rural	Berowra	Freshwater	002	Tunks Creek	17
Rural	Berowra	Freshwater	042	Colah Creek	69
Rural	Berowra	Freshwater	049	Still Creek	85
Rural	Berowra	Freshwater	062	Kimmerikong Creek	105
Rural	Berowra	Freshwater	063	Colah Creek	109
Rural	Berowra	Freshwater	064	Unnamed Tributary of Colah Creek	113
Rural	Berowra	Freshwater	080	Glenorie Creek	121
Urban	Berowra	Freshwater	077	Gleeson Creek	117
Urban	Berowra	Freshwater	004	Berowra Creek, Westleigh	21
Urban	Berowra	Freshwater	005	Pyes Creek	25
Urban	Berowra	Freshwater	006	Georges Creek	29
Urban	Berowra	Freshwater	023	Waitara Creek	49
Urban	Berowra	Freshwater	039	Joe Crafts Creek	65
Urban	Berowra	Freshwater	052	Calna Creek	89
Urban	Lane Cove	Freshwater	008	Devlins Creek	33
WWTP	Berowra	Freshwater	001	Berowra Creek, Galston Gorge	13
WWTP	Berowra	Freshwater	043	Calna Creek	73
WWTP	Berowra	Freshwater	045	Fishponds, Berowra Creek	77
WWTP/Estuarine	Berowra	Estuarine	060	Berowra Waters	97
WWTP/Estuarine	Berowra	Estuarine	061	Calabash Point	101

Site 001 – Berowra Creek, Galston Gorge

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (001)	Nov 1994 – Sept 2017	Monthly
Ecohealth (BERO4)	Oct 2017 ongoing	Quarterly
Event (BERO4)	Oct 2017 ongoing	Post rainfall event

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and consistently exceed REHVs. DO results are less variable post 2003. Clarity: Turbidity and TSS are low and consistently comply with REHVs. Nutrients: TP is elevated and consistently exceeds the REHV. TN and NOx-N are elevated and consistently exceed REHVs despite a significant decrease following WWTP upgrades (post 2003). Bacteria: Bacteria levels are generally low but sometimes variable exceeding REHVs approximately 25% of the time.
Issues	– Influenced by a large diverse catchment including urban, rural and industrial land-uses – Impacted by West Hornsby WWTP discharge
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment (other than those from the WWTP) – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Investigate the influence of wet-weather events on local conditions

Site Photos

Berowra Creek looking upstream during high flow

Berowra Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 001

001	REHV	Long-term				Post WWTP Upgrades (>2004)				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	267	17.08	NA	NS	159	16.88	NA	NS	59	16.88	NA	NS
pH	4.8-7	266	7.60	98	NS	159	7.57	97	NS	59	7.60	98	↑
DO (%sat)	75-118	249	95.20	5	↓	160	92.85	2	NS	60	92.00	2	NS
EC (mS/cm)	0.32	267	0.59	83	↓	159	0.52	83	↓	60	0.50	77	NS
Turbidity (NTU)	8	267	1.6	21	↓	146	1.2	18	NS	59	0.9	17	NS
TSS (mg/L)	7	275	2	13	↓	166	1	8	NS	61	1	8	NS
TP (mg/L)	0.01	275	0.045	95	NS	166	0.043	95	NS	61	0.040	100	↓
TN (mg/L)	0.32	275	2.910	100	↓	166	2.105	100	NS	61	2.110	100	NS
NH_3-N (mg/L)	0.02	275	0.020	31	↓	166	0.012	28	NS	61	0.010	16	NS
NO_x-N (mg/L)	0.05	275	2.300	100	↓	166	1.650	100	NS	61	1.750	100	NS
F.Cols (CFU/100ml)	150	275	51	27	NS	166	48	28	NS	61	47	25	NS

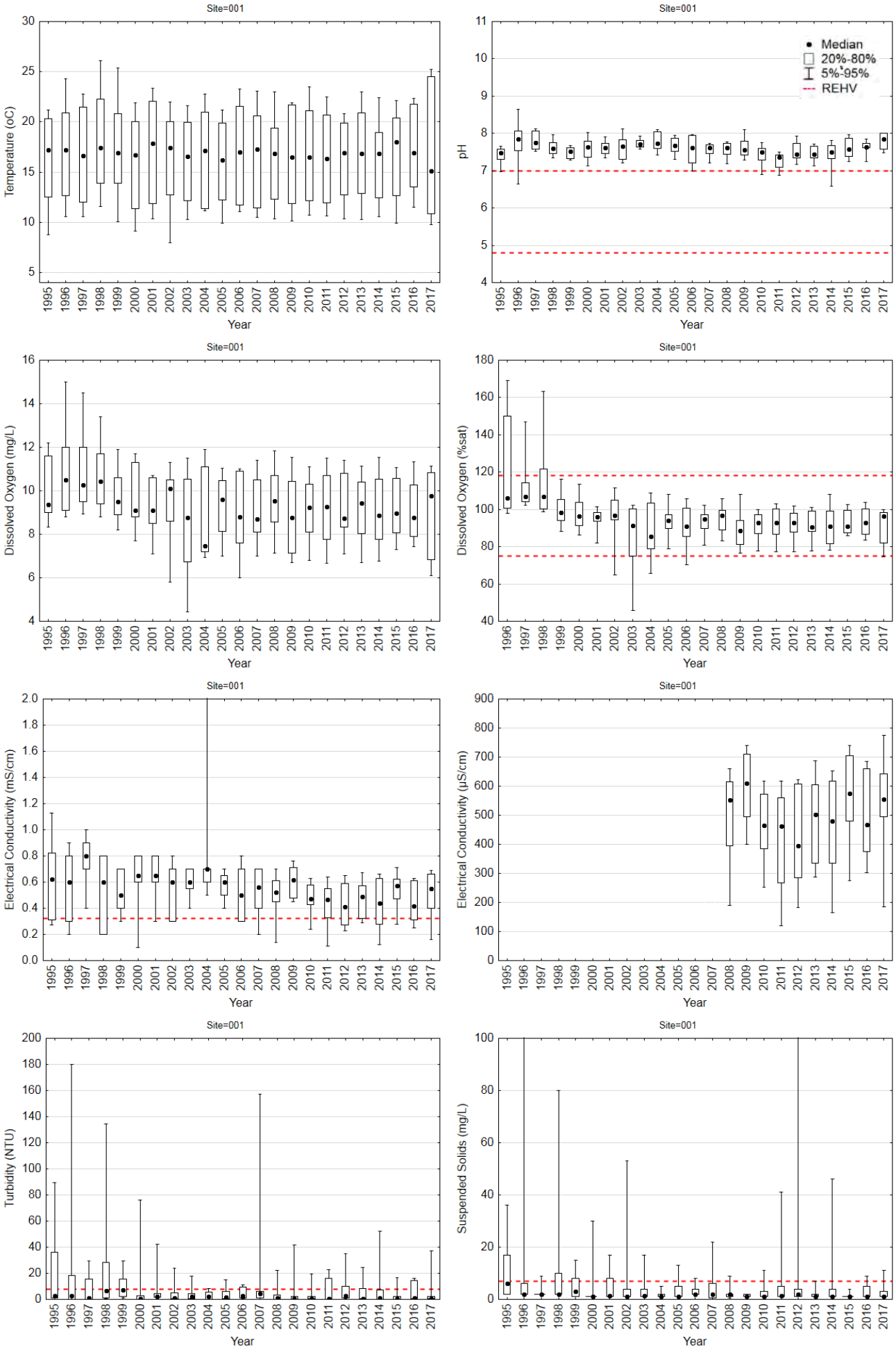
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

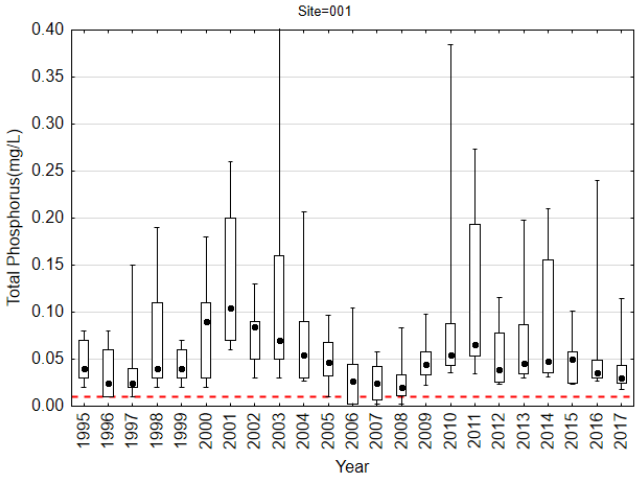
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 001 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	267	16.62	17.08	7.99	26.10	12.16	20.84	4.196
pH	266	7.59	7.60	6.59	8.64	7.38	7.77	0.265
DO (mg/L)	267	9.44	9.36	4.45	15.00	8.11	10.80	1.589
DO (%sat)	249	95.56	95.20	45.95	169.10	87.30	102.15	12.636
EC (mS/cm)	267	0.57	0.59	0.10	6.60	0.39	0.70	0.413
EC (µS/cm)	118	494.57	519.00	119.00	774.47	347.00	623.00	151.560
Turbidity (NTU)	267	8.2	1.6	0.0	180.0	0.4	8.5	21.11
TSS (mg/L)	275	6	2	1	296	1	4	20.7
TP (mg/L)	275	0.063	0.045	0.003	0.780	0.029	0.082	0.0680
TN (mg/L)	275	5.592	2.910	0.500	31.500	1.580	9.075	6.1430
NH_3-N (mg/L)	275	0.038	0.020	0.005	1.120	0.010	0.030	0.0900
NOx-N (mg/L)	275	4.635	2.300	0.010	27.000	1.070	7.965	5.3340
F.Cols (CFU/100ml)	275	1499	51	1	61000	22	280	7201.5
E.Coli (CFU/100ml)	20	925	40	4	10000	20	395	2563.8
Entero (CFU/100ml)	33	364	43	10	5600	17	570	997.4

Boxplots showing annual variability for each variable measured

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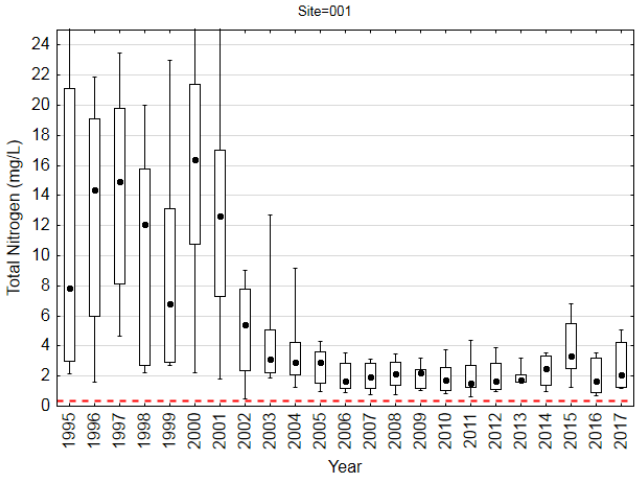
Total Phosphorus(mg/L)
Year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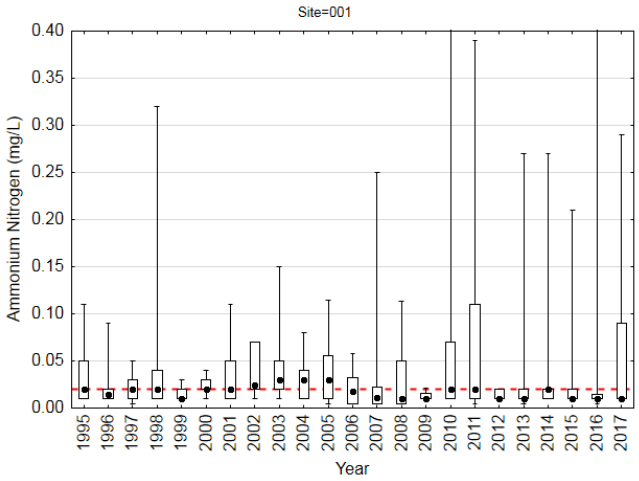
Total Nitrogen (mg/L)
Year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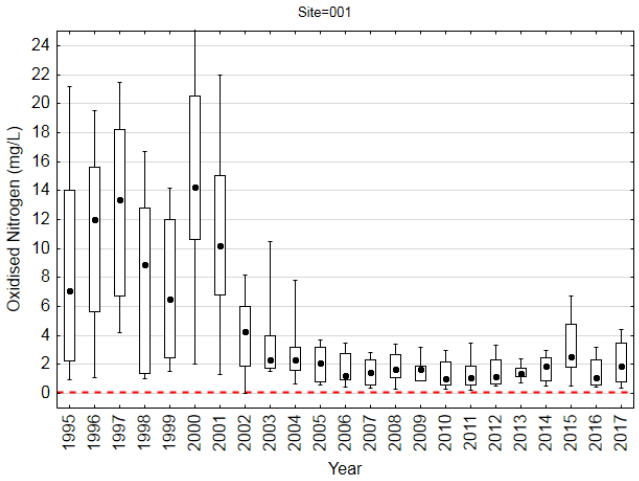
Ammonium Nitrogen (mg/L)
Year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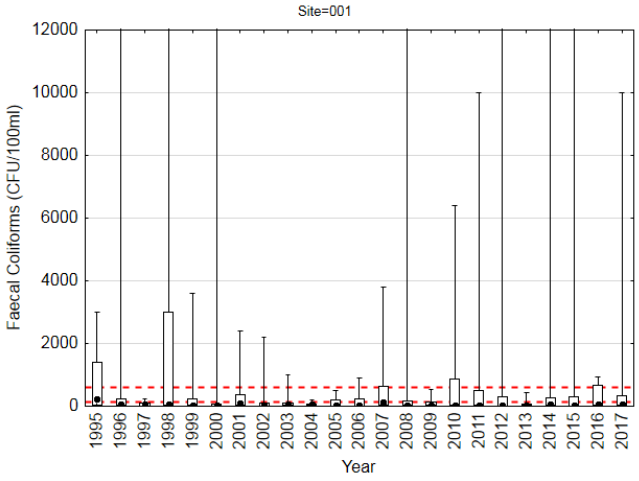
Oxidised Nitrogen (mg/L)
Year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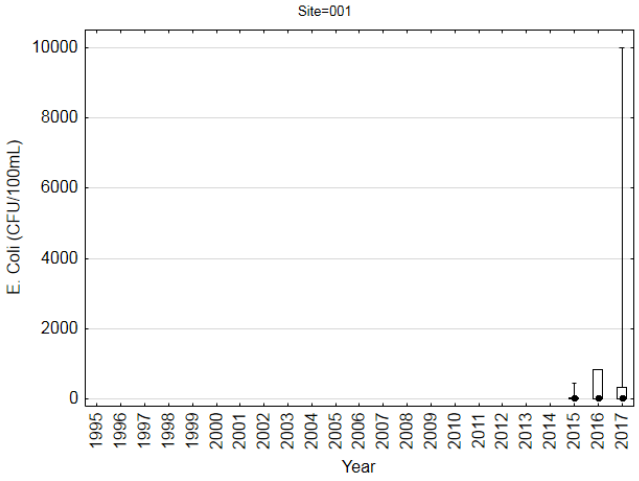
Faecal Coliforms (CFU/100ml)
Year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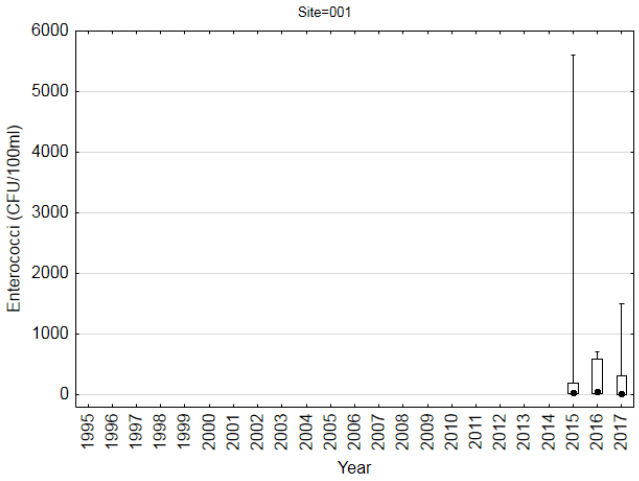
E. Coli (CFU/100mL)
Year


Site=001
Enterococci (CFU/100ml)
Year

Site 002 – Tunks Creek, Galston Gorge

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (002)	Oct 1994 – Sept 2017	Monthly
Ecohealth (TUNK1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated and often exceeds REHVs. EC is generally low but exceeds REHVs approximately 40% of the time. Clarity: Turbidity and TSS are low and consistently comply with REHVs. Nutrients: Nutrient levels are low and generally comply with REHVs. A decrease in the variability of N-based nutrients is evident post 2005. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Some influence from rural land-use in the upper catchment – Surrounding bushland and riparian zone are likely to be buffering the impacts of upstream land-use
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Protection of the bushland and riparian zone in the catchment to maintain buffering – Identify further opportunities for WSUD in the catchment – Education and collaboration with landholders to minimise impacts from rural activities

Site Photos

Tunks Creek looking upstream during high flow

Tunks Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 002

002	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	266	15.43	NA	NS	60	15.73	NA	NS
pH	4.8-7	264	7.16	71	↓	59	7.17	83	NS
DO (%sat)	75-118	248	99.10	8	↓	60	96.70	0	NS
EC (mS/cm)	0.32	265	0.30	43	↓	60	0.30	33	NS
Turbidity (NTU)	8	265	1.8	12	NS	59	1.8	12	NS
TSS (mg/L)	7	274	1	6	↓	61	1	8	NS
TP (mg/L)	0.01	274	0.010	32	↓	61	0.008	26	NS
TN (mg/L)	0.32	274	0.290	39	↓	61	0.240	15	NS
NH_3-N (mg/L)	0.02	274	0.010	5	↓	61	0.005	0	NS
NO_x-N (mg/L)	0.05	274	0.050	47	↓	61	0.040	28	NS
F.Cols (CFU/100ml)	150	274	10	12	↓	61	6	10	NS

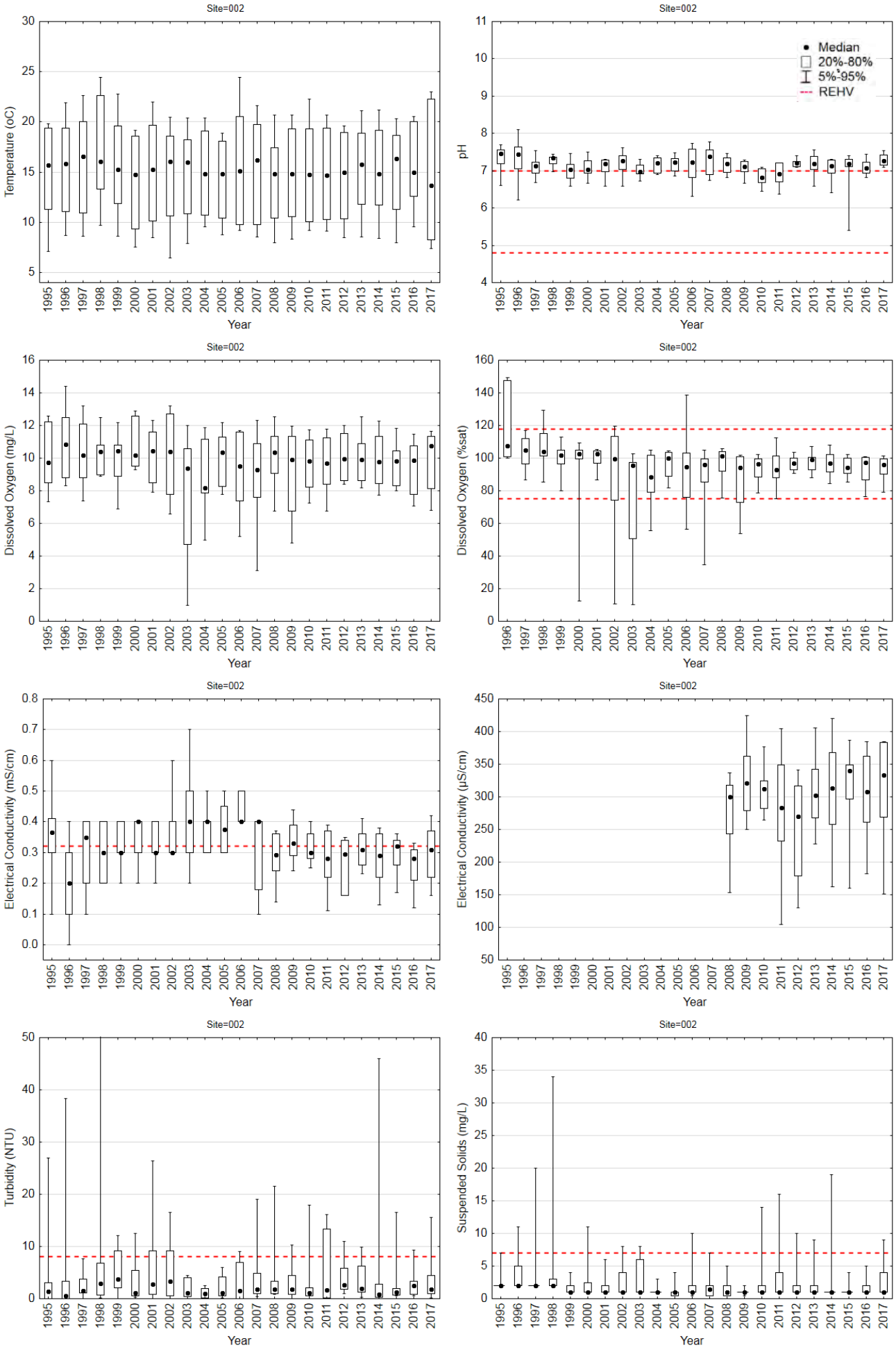
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

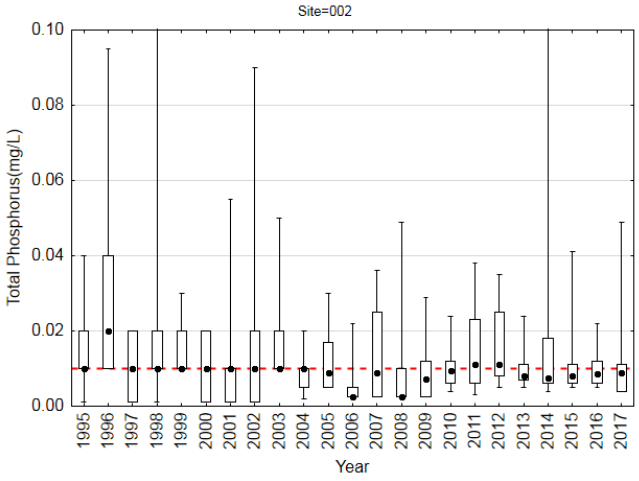
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 002 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	266	15.02	15.43	6.48	24.46	10.38	19.33	4.320
pH	264	7.13	7.16	5.40	8.10	6.92	7.35	0.298
DO (mg/L)	265	9.86	10.00	1.00	14.40	8.41	11.50	1.895
DO (%sat)	248	95.62	99.10	10.40	149.50	89.20	103.60	16.273
EC (mS/cm)	265	0.32	0.30	0.00	0.70	0.26	0.40	0.093
EC (µS/cm)	117	297.46	307.00	104.00	425.00	258.00	349.00	66.159
Turbidity (NTU)	265	4.2	1.8	0.0	81.0	0.6	4.7	8.75
TSS (mg/L)	274	2	1	1	34	1	2	3.7
TP (mg/L)	274	0.014	0.010	0.001	0.140	0.005	0.020	0.0167
TN (mg/L)	274	0.417	0.290	0.025	8.500	0.210	0.470	0.5749
NH_3-N (mg/L)	274	0.013	0.010	0.003	0.340	0.005	0.010	0.0241
NOx-N (mg/L)	274	0.157	0.050	0.005	6.500	0.020	0.160	0.4444
F.Cols (CFU/100ml)	274	130	10	0	5500	2	64	517.0
E.Coli (CFU/100ml)	20	186	6	1	3000	2	93	666.0
Entero (CFU/100ml)	32	51	13	1	720	2	50	129.7

Boxplots showing annual variability for each variable measured

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Total Phosphorus(mg/L)
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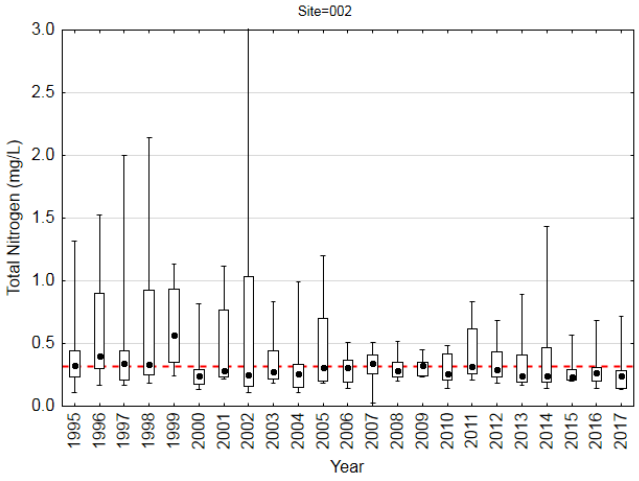
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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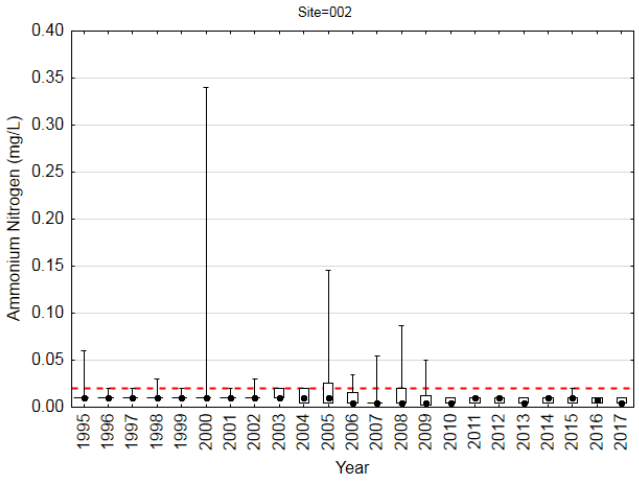
2.5
2.0
1.5
1.0
0.5
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Ammonium Nitrogen (mg/L)
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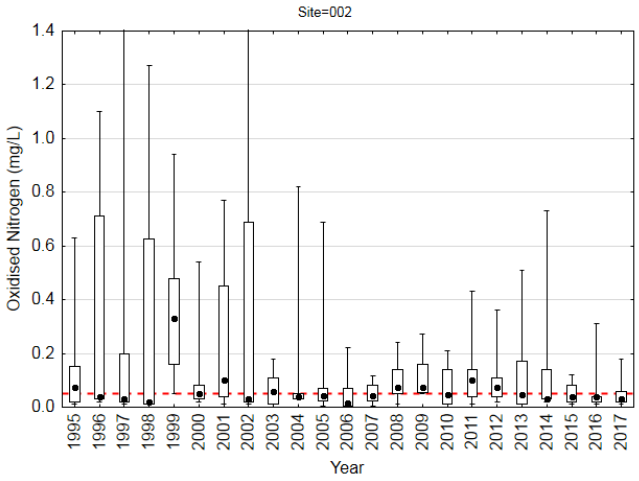
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Oxidised Nitrogen (mg/L)
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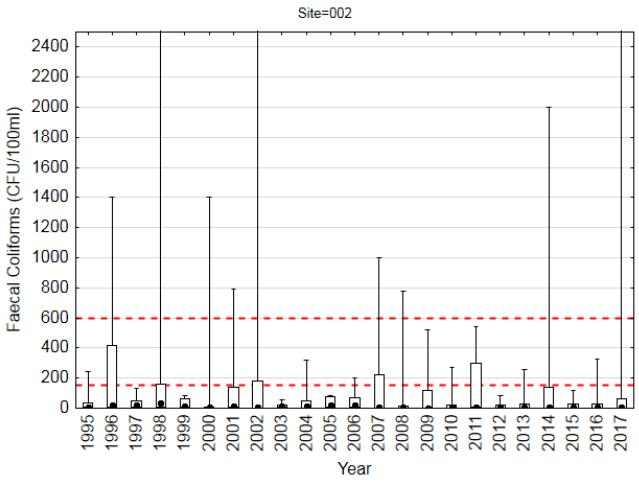
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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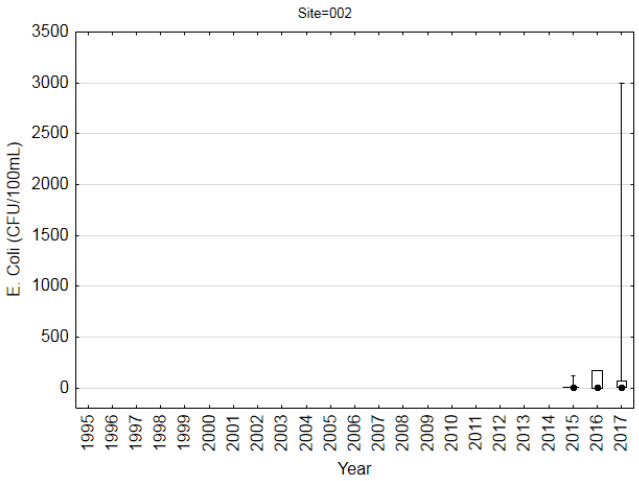
Faecal Coliforms (CFU/100ml)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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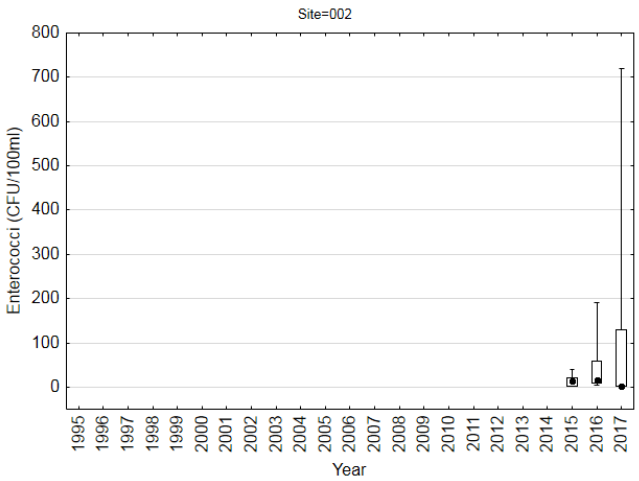
E. Coli (CFU/100mL)
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=002
Enterococci (CFU/100ml)
800
700
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 004 – Berowra Creek, Westleigh

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (004)	Oct 1994 – Sept 2017	Monthly
Ecohealth (BERO7)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated and consistently exceeds REHVs. EC is elevated and exceeds REHVs approximately 50% of the time. Clarity: Turbidity and TSS are low and generally comply with REHVs. A long-term decreasing trend in both turbidity and TSS is evident. Nutrients: TP and NOx-N are slightly elevated and consistently exceed REHVs. TN is slightly elevated and exceeds REHVs approximately 60% of the time. Long-term trends of decrease in N-based nutrients. Bacteria: Bacteria levels are generally low but variable, exceeding with REHVs approximately 40% of the time.
Issues	– Influenced by a highly urbanised catchment – Surrounding bushland and riparian zone are likely to be buffering the impacts of upstream land-use
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events – Protection of the bushland and riparian zone in the catchment to maintain buffering

Site Photos

Berowra Creek looking upstream during high flow

Berowra Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 004

004	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	257	15.01	NA	NS	60	14.95	NA	NS
pH	4.8-7	255	7.29	90	NS	59	7.34	95	↑
DO (%sat)	75-118	238	92.70	15	↓	60	88.95	25	NS
EC (mS/cm)	0.32	256	0.30	39	NS	60	0.28	32	NS
Turbidity (NTU)	8	257	3.5	30	↓	60	2.9	22	NS
TSS (mg/L)	7	269	1	10	↓	60	1	8	NS
TP (mg/L)	0.01	269	0.024	83	NS	60	0.027	92	NS
TN (mg/L)	0.32	269	0.400	73	↓	60	0.365	70	NS
NH_3-N (mg/L)	0.02	269	0.010	10	↓	60	0.010	7	NS
NO_x-N (mg/L)	0.05	269	0.170	94	↓	60	0.125	93	NS
F.Cols (CFU/100ml)	150	269	80	40	NS	60	78	42	NS

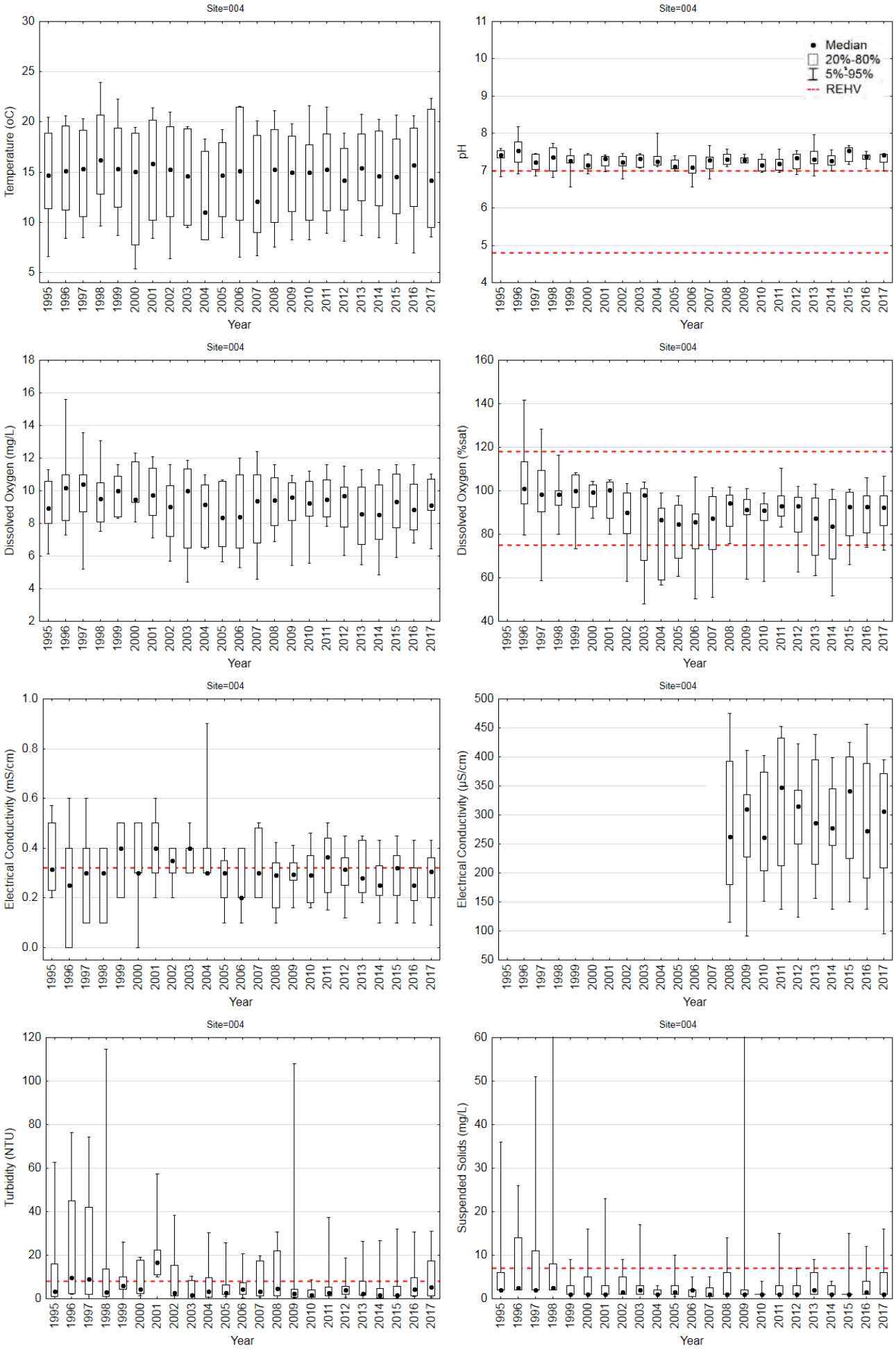
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

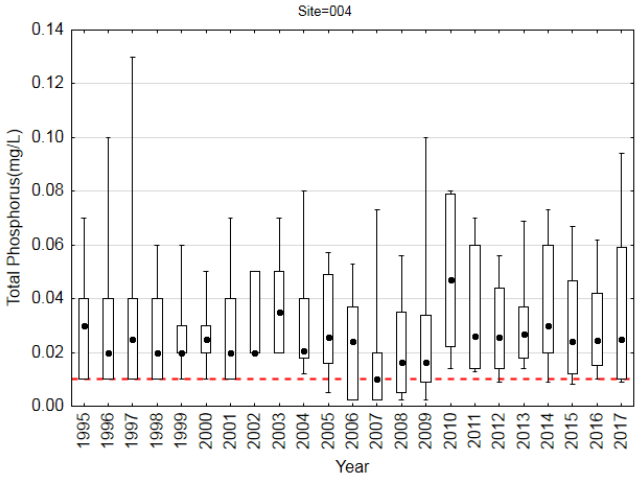
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

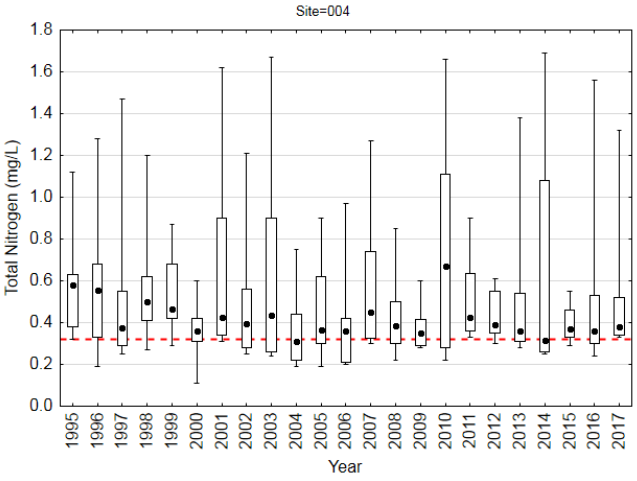
Table 2 Descriptive statistics for variables measured at Site 004 from January 1995 to September 2017

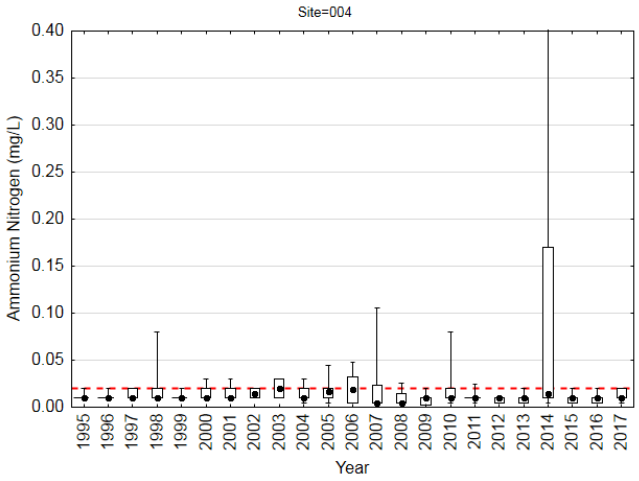
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	257	14.77	15.01	5.40	23.90	10.48	19.18	4.277
pH	255	7.29	7.29	6.57	8.19	7.11	7.45	0.222
DO (mg/L)	255	9.27	9.39	4.40	15.60	7.81	10.85	1.800
DO (%sat)	238	90.31	92.70	48.15	141.60	82.10	99.60	13.469
EC (mS/cm)	256	0.31	0.30	0.00	0.90	0.20	0.40	0.121
EC (µS/cm)	115	294.11	293.00	91.00	475.00	213.00	391.00	93.601
Turbidity (NTU)	257	9.2	3.5	0.0	114.7	1.4	15.0	15.15
TSS (mg/L)	269	4	1	1	132	1	4	11.6
TP (mg/L)	269	0.030	0.024	0.003	0.130	0.014	0.043	0.0210
TN (mg/L)	269	0.499	0.400	0.110	1.690	0.310	0.600	0.2960
NH_3-N (mg/L)	269	0.017	0.010	0.003	0.650	0.010	0.020	0.0430
NOx-N (mg/L)	269	0.247	0.170	0.010	1.500	0.090	0.316	0.2500
F.Cols (CFU/100ml)	269	1482	80	2	37000	28	920	4400.3
E.Coli (CFU/100ml)	18	1075	75	11	6400	40	2400	1896.6
Entero (CFU/100ml)	30	640	58	6	4200	27	1140	1183.9

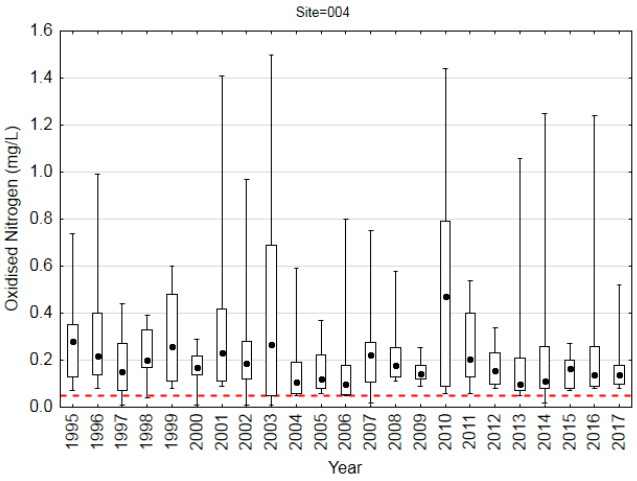
Boxplots showing annual variability for each variable measured




Site=004
Total Phosphorus(mg/L)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=004
Total Nitrogen (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=004
Ammonium Nitrogen (mg/L)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=004
Oxidised Nitrogen (mg/L)
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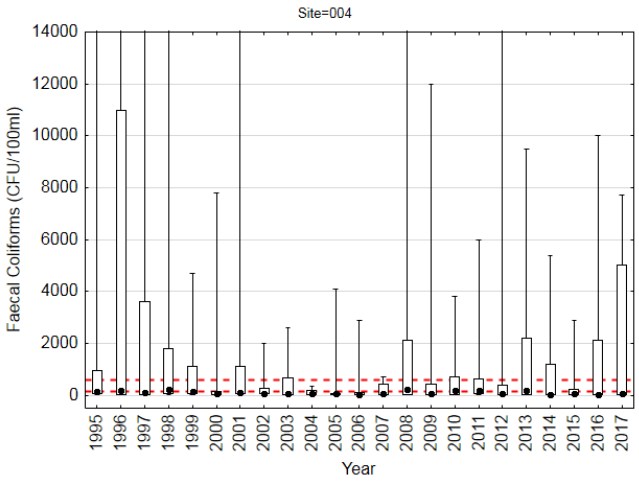
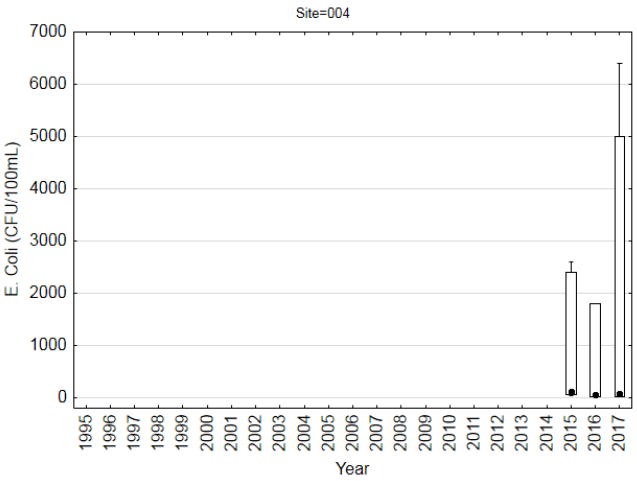
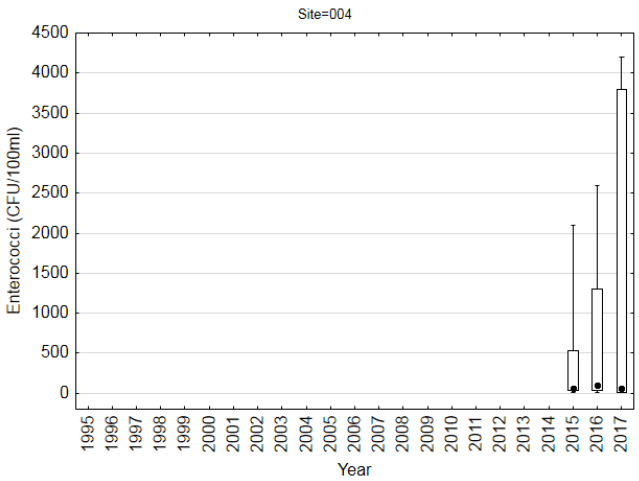
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=004
Faecal Coliforms (CFU/100ml)
14000
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=004
E. Coli (CFU/100mL)
7000
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=004
Enterococci (CFU/100ml)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 005 – Pyes Creek, Cherrybrook

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (005)	Oct 1994 – Sept 2017	Monthly
Ecohealth (PYES1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and consistently exceed REHVs. A long-term decrease in DO is evident, resulting in reduced compliance with the REHV. Clarity: Turbidity and TSS are low but variable, generally complying with REHVs. A long-term decreasing trend is evident with improved, less variable results post-2004. Nutrients: Nutrient levels are elevated and consistently exceed REHVs. Some long-term reduction in TN and NOx-N although still above REHVs. Bacteria: Bacteria levels are elevated and exceed REHVs around 50% of the time.
Issues	– Influenced by a highly urbanised catchment – Possible pressure from wastewater infrastructure
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events

Site Photos

Pyes Creek looking downstream during high flow

Pyes Creek looking downstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 005

005	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	265	15.83	NA	NS	61	15.37	NA	NS
pH	4.8-7	262	7.31	93	NS	60	7.40	100	↑
DO (%sat)	75-118	245	88.60	20	↓	61	81.20	33	NS
EC (mS/cm)	0.32	264	0.55	77	↓	61	0.49	72	NS
Turbidity (NTU)	8	265	4.9	35	↓	61	4.6	26	NS
TSS (mg/L)	7	275	2	21	↓	61	1	11	NS
TP (mg/L)	0.01	275	0.030	88	NS	61	0.040	100	NS
TN (mg/L)	0.32	275	0.770	99	↓	61	0.680	98	NS
NH_3-N (mg/L)	0.02	275	0.020	33	NS	61	0.020	30	NS
NO_x-N (mg/L)	0.05	275	0.480	96	↓	61	0.330	93	NS
F.Cols (CFU/100ml)	150	275	210	57	NS	61	220	57	NS

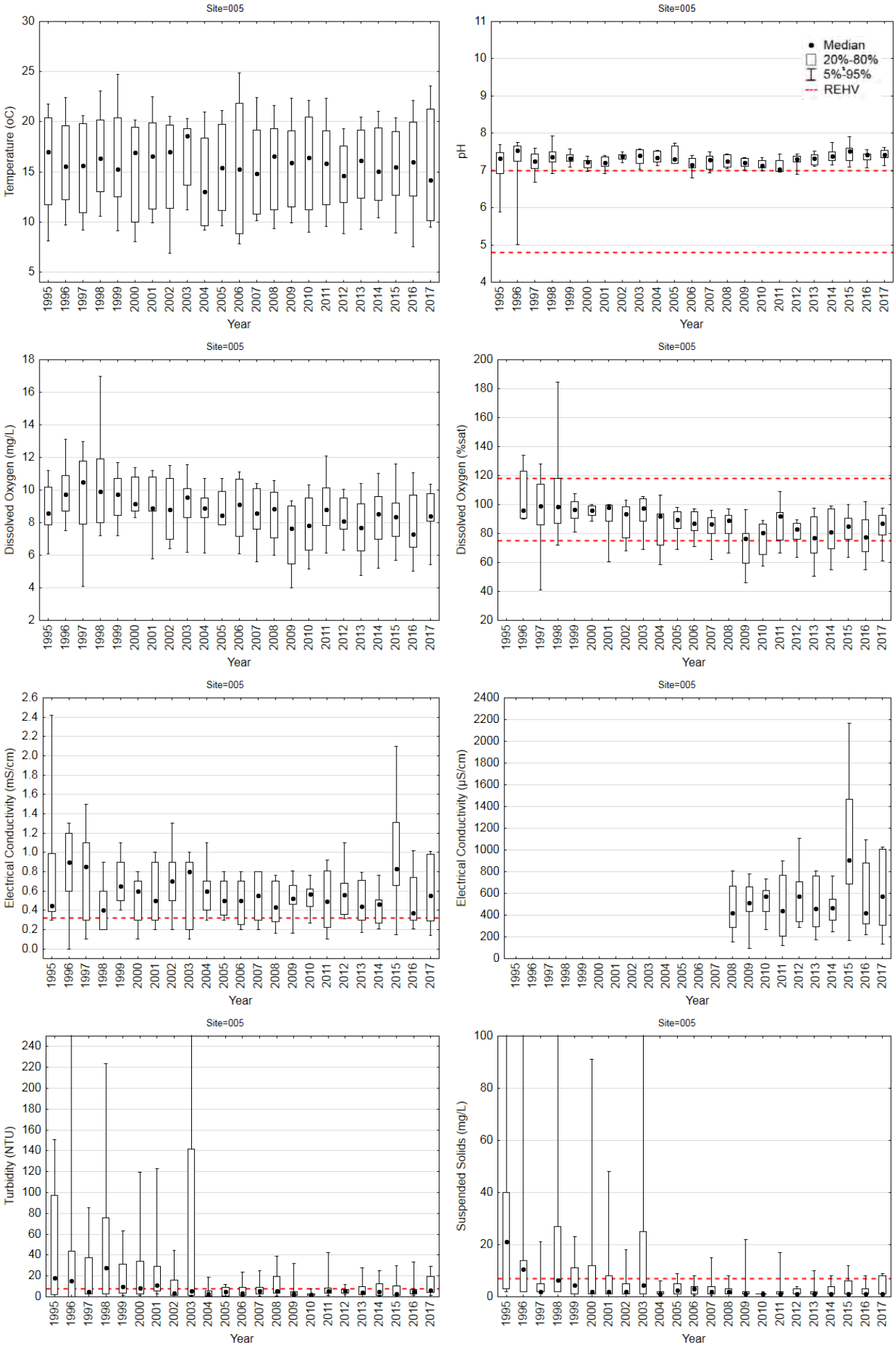
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

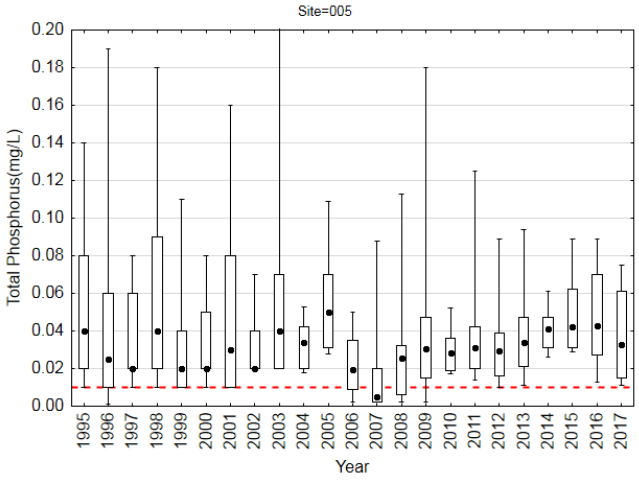
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

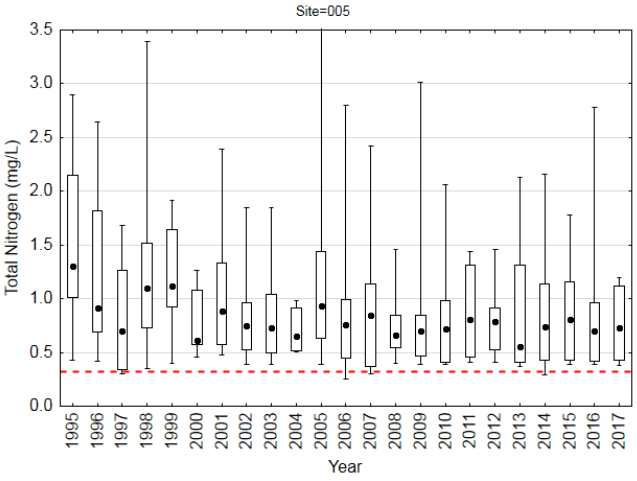
Table 2 Descriptive statistics for variables measured at Site 005 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	265	15.61	15.83	6.88	24.90	11.30	19.55	4.130
pH	262	7.29	7.31	5.02	7.90	7.13	7.45	0.250
DO (mg/L)	263	8.77	8.80	4.00	17.00	7.50	10.20	1.770
DO (%sat)	245	87.16	88.60	41.00	184.50	76.80	97.40	15.390
EC (mS/cm)	264	0.60	0.55	0.00	2.40	0.30	0.81	0.330
EC (µS/cm)	117	565.13	512.00	93.00	2168.00	305.00	757.00	326.330
Turbidity (NTU)	265	17.6	4.9	0.0	600.0	2.0	18.3	48.63
TSS (mg/L)	275	10	2	1	459	1	8	45.1
TP (mg/L)	275	0.039	0.030	0.001	0.300	0.019	0.058	0.0400
TN (mg/L)	275	0.926	0.770	0.250	4.500	0.490	1.210	0.5700
NH_3-N (mg/L)	275	0.063	0.020	0.005	2.900	0.010	0.040	0.2800
NOx-N (mg/L)	275	0.558	0.480	0.010	2.700	0.190	0.820	0.4200
F.Cols (CFU/100ml)	275	2283	210	4	110000	60	1950	8287.3
E.Coli (CFU/100ml)	18	8767	350	20	110000	62	3100	26383.0
Entero (CFU/100ml)	31	1183	94	22	12000	60	670	2931.3

Boxplots showing annual variability for each variable measured




Site=005
Total Phosphorus(mg/L)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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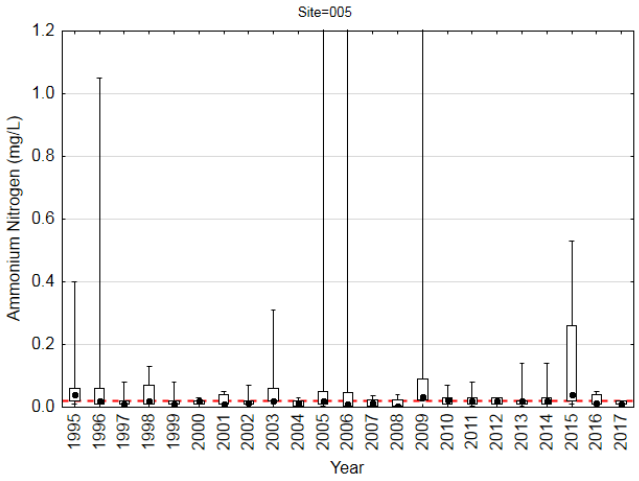
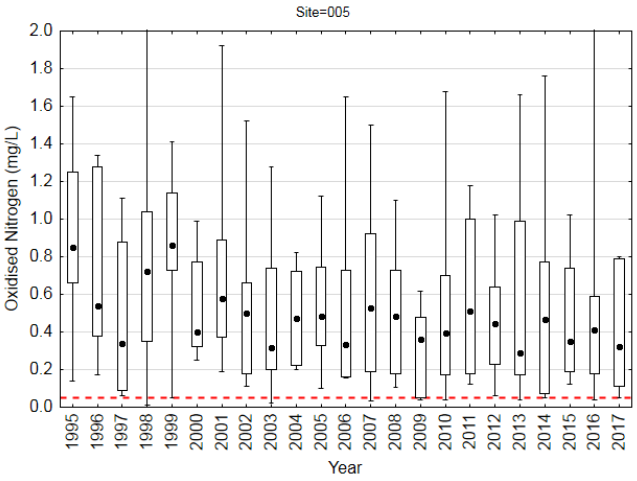
Total Nitrogen (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=005
Ammonium Nitrogen (mg/L)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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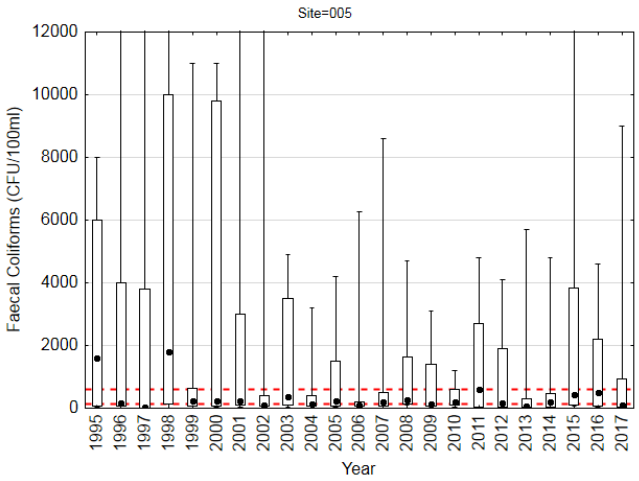
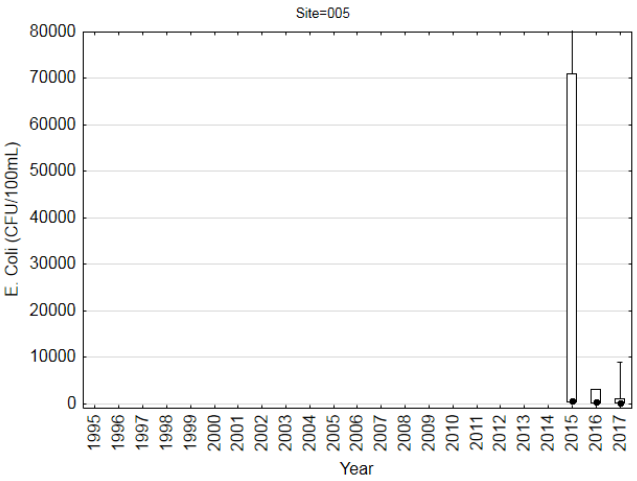
Oxidised Nitrogen (mg/L)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=005
Faecal Coliforms (CFU/100ml)
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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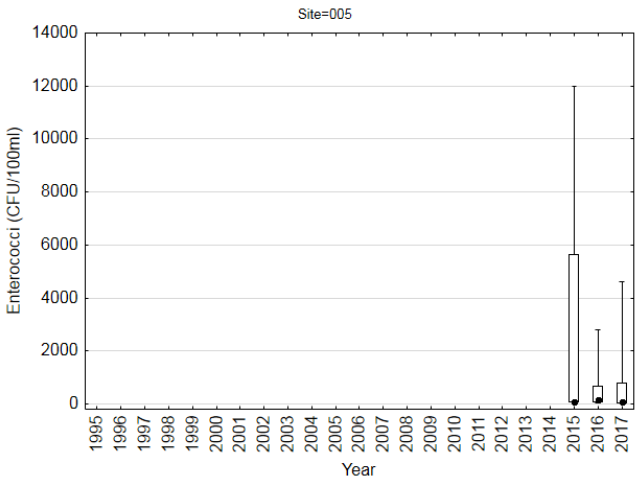
E. Coli (CFU/100mL)
80000
70000
60000
50000
40000
30000
20000
10000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Enterococci (CFU/100ml)
14000
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 006 – Georges Creek, Cherrybrook

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (006)	Oct 1994 – Sept 2017	Monthly
Ecohealth (GEOR1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated with pH consistently exceeding REHVs. A long-term decreasing trend in EC is evident. Clarity: Turbidity and TSS are low and generally comply with REHVs. A long-term decreasing trend is evident with improved, less variable results post-2004. Nutrients: TN and TP are elevated and consistently exceed REHVs. A weak long-term improvement in N-based nutrients is evident. Bacteria: Bacteria levels are slightly elevated and variable, exceeding REHVs approximately 50% of the time.
Issues	– Influenced by changing primary land-use from traditionally rural to more intensified urban development in the catchment – Possible pressure from wastewater infrastructure – Potential for results to be locally influenced by infrastructure associated with the sewage pumping station adjacent to the site
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate the significance of local impacts and subsequently the suitability of the site for catchment health assessment – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events

Site Photos

Georges Creek looking upstream during high flow

Georges Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 006

006	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	261	15.39	NA	NS	60	15.12	NA	NS
pH	4.8-7	258	7.43	96	NS	59	7.50	100	NS
DO (%sat)	75-118	241	95.40	15	↓	60	91.75	15	NS
EC (mS/cm)	0.32	259	0.40	68	↓	60	0.35	65	NS
Turbidity (NTU)	8	261	6.0	41	↓	60	3.3	23	NS
TSS (mg/L)	7	270	2	19	↓	59	1	8	NS
TP (mg/L)	0.01	270	0.030	89	NS	59	0.029	97	NS
TN (mg/L)	0.32	270	0.520	90	↓	59	0.440	78	↑
NH_3-N (mg/L)	0.02	270	0.010	21	↓	59	0.010	10	NS
NO_x-N (mg/L)	0.05	270	0.170	75	↓	59	0.090	63	↑
F.Cols (CFU/100ml)	150	270	80	40	NS	59	180	51	NS

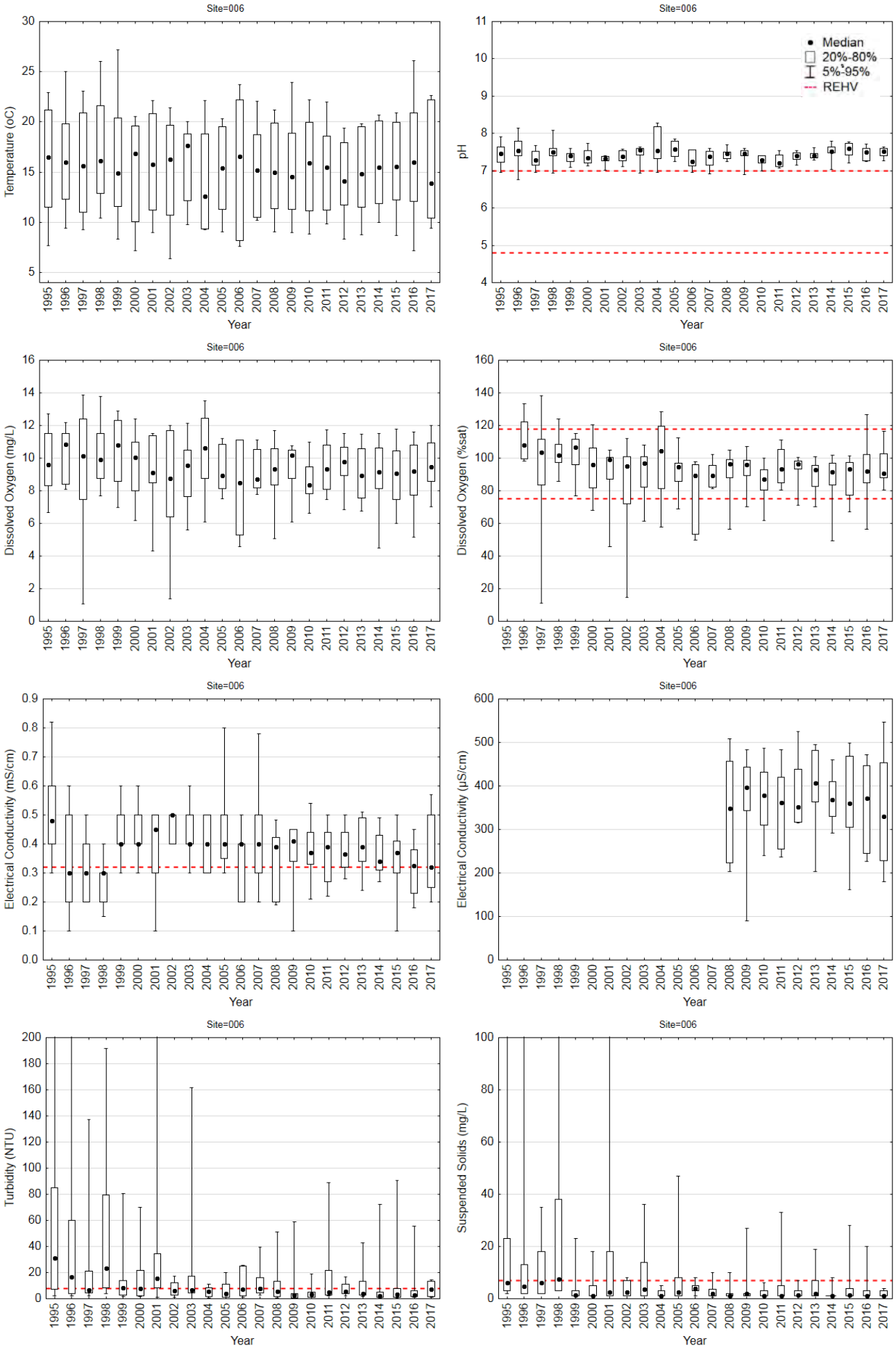
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

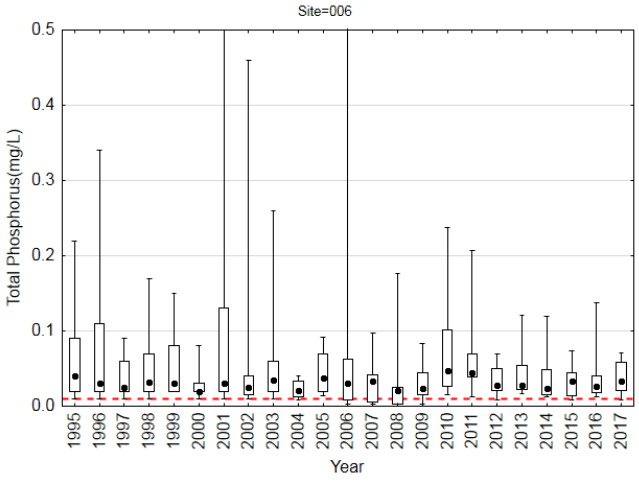
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

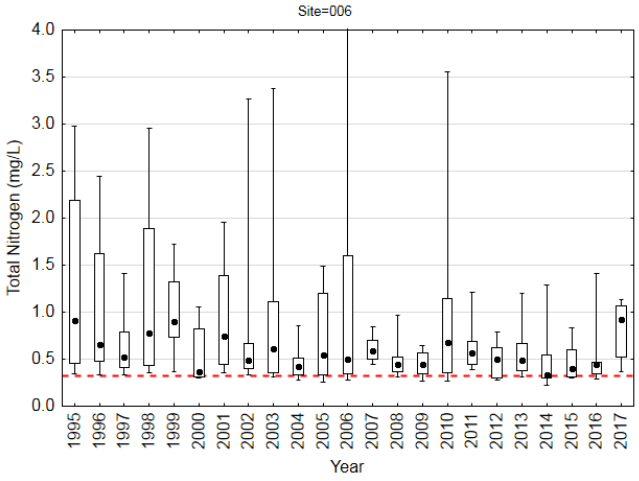
Table 2 Descriptive statistics for variables measured at Site 006 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	261	15.50	15.39	6.36	27.00	11.22	19.91	4.400
pH	258	7.42	7.43	6.77	8.00	7.25	7.58	0.200
DO (mg/L)	259	9.40	9.45	1.05	14.00	8.00	11.10	1.900
DO (%sat)	241	93.05	95.40	11.05	138.00	84.65	102.10	16.000
EC (mS/cm)	259	0.38	0.40	0.10	1.00	0.30	0.50	0.100
EC (µS/cm)	115	365.60	369.00	90.00	546.00	296.50	448.50	87.900
Turbidity (NTU)	261	22.1	6.0	0.0	600.0	2.3	19.9	64.40
TSS (mg/L)	270	9	2	1	423	1	6	35.0
TP (mg/L)	270	0.049	0.030	0.003	1.000	0.020	0.062	0.1000
TN (mg/L)	270	0.743	0.520	0.220	7.000	0.360	0.930	0.7000
NH_3-N (mg/L)	270	0.080	0.010	0.003	7.000	0.010	0.025	0.5000
NOx-N (mg/L)	270	0.280	0.170	0.001	3.000	0.030	0.485	0.3000
F.Cols (CFU/100ml)	270	8504	80	0	1900000	22	735	115888.6
E.Coli (CFU/100ml)	19	993	280	16	5400	46	2000	1548.5
Entero (CFU/100ml)	31	504	100	6	2700	46	890	762.1

Boxplots showing annual variability for each variable measured




Site=006
Total Phosphorus(mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Total Nitrogen (mg/L)
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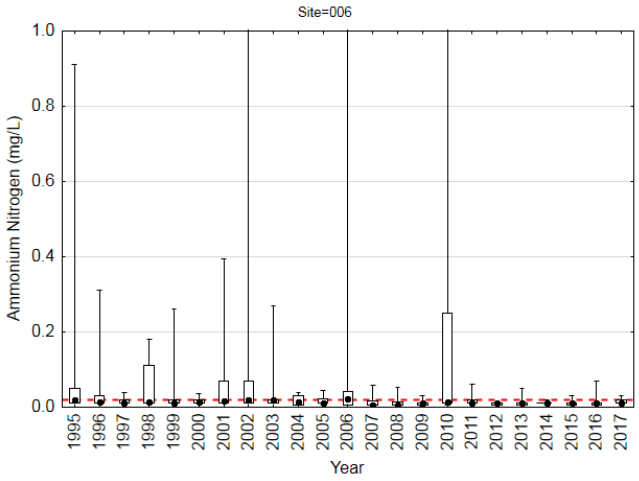
1.5
2.0
2.5
3.0
3.5
4.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Ammonium Nitrogen (mg/L)
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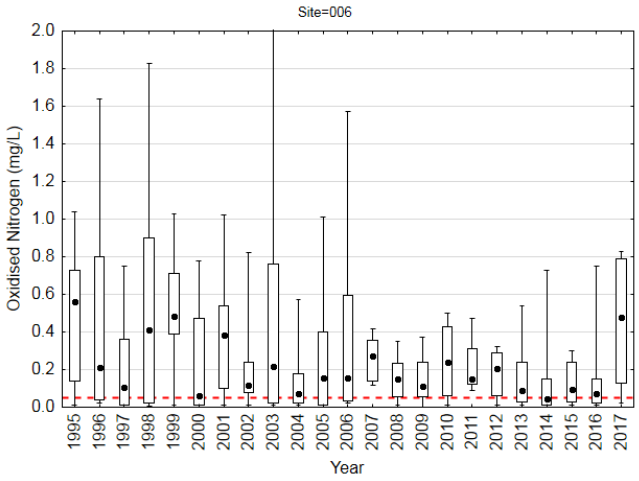
0.6
0.8
1.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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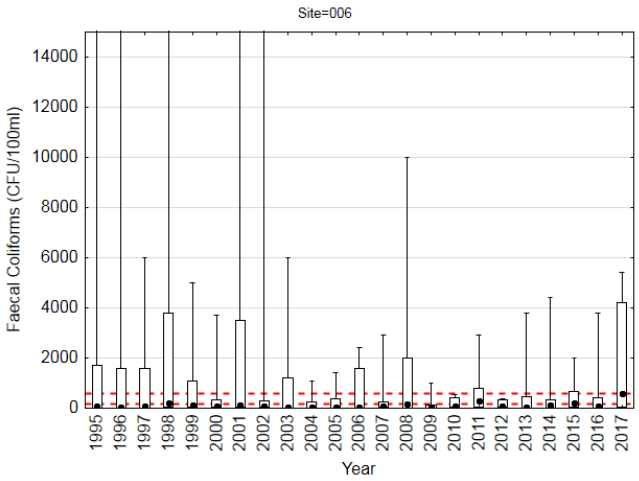
Oxidised Nitrogen (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Faecal Coliforms (CFU/100ml)
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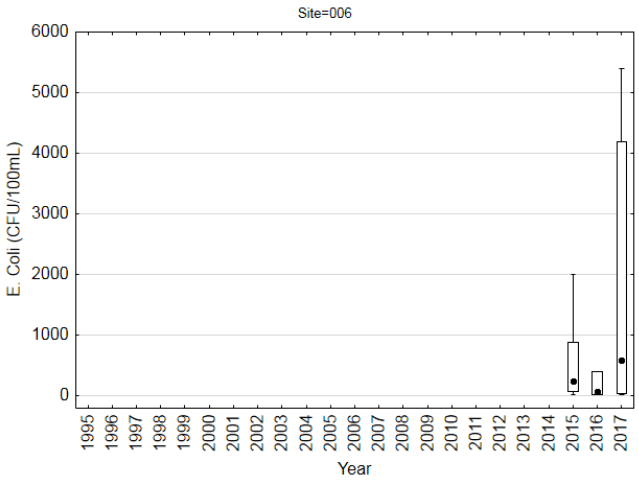
4000
6000
8000
10000
12000
14000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=006
E. Coli (CFU/100mL)
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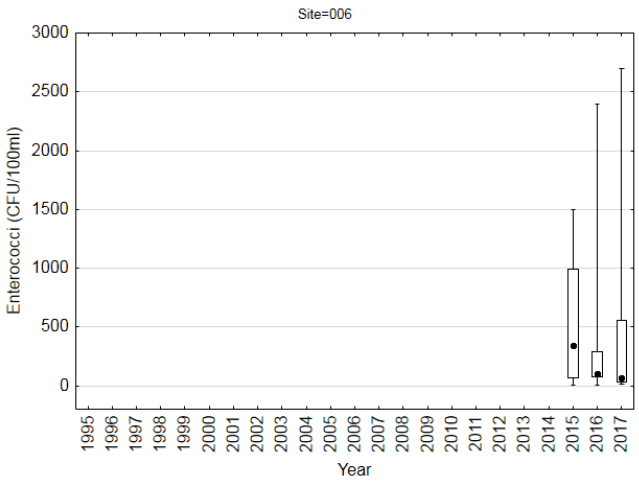
1000
2000
3000
4000
5000
6000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=006
Enterococci (CFU/100ml)
0
500
1000
1500
2000
2500
3000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 008 – Devlins Creek, Cheltenham

Freshwater site
Lane Cove River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (008)	Oct 1994 – Sept 2017	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and consistently exceed REHVs. A long-term decreasing trend in EC is evident. Clarity: Turbidity and TSS are generally low but variable, with turbidity exceeding REHVs approximately 40% of the time. Nutrients: TP, TN and NOx-N levels are elevated and consistently exceed REHVs. NH_3-N is elevated and exceeds the REHV approximately 60% of the time. Bacteria: Bacteria levels are elevated and exceed REHVs approximately 70% of the time.
Issues	– Influenced by a highly urbanised catchment – Influenced by intensified development – Possible pressure from wastewater infrastructure – Catchment management is challenging with only a limited portion of the catchment within Hornsby LGA
Recommendations	– Implementation of stringent sediment and erosion control standards in the catchment – Develop a partnership with Parramatta City Council to collaboratively manage Devlins Creek – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Monitoring to cease at this location and catchment health to be monitored in partnership with Parramatta City Council

Site Photos

Devlins Creek looking upstream during high flow

Devlins Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 008

008	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	264	17.13	NA	NS	60	16.62	NA	NS
pH	4.8-7	261	7.35	95	NS	59	7.47	97	↑
DO (%sat)	75-118	245	91.50	29	↓	60	84.85	33	NS
EC (mS/cm)	0.32	263	0.50	76	↑	60	0.55	83	↑
Turbidity (NTU)	8	264	5.6	40	NS	60	6.1	37	NS
TSS (mg/L)	7	273	3	23	↓	60	3	25	NS
TP (mg/L)	0.01	273	0.038	95	NS	60	0.050	100	NS
TN (mg/L)	0.32	273	0.640	97	NS	60	0.635	98	NS
NH_3-N (mg/L)	0.02	273	0.030	59	NS	60	0.040	67	NS
NO_x-N (mg/L)	0.05	273	0.280	92	NS	60	0.240	95	NS
F.Cols (CFU/100ml)	150	273	340	68	NS	60	395	77	NS

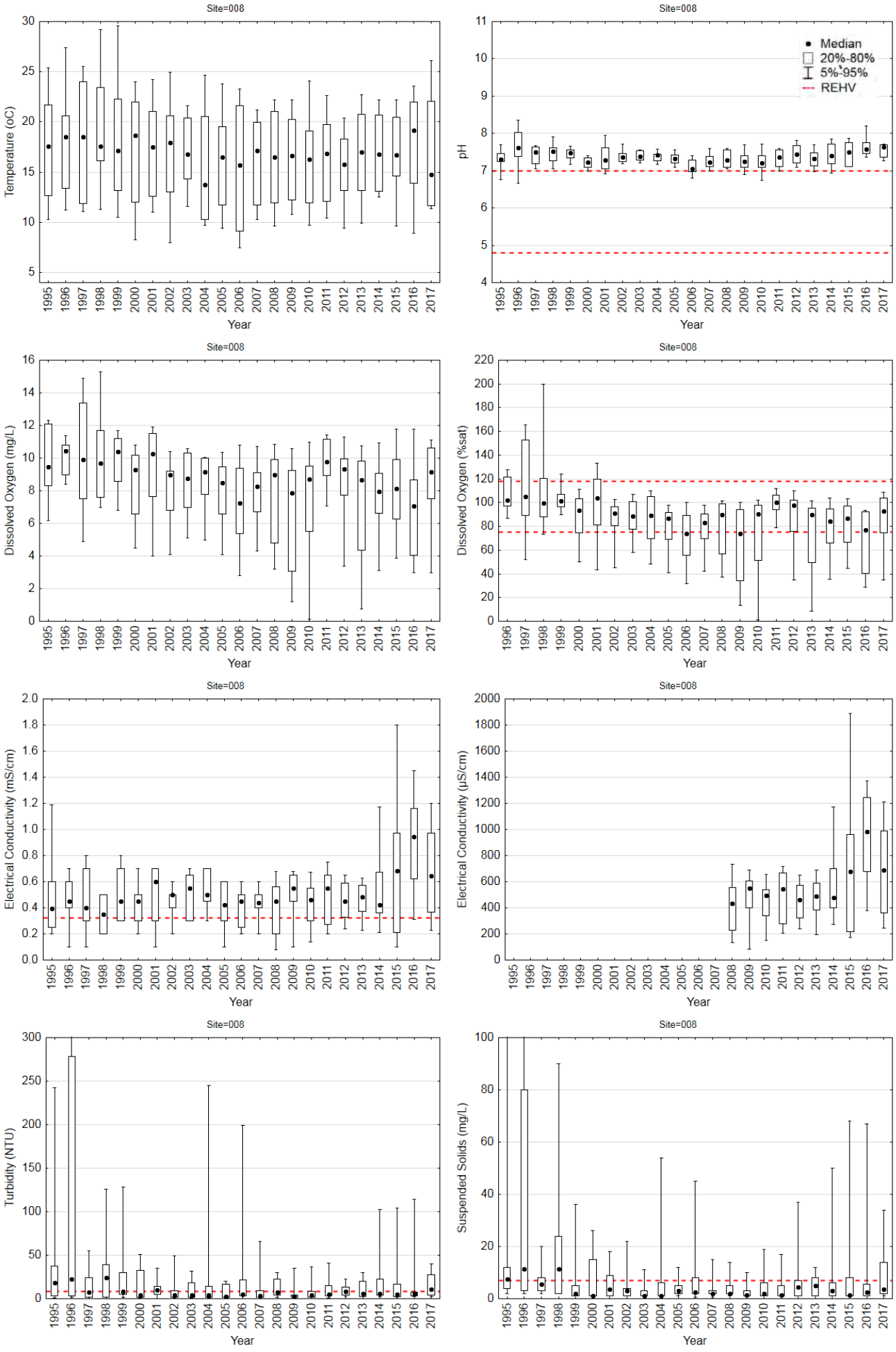
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

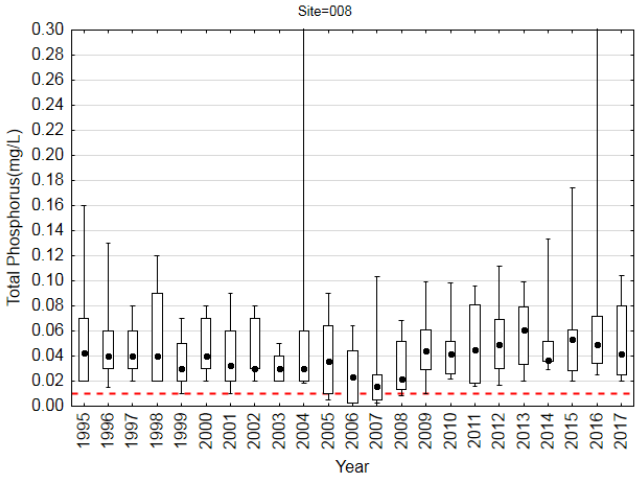
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 008 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	264	16.89	17.13	7.44	29.60	12.20	20.78	4.480
pH	261	7.37	7.35	6.67	8.40	7.17	7.58	0.250
DO (mg/L)	262	8.56	9.02	0.13	15.30	6.80	10.50	2.430
DO (%sat)	245	86.70	91.50	1.40	200.00	71.85	102.00	24.820
EC (mS/cm)	263	0.50	0.50	0.08	1.80	0.30	0.63	0.230
EC (µS/cm)	116	565.27	511.00	83.00	1889.00	349.00	702.00	289.070
Turbidity (NTU)	264	19.8	5.6	0.0	416.8	2.5	22.9	48.55
TSS (mg/L)	273	8	3	1	222	1	8	20.5
TP (mg/L)	273	0.047	0.038	0.003	0.500	0.020	0.064	0.0400
TN (mg/L)	273	0.769	0.640	0.220	7.000	0.480	0.980	0.5300
NH_3-N (mg/L)	273	0.070	0.030	0.005	5.700	0.020	0.058	0.3500
NOx-N (mg/L)	273	0.358	0.280	0.005	2.000	0.110	0.530	0.3100
F.Cols (CFU/100ml)	273	3944	340	12	400000	88	2900	24976.1
E.Coli (CFU/100ml)	19	2313	740	21	11000	170	3700	3434.2
Entero (CFU/100ml)	29	905	98	14	10000	52	1500	2089.5

Boxplots showing annual variability for each variable measured

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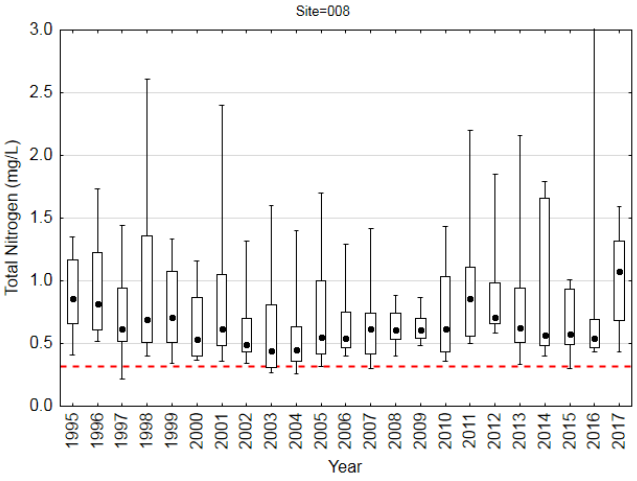
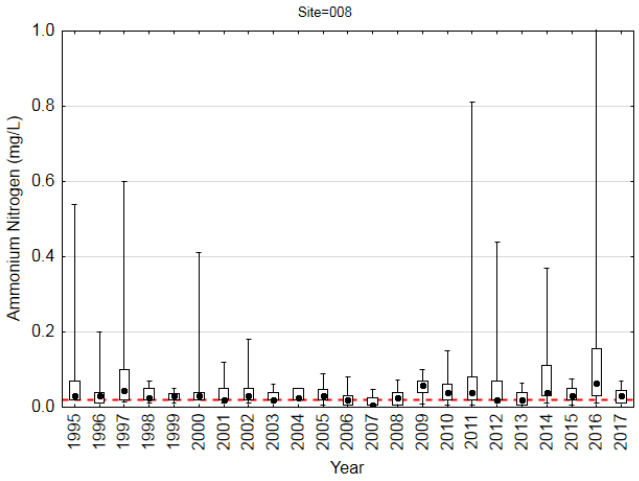
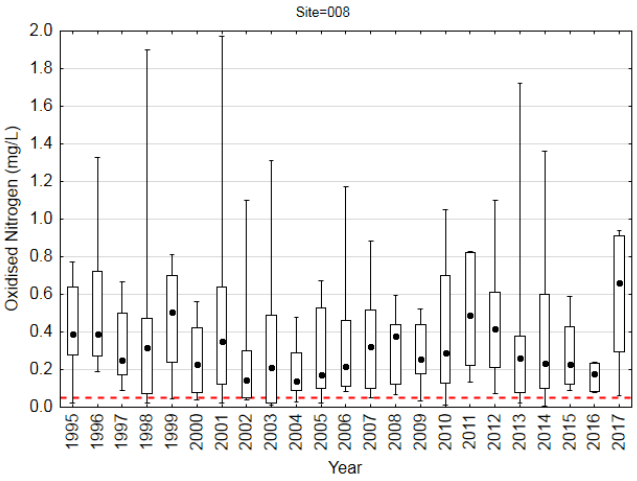
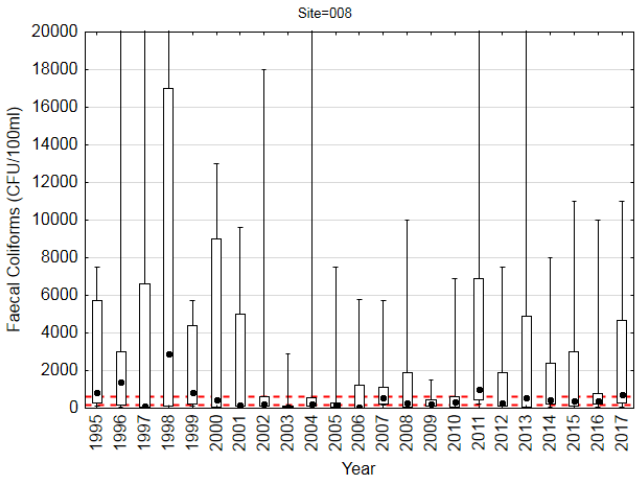
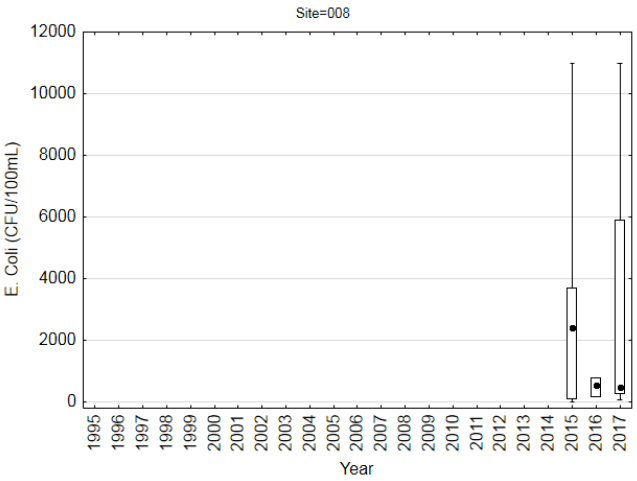
Total Phosphorus(mg/L)
Year

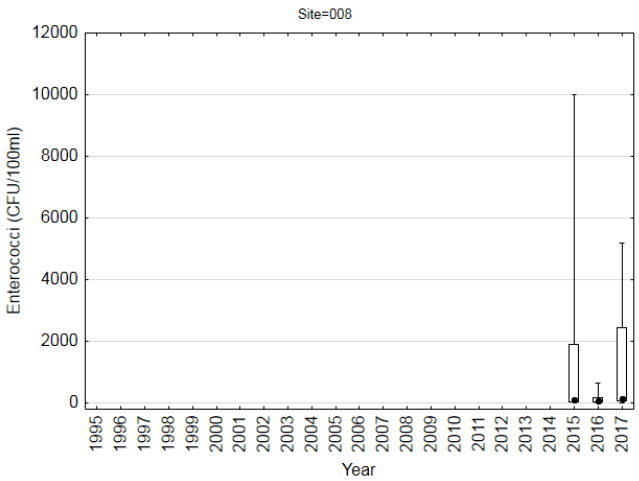

Site=008
Total Nitrogen (mg/L)
Year


Site=008
Ammonium Nitrogen (mg/L)
Year


Site=008
Oxidised Nitrogen (mg/L)
Year


Site=008
Faecal Coliforms (CFU/100ml)
Year


Site=008
E. Coli (CFU/100mL)
Year


Site=008
Enterococci (CFU/100ml)
Year

Site 010 – Larool Creek, Thornleigh

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (010)	Oct 1994 – Jun 2016	Fortnightly
	Jul 2016 – Sept 2017	Monthly
Industrial (010)	Oct 2017 ongoing	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and consistently exceed REHVs. DO is slightly suppressed and variable, complying with REHVs approximately 60% of the time. Clarity: Turbidity and TSS are slightly elevated but a long-term decreasing trend is evident. Turbidity and TSS exceed REHVs approximately 50% and 25% of the time, respectively. Nutrients: Nutrient levels are elevated and consistently exceed REHVs. Long-term trends of increase for N-based nutrients, particularly post-2012. TP has a long-term trend of decrease. Bacteria: Bacteria levels are elevated and consistently exceed REHVs. A weak long-term decreasing trend and a reduction in variability post-2012 is evident.
Issues	– Strongly influenced by industrial development in the catchment – Impacts from wastewater infrastructure – Difficulty in meeting REHVs in highly modified catchments
Recommendations	– Investigate sources of nutrients and bacteria in the catchment – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Collaboration with State Government agencies (i.e. EPA) to improve the management of industrial developments – Engage with industry to identify opportunities to reduce sources of pollutants – Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved – Maintain high sediment and erosion control standards

Site Photos

Larool Creek looking downstream during high flow

Larool Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 010

010	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	482	16.93	NA	↓	102	16.17	NA	NS
pH	4.8-7	478	7.50	94	↑	100	7.63	100	NS
DO (%sat)	75-118	443	76.50	48	NS	102	77.45	42	↓
EC (mS/cm)	0.32	481	0.70	89	NS	102	0.63	91	NS
Turbidity (NTU)	8	481	21.4	78	↓	102	8.3	51	NS
TSS (mg/L)	7	496	12	60	↓	102	4	25	NS
TP (mg/L)	0.01	496	0.083	98	↓	102	0.038	100	NS
TN (mg/L)	0.32	495	1.550	100	NS	101	1.640	100	↑
NH_3-N (mg/L)	0.02	496	0.130	87	↑	102	0.110	96	↑
NO_x-N (mg/L)	0.05	496	0.740	95	↑	102	1.135	100	↑
F.Cols (CFU/100ml)	150	496	1900	92	↓	102	775	92	NS

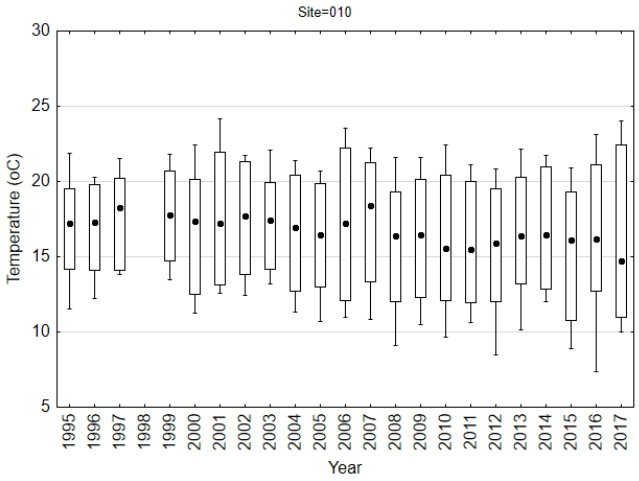
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

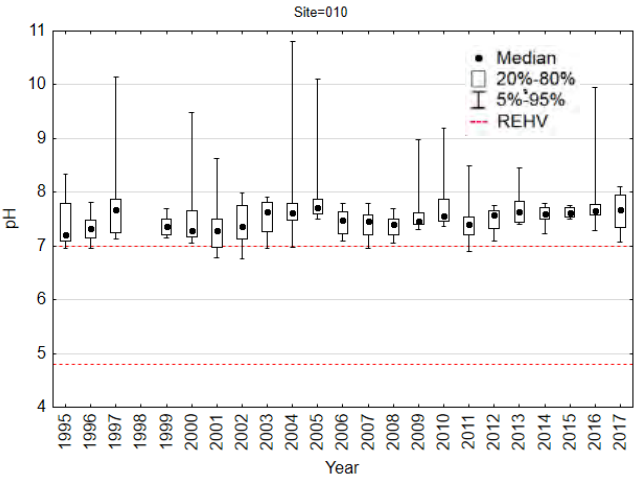
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

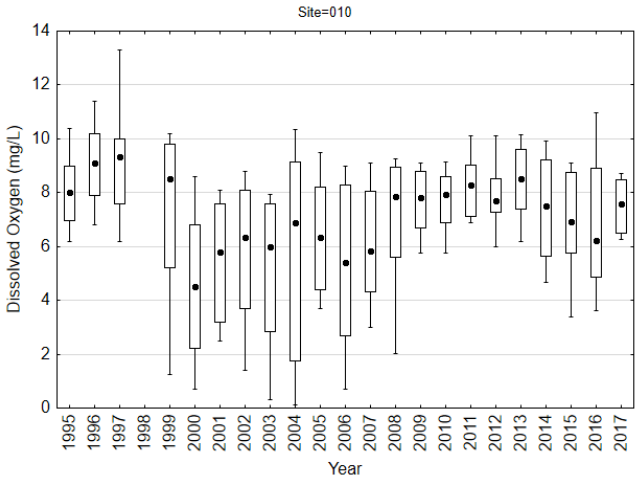
Table 2 Descriptive statistics for variables measured at Site 010 from January 1995 to September 2017

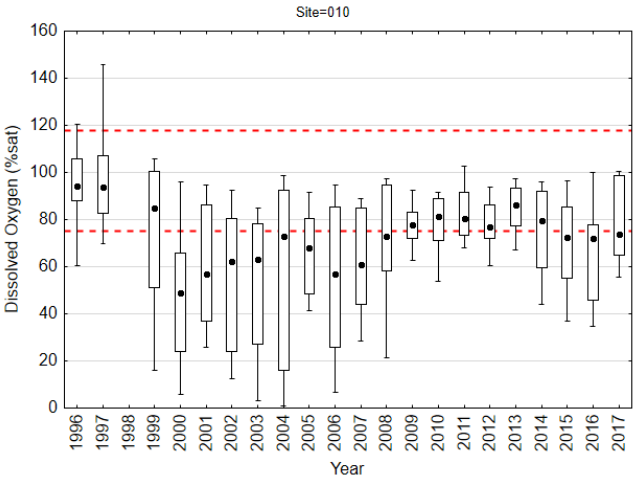
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	482	16.70	16.93	7.17	27.00	13.14	20.38	3.800
pH	478	7.59	7.50	6.00	12.00	7.27	7.73	0.600
DO (mg/L)	479	7.06	7.58	0.00	18.00	5.20	8.90	2.400
DO (%sat)	443	70.99	76.50	0.05	200.00	50.95	91.20	25.200
EC (mS/cm)	481	0.71	0.70	0.00	7.00	0.48	0.90	0.400
EC (µS/cm)	207	690.40	666.00	41.00	6272.00	433.00	847.00	482.900
Turbidity (NTU)	481	54.4	21.4	0.5	725.0	7.8	72.0	90.10
TSS (mg/L)	496	34	12	1	1390	3	38	97.0
TP (mg/L)	496	0.250	0.083	0.003	23.000	0.037	0.230	1.1000
TN (mg/L)	495	2.140	1.550	0.330	32.000	1.030	2.570	2.4000
NH_3-N (mg/L)	496	0.320	0.130	0.005	9.000	0.040	0.360	0.7000
NOx-N (mg/L)	496	0.930	0.740	0.005	18.000	0.390	1.190	1.1000
F.Cols (CFU/100ml)	496	44416	1900	0	9300000	400	13000	443390.3
E.Coli (CFU/100ml)	25	2238	680	120	22000	240	1600	4623.4
Entero (CFU/100ml)	47	1098	510	38	5800	200	1200	1485.7

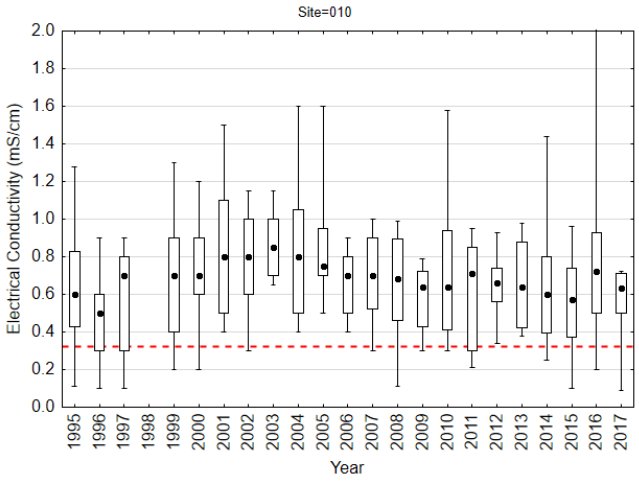
Boxplots showing annual variability for each variable measured

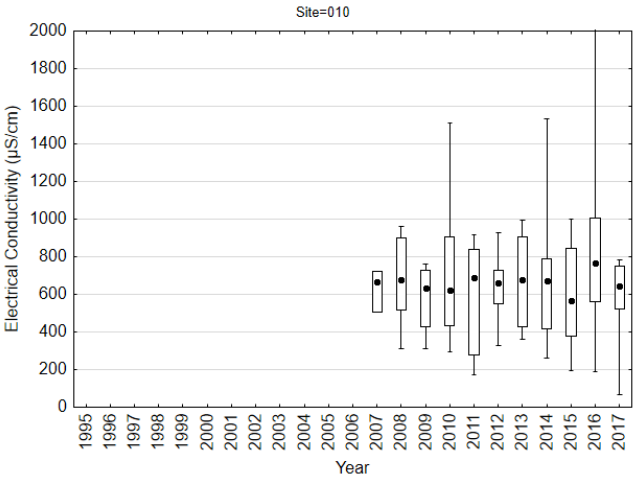


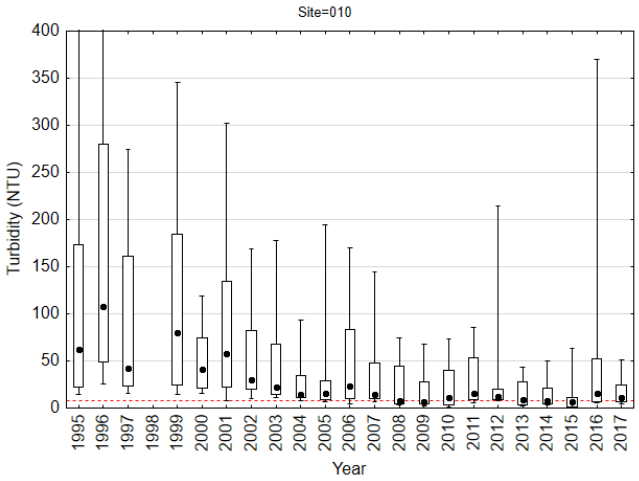


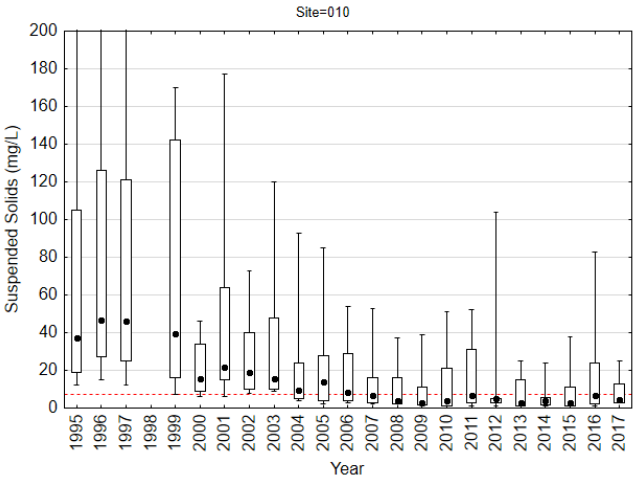


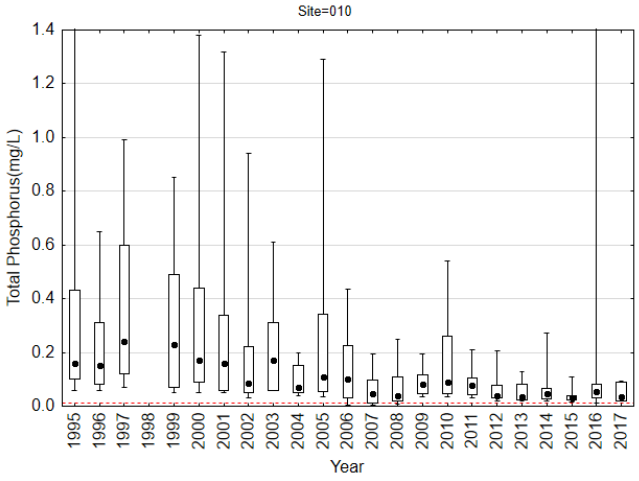


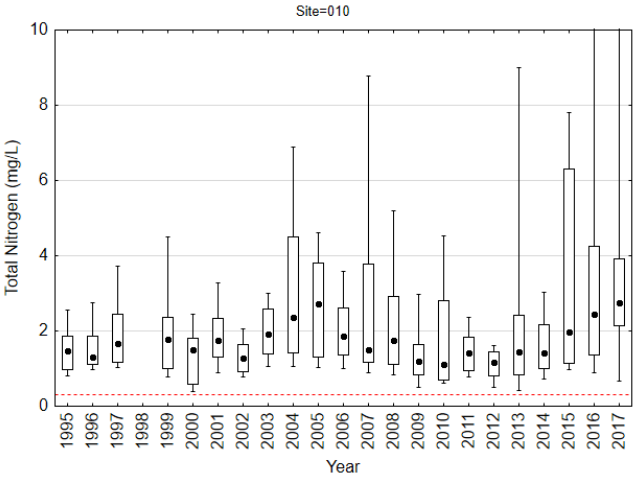









Site=010
Total Phosphorus(mg/L)
Year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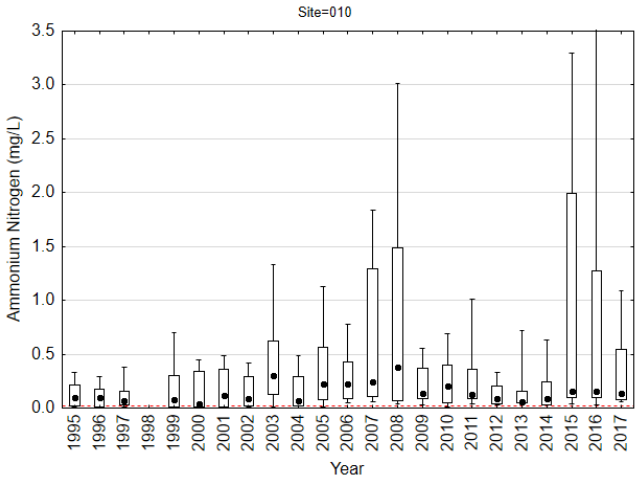
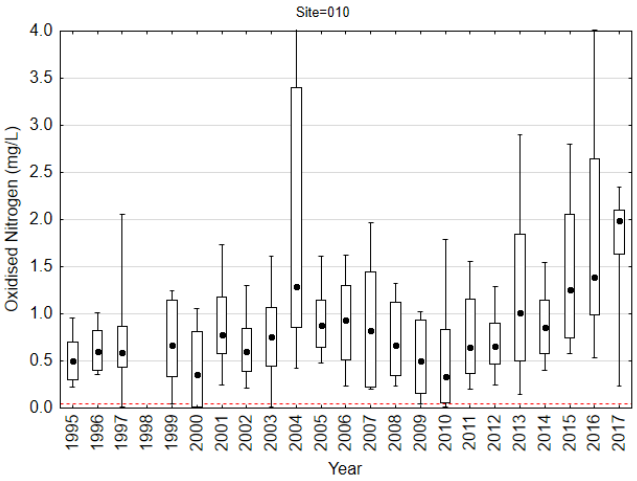
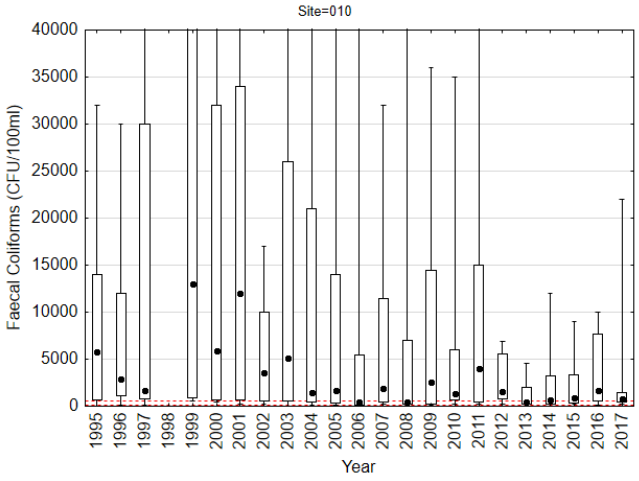
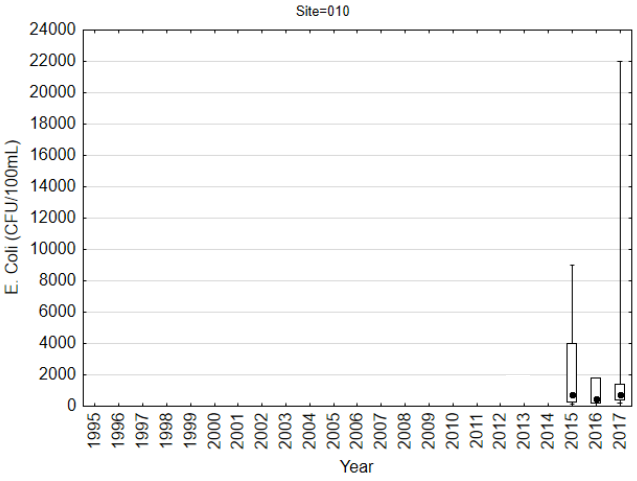
Total Nitrogen (mg/L)
Year


Site=010
Ammonium Nitrogen (mg/L)
Year


Site=010
Oxidised Nitrogen (mg/L)
Year


Site=010
Faecal Coliforms (CFU/100ml)
Year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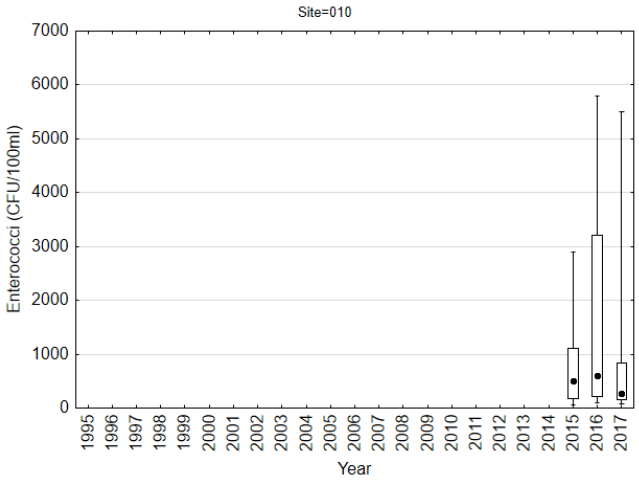
E. Coli (CFU/100mL)
Year


Site=010
Enterococci (CFU/100ml)
Year

Site 012 – Hornsby Creek, Hornsby

Freshwater site
Cowan Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (012)	Oct 1994 – Jun 2016	Fortnightly
	Jul 2016 – Sept 2017	Monthly
Industrial (012)	Oct 2017 ongoing	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated and consistently exceeds REHVs. EC is elevated but variable, exceeding REHVs around 70% of the time. DO consistently complies with REHVs following a long-term decrease with particular improvement from 2001 onwards. Clarity: Turbidity and TSS are decreasing through time and generally comply with REHVs. Nutrients: Nutrient levels are elevated, particularly NOx-N, and consistently exceed REHVs. Bacteria: Bacteria levels elevated and consistently exceed REHVs.
Issues	– Strongly influenced by industrial development in the catchment – Potential impacts from wastewater infrastructure – Difficult meeting REHVs in highly modified catchments
Recommendations	– Investigate sources of nutrients and bacteria in the catchment – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Collaboration with State Government agencies (i.e. EPA) to improve the management of industrial developments – Engage with industry to identify opportunities to reduce sources of pollutants – Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved – Maintain high sediment and erosion control standards

Site Photos

Hornsby Creek looking upstream during high flow

Hornsby Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 012

012	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	508	16.83	NA	NS	104	15.80	NA	NS
pH	4.8-7	505	7.74	98	↓	102	7.72	98	↑
DO (%sat)	75-118	469	102.10	20	↓	104	96.65	1	NS
EC (mS/cm)	0.32	507	0.40	67	NS	104	0.38	74	NS
Turbidity (NTU)	8	508	6.0	42	↓	104	4.8	36	↑
TSS (mg/L)	7	519	3	26	↓	104	2	23	NS
TP (mg/L)	0.01	520	0.058	98	↓	104	0.050	100	↑
TN (mg/L)	0.32	520	1.020	100	↑	104	0.990	100	NS
NH_3-N (mg/L)	0.02	519	0.030	62	↑	104	0.040	76	NS
NO_x-N (mg/L)	0.05	520	0.650	100	NS	104	0.655	100	NS
F.Cols (CFU/100ml)	150	519	920	93	NS	104	850	97	NS

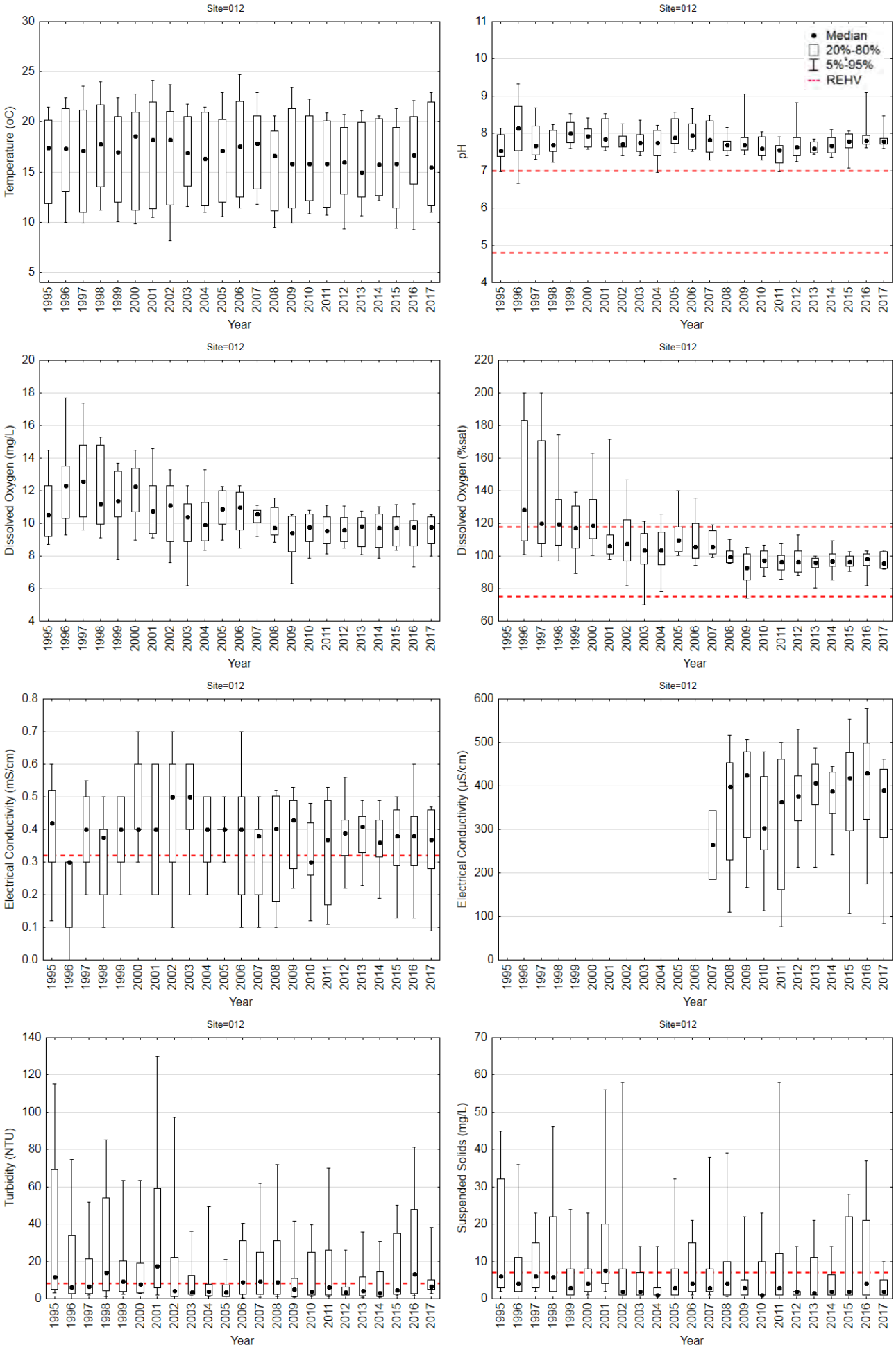
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

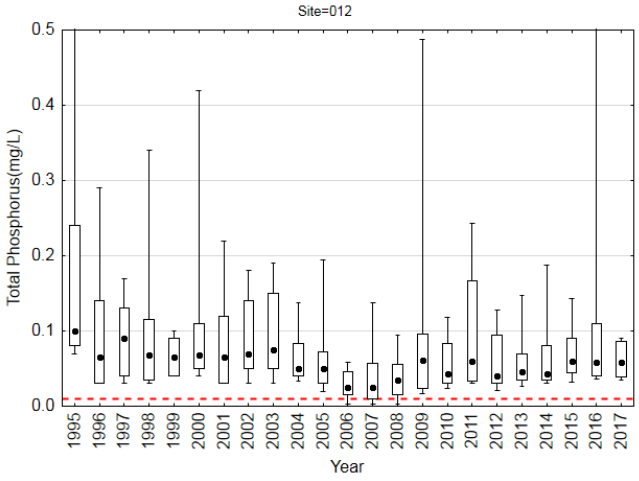
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 012 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	508	16.59	16.83	8.03	29.70	12.28	20.50	4.200
pH	505	7.81	7.74	6.50	10.00	7.53	8.04	0.410
DO (mg/L)	505	10.55	10.34	2.00	17.90	9.12	11.80	1.910
DO (%sat)	469	107.18	102.10	14.60	200.00	95.10	116.80	21.490
EC (mS/cm)	507	0.38	0.40	0.00	0.90	0.29	0.50	0.140
EC (µS/cm)	205	382.96	394.00	0.39	3850.00	277.50	451.50	268.660
Turbidity (NTU)	508	17.4	6.0	0.0	333.0	2.4	25.0	29.43
TSS (mg/L)	519	9	3	1	251	1	10	16.9
TP (mg/L)	520	0.090	0.058	0.003	1.500	0.033	0.100	0.1200
TN (mg/L)	520	1.490	1.020	0.410	26.500	0.770	1.510	1.9400
NH_3-N (mg/L)	519	0.120	0.030	0.005	7.000	0.010	0.090	0.4100
NOx-N (mg/L)	520	0.700	0.650	0.060	2.100	0.410	0.965	0.3500
F.Cols (CFU/100ml)	519	11312	920	1	800000	340	7000	49826.1
E.Coli (CFU/100ml)	26	5050	865	130	36000	520	3300	9278.8
Entero (CFU/100ml)	48	3257	240	44	110000	82	1000	15880.1

Boxplots showing annual variability for each variable measured

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Total Phosphorus(mg/L)
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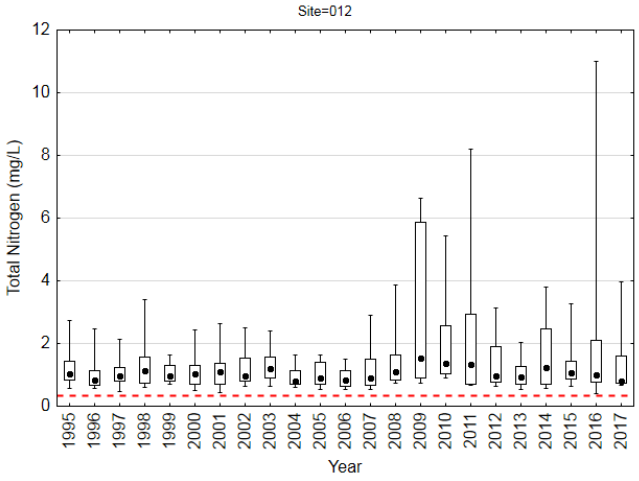
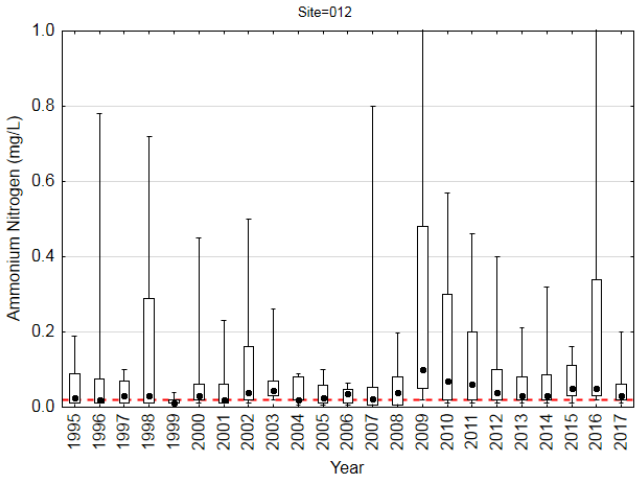
0.1
0.2
0.3
0.4
0.5
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=012
Total Nitrogen (mg/L)
0
2
4
6
8
10
12
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=012
Ammonium Nitrogen (mg/L)
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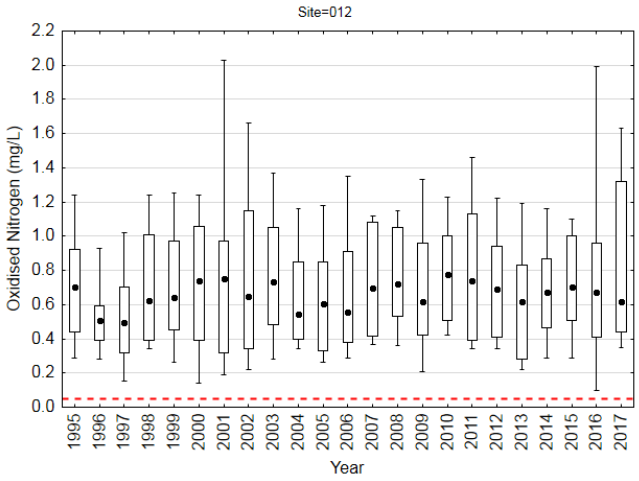
0.4
0.6
0.8
1.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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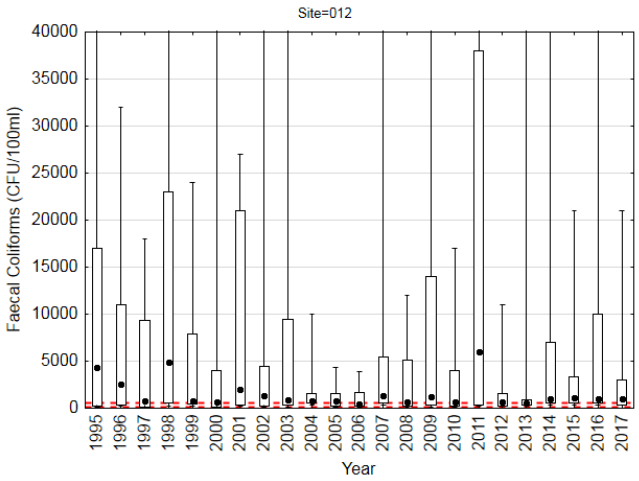
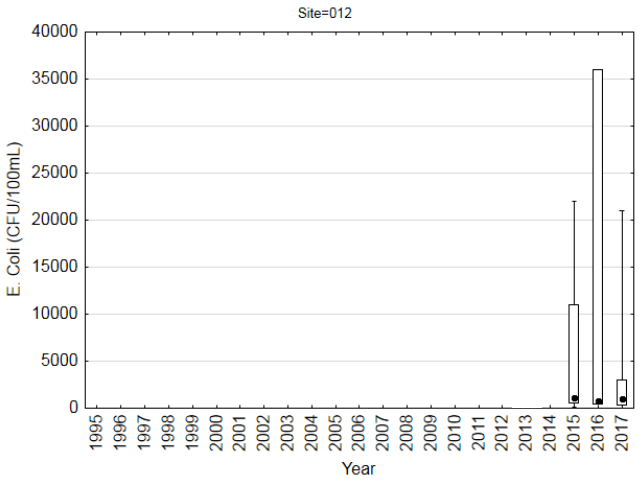
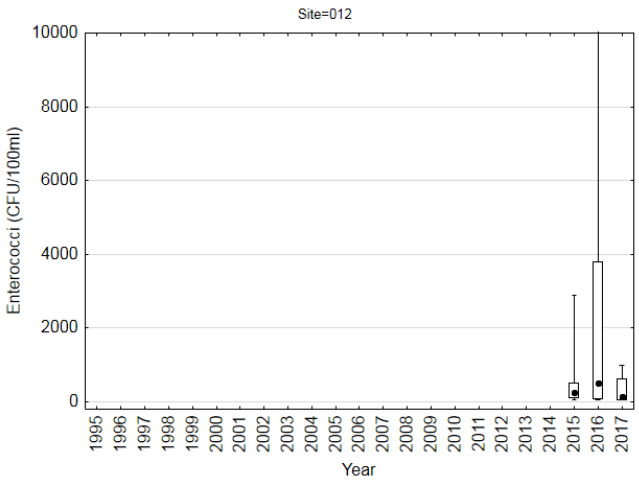
Oxidised Nitrogen (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=012
Faecal Coliforms (CFU/100ml)
0
5000
10000
15000
20000
25000
30000
35000
40000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=012
E. Coli (CFU/100mL)
0
5000
10000
15000
20000
25000
30000
35000
40000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=012
Enterococci (CFU/100ml)
0
2000
4000
6000
8000
10000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 013 – Sams Creek, Mount Kuring-gai

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (013)	Oct 1994 – Jun 2016	Fortnightly
	Jul 2016 – Sept 2017	Monthly
Industrial (013)	Oct 2017 ongoing	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated and consistently exceeds REHVs. DO is slightly suppressed only complying with REHVs approximately 50% of the time. Clarity: Turbidity and TSS are low and generally compliant with REHVs. Long-term decreasing trend with particular improvement evident after 2012. Nutrients: Nutrients are elevated and consistently exceed REHVs despite a long-term decrease, particularly in TP. Bacteria: Bacteria levels are slightly elevated and exceed REHVs around 50% of the time despite a long-term decreasing trend. A reduction in data variability evident after 2008.
Issues	– Strongly influenced by industrial development in the catchment – Potential impacts from wastewater infrastructure – Difficulty in meeting REHVs in highly modified catchments
Recommendations	– Investigate sources of nutrients and bacteria in the catchment – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Collaboration with State Government agencies (i.e. EPA) to improve the management of industrial developments – Engage with industry to identify opportunities to reduce sources of pollutants – Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved – Maintain high sediment and erosion control standards

Site Photos

Sams Creek looking downstream during low flow

Sams Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 013

013	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	496	16.74	NA	NS	102	16.42	NA	NS
pH	4.8-7	494	7.23	81	↓	101	7.24	90	NS
DO (%sat)	75-118	457	80.90	42	↓	102	73.75	52	NS
EC (mS/cm)	0.32	495	0.30	37	NS	102	0.29	28	NS
Turbidity (NTU)	8	496	6.9	45	↓	102	3.3	21	NS
TSS (mg/L)	7	507	4	35	↓	102	2	16	NS
TP (mg/L)	0.01	507	0.051	97	↓	102	0.030	100	↓
TN (mg/L)	0.32	507	0.610	90	↓	102	0.460	75	NS
NH_3-N (mg/L)	0.02	507	0.050	74	↓	102	0.040	71	↓
NO_x-N (mg/L)	0.05	507	0.200	85	↓	102	0.140	81	NS
F.Cols (CFU/100ml)	150	507	410	69	↓	102	210	56	NS

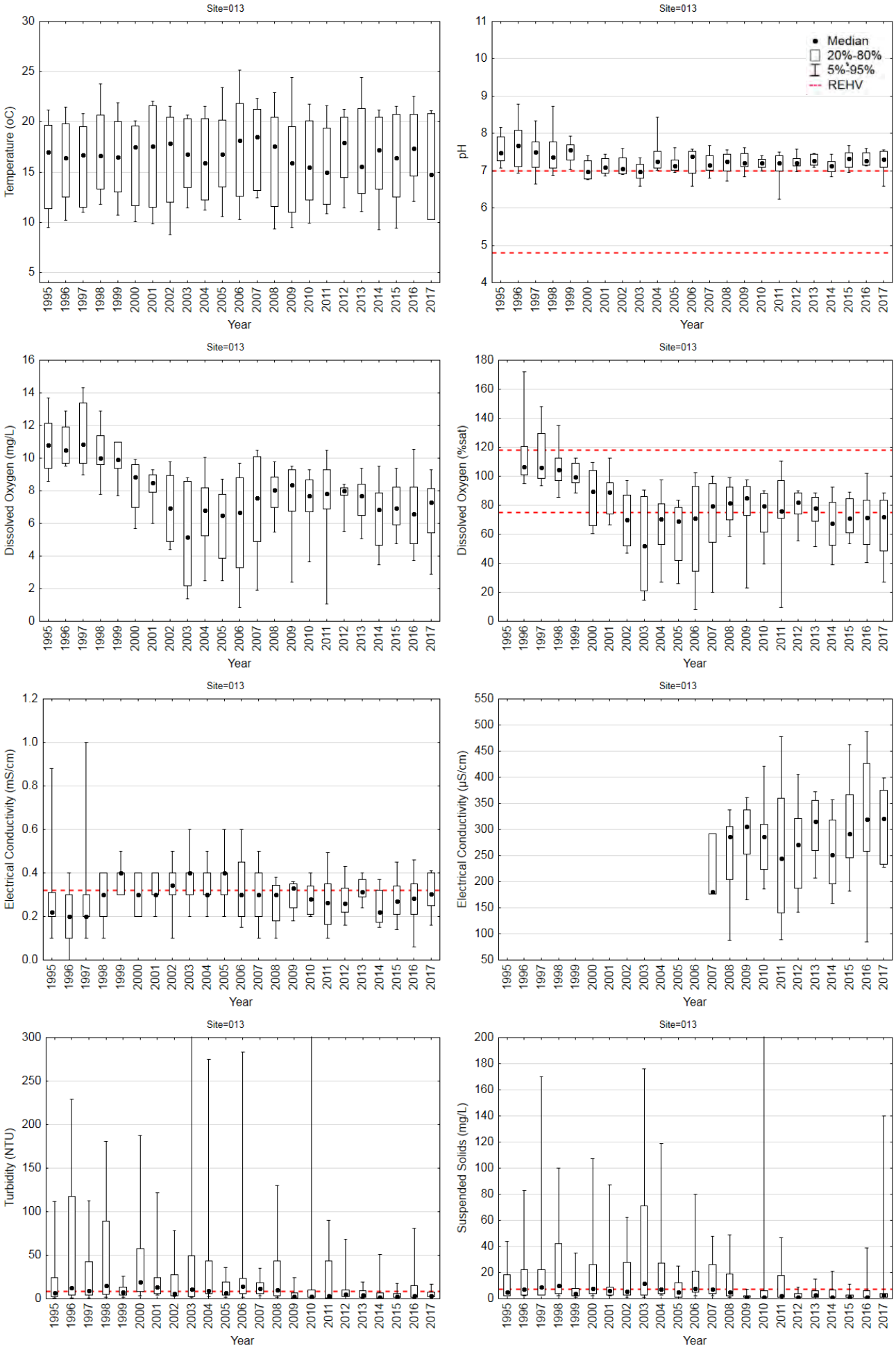
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

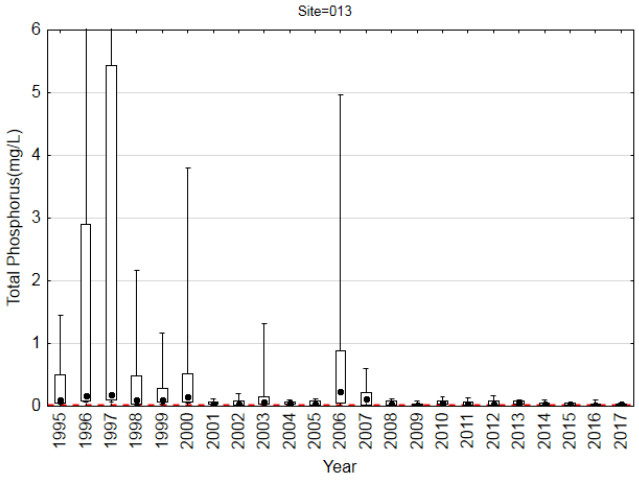
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

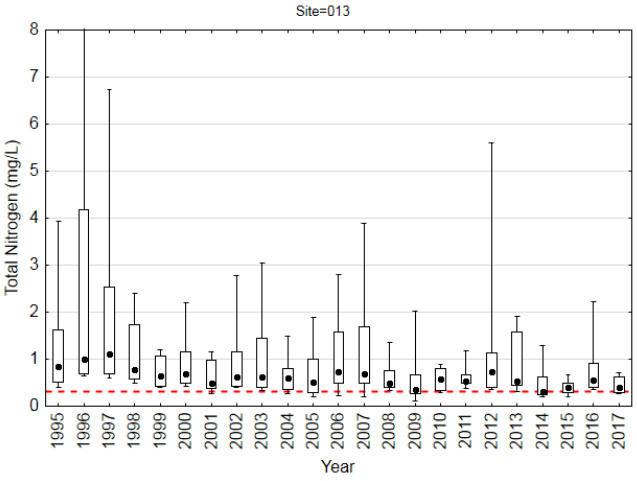
Table 2 Descriptive statistics for variables measured at Site 013 from January 1995 to September 2017

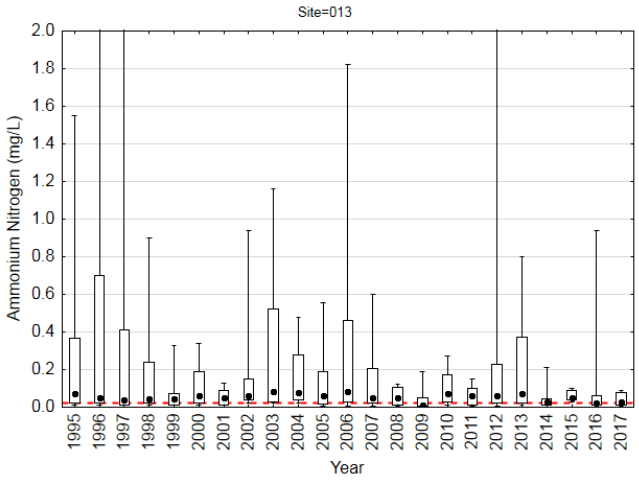
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	496	16.52	16.74	7.54	28.00	12.52	20.32	4.000
pH	494	7.28	7.23	4.05	11.00	7.01	7.48	0.400
DO (mg/L)	492	7.97	8.16	0.20	18.00	6.14	9.80	2.500
DO (%sat)	457	78.98	80.90	2.00	200.00	61.00	98.10	25.000
EC (mS/cm)	495	0.32	0.30	0.00	8.00	0.20	0.40	0.400
EC (µS/cm)	196	292.66	292.00	48.00	2840.00	217.00	340.00	201.300
Turbidity (NTU)	496	30.8	6.9	0.0	800.0	2.5	24.0	86.50
TSS (mg/L)	507	32	4	1	5460	1	14	257.7
TP (mg/L)	507	0.630	0.051	0.003	93.000	0.027	0.150	4.6000
TN (mg/L)	507	1.170	0.610	0.080	92.000	0.400	1.140	4.3000
NH_3-N (mg/L)	507	0.390	0.050	0.005	74.000	0.020	0.150	3.4000
NOx-N (mg/L)	507	0.270	0.200	0.005	2.000	0.080	0.400	0.3000
F.Cols (CFU/100ml)	507	26766	410	1	7000000	70	3600	320485.0
E.Coli (CFU/100ml)	25	537	110	1	7800	26	450	1553.8
Entero (CFU/100ml)	45	644	210	2	9000	43	600	1513.9

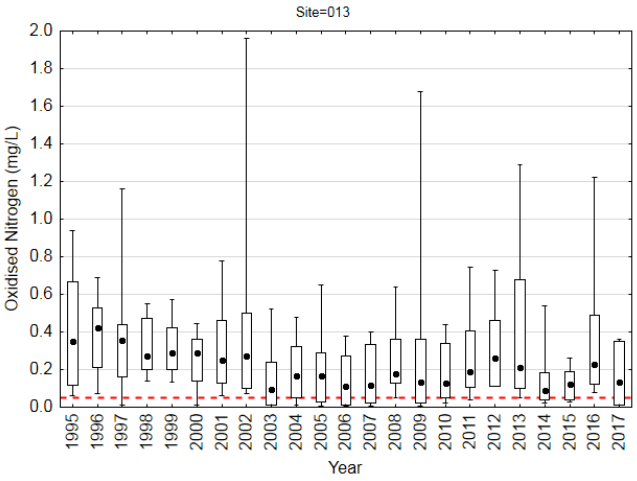
Boxplots showing annual variability for each variable measured

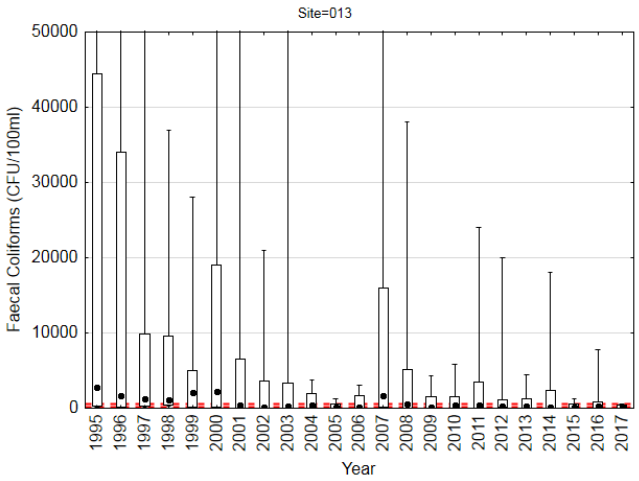


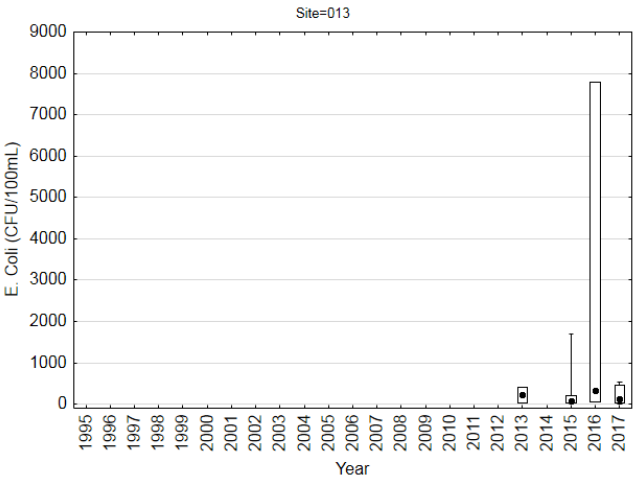

Site=013
Total Phosphorus(mg/L)
Year


Site=013
Total Nitrogen (mg/L)
Year


Site=013
Ammonium Nitrogen (mg/L)
Year


Site=013
Oxidised Nitrogen (mg/L)
Year


Site=013
Faecal Coliforms (CFU/100ml)
Year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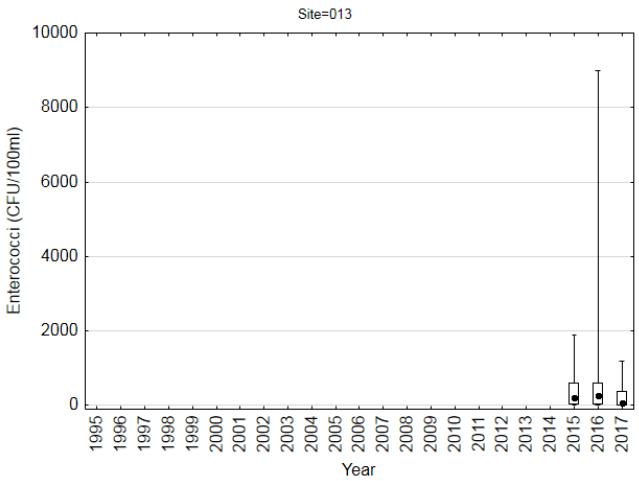
E. Coli (CFU/100mL)
Year


Site=013
Enterococci (CFU/100ml)
Year

Site 023 – Waitara Creek, Hornsby

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (023)	Oct 1994 – Sept 2017	Monthly
Targeted assessment (023)	Post management actions	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and often exceed REHVs. DO is often suppressed complying with the REHV approximately 40% of the time. Clarity: Turbidity and TSS are generally low however turbidity exceeds the REHV around 40% of the time. Nutrients: Nutrient levels are elevated and consistently exceed REHVs. Bacteria: Bacteria levels are elevated and consistently exceed REHVs.
Issues	– Influenced by a large highly urbanised catchment – Impacts from wastewater infrastructure
Recommendations	– Investigate sources of nutrients and bacteria in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Identify further opportunities for WSUD in the catchment – Targeted monitoring to assess changes following the implementation of any management actions within the catchment

Site Photos

Waitara Creek looking downstream during high flow

Waitara Creek looking downstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 023

023	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	381	16.20	NA	NS	58	16.18	NA	NS
pH	4.8-7	378	7.08	65	↓	57	7.16	70	NS
DO (%sat)	75-118	338	63.35	64	↓	58	60.10	59	NS
EC (mS/cm)	0.32	380	0.37	53	NS	58	0.29	40	NS
Turbidity (NTU)	8	380	7.6	47	NS	58	5.8	38	NS
TSS (mg/L)	7	391	4	22	NS	58	3	16	NS
TP (mg/L)	0.01	391	0.040	97	↑	58	0.050	100	NS
TN (mg/L)	0.32	391	0.520	95	NS	58	0.445	97	NS
NH_3-N (mg/L)	0.02	391	0.030	60	NS	58	0.020	36	NS
NO_x-N (mg/L)	0.05	391	0.150	73	NS	58	0.160	78	NS
F.Cols (CFU/100ml)	150	391	1100	94	NS	58	515	90	NS

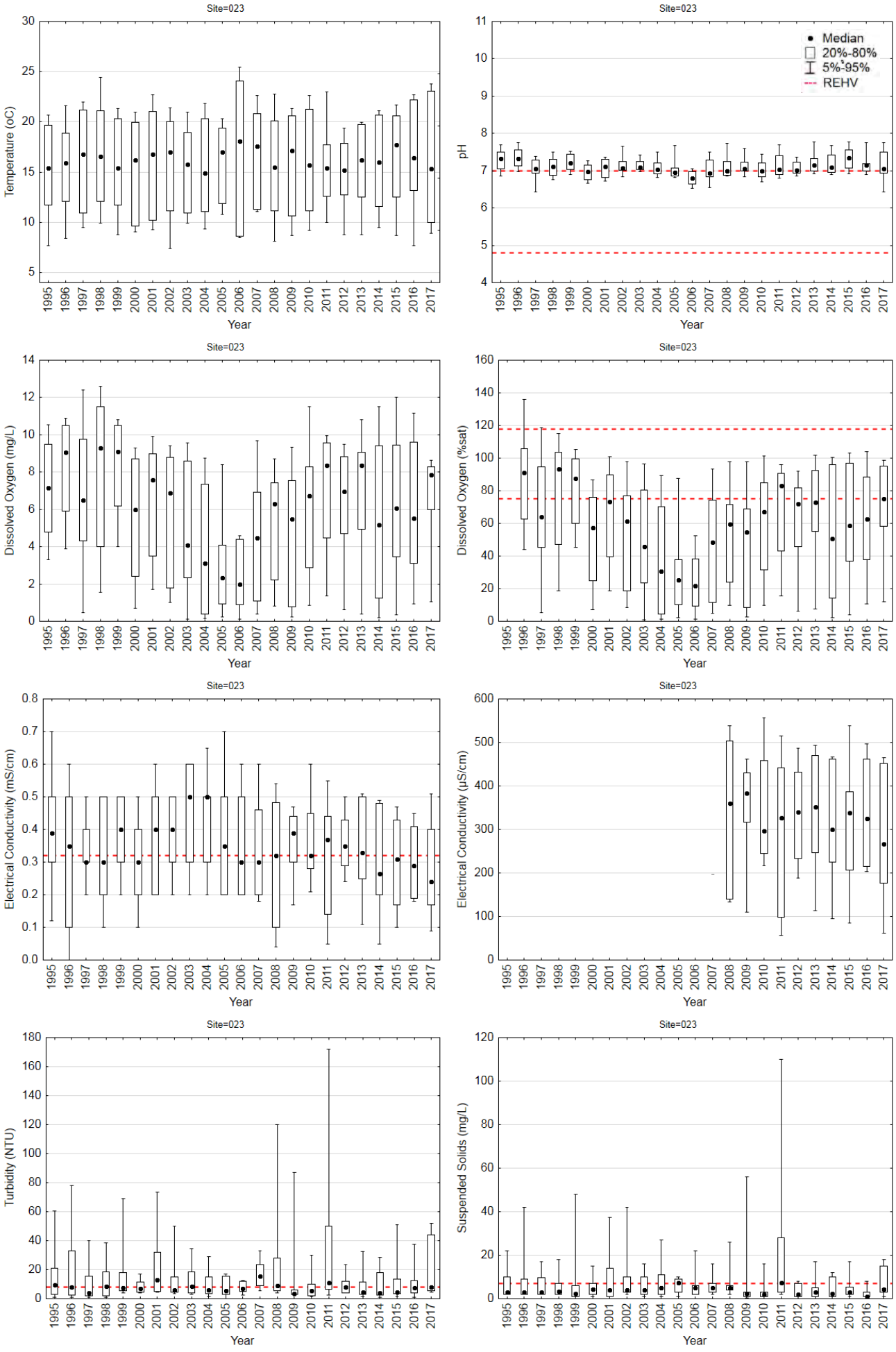
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

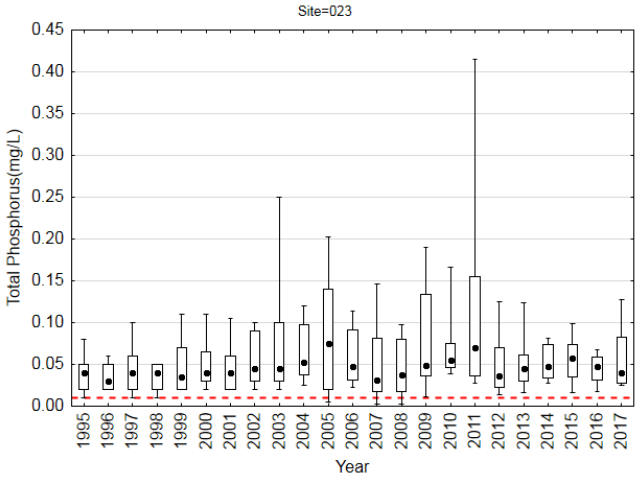
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

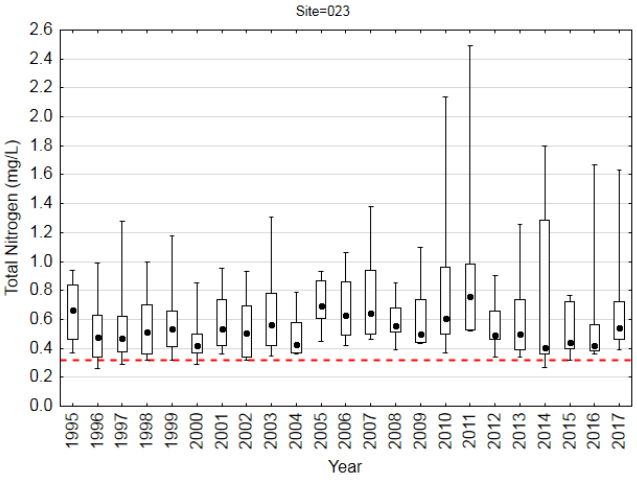
Table 2 Descriptive statistics for variables measured at Site 023 from January 1995 to September 2017

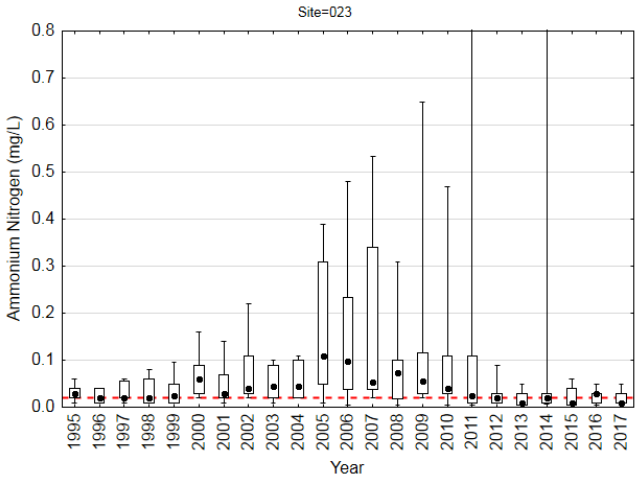
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	381	15.88	16.20	7.09	25.48	11.20	20.20	4.337
pH	378	7.12	7.08	4.66	7.90	6.92	7.34	0.291
DO (mg/L)	374	6.18	6.57	0.05	16.20	2.80	9.30	3.367
DO (%sat)	338	59.10	63.35	0.20	183.05	23.70	90.40	32.504
EC (mS/cm)	380	0.36	0.37	0.00	1.86	0.20	0.50	0.166
EC (µS/cm)	111	325.17	338.00	57.00	557.00	212.00	452.00	125.008
Turbidity (NTU)	380	14.6	7.6	0.0	190.3	3.8	17.7	22.39
TSS (mg/L)	391	7	4	1	124	2	9	12.7
TP (mg/L)	391	0.055	0.040	0.003	0.480	0.028	0.074	0.0480
TN (mg/L)	391	0.702	0.520	0.220	36.100	0.400	0.740	1.8380
NH_3-N (mg/L)	391	0.062	0.030	0.005	1.250	0.010	0.080	0.1140
NOx-N (mg/L)	391	0.297	0.150	0.005	34.000	0.040	0.320	1.7350
F.Cols (CFU/100ml)	391	3072	1100	0	95000	310	3300	8363.4
E.Coli (CFU/100ml)	16	2105	485	93	12000	210	3300	3286.8
Entero (CFU/100ml)	29	580	76	18	5000	45	900	1103.5

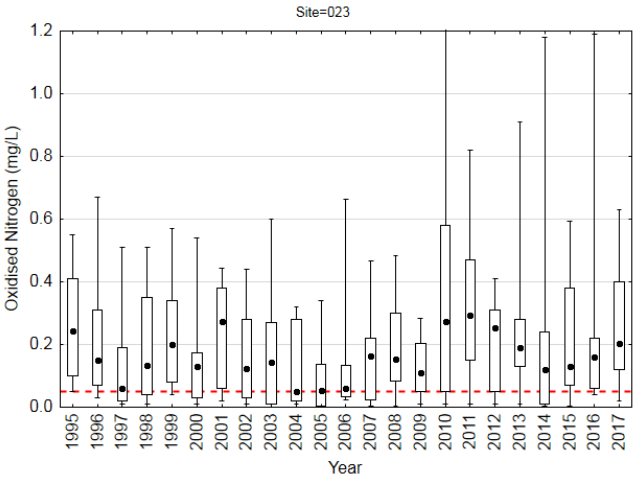
Boxplots showing annual variability for each variable measured

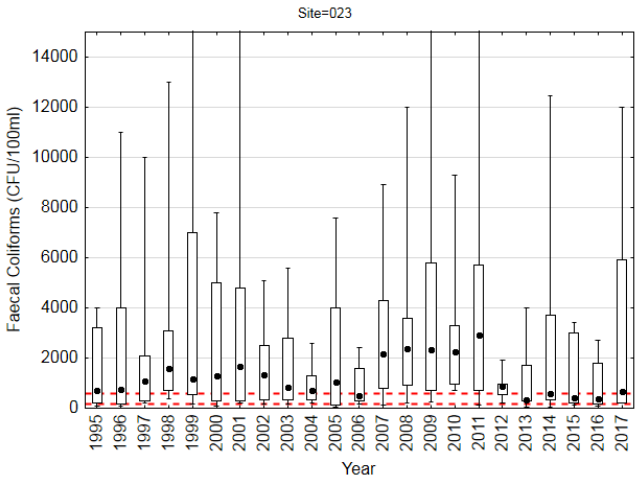


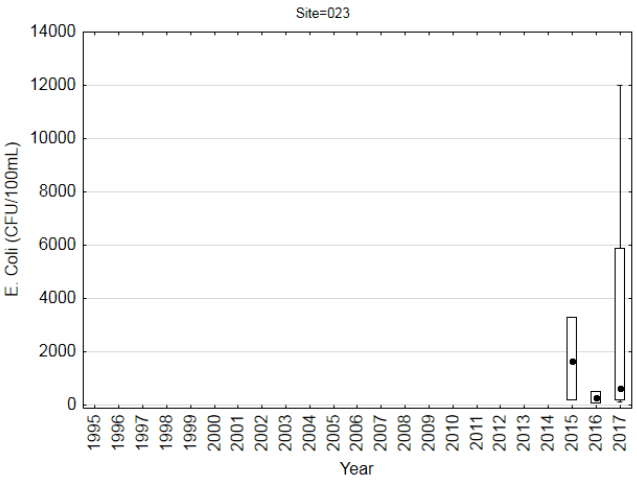

Site=023
Total Phosphorus(mg/L)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

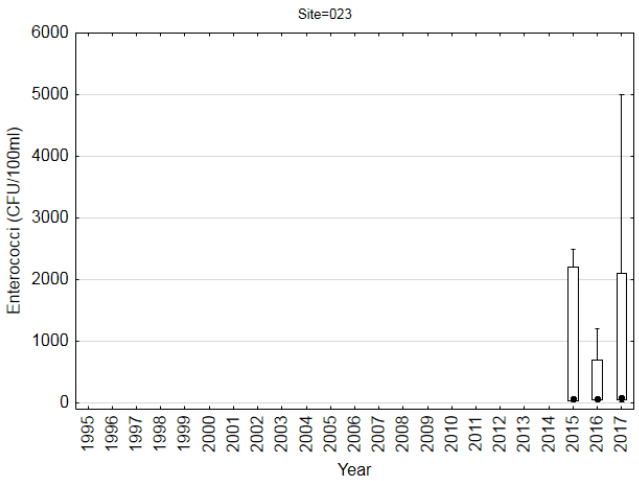

Site=023
Total Nitrogen (mg/L)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=023
Ammonium Nitrogen (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=023
Oxidised Nitrogen (mg/L)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=023
Faecal Coliforms (CFU/100ml)
14000
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=023
E. Coli (CFU/100mL)
14000
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=023
Enterococci (CFU/100ml)
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 036 – Murray Anderson Creek, Ku-ring-gai Chase National Park

Freshwater (Reference) site
Cowan Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (036)	Jan 1995 – Sept 2017	Monthly
Ecohealth (MAND1)	Oct 2017 ongoing	Quarterly
Reference (MAND1)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH, EC and DO consistently comply with REHVs. Long-term decreasing trend is evident for pH. Clarity: Turbidity and TSS are low and consistently comply with REHVs. Nutrients: Nutrient levels are low and consistently comply with REHVs. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Long-term reference site due to undisturbed bushland catchment
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Continued monitoring for local reference conditions – Further investigation of the influence of key SE Australian climate drivers on local reference conditions – Review of REHVs and suitability of long-term reference sites using targeted short-term reference site data

Site Photos

Murray Anderson Creek looking upstream during high flow

Murray Anderson Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 036

036	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	269	16.15	NA	NS	61	16.66	NA	NS
pH	4.8-7	270	5.78	10	↓	61	5.44	7	NS
DO (%sat)	75-118	249	99.90	5	↓	61	99.30	0	NS
EC (mS/cm)	0.32	269	0.19	0	NS	61	0.17	0	↓
Turbidity (NTU)	8	270	0.2	2	NS	61	0.3	2	↑
TSS (mg/L)	7	270	1	1	↓	60	1	0	NS
TP (mg/L)	0.01	271	0.003	3	↑	61	0.003	0	NS
TN (mg/L)	0.32	271	0.100	0	NS	61	0.090	0	NS
NH_3-N (mg/L)	0.02	271	0.010	3	*	61	0.005	0	NS
NO_x-N (mg/L)	0.05	271	0.010	0	*	61	0.005	0	NS
F.Cols (CFU/100ml)	150	271	6	6	↑	61	14	7	NS

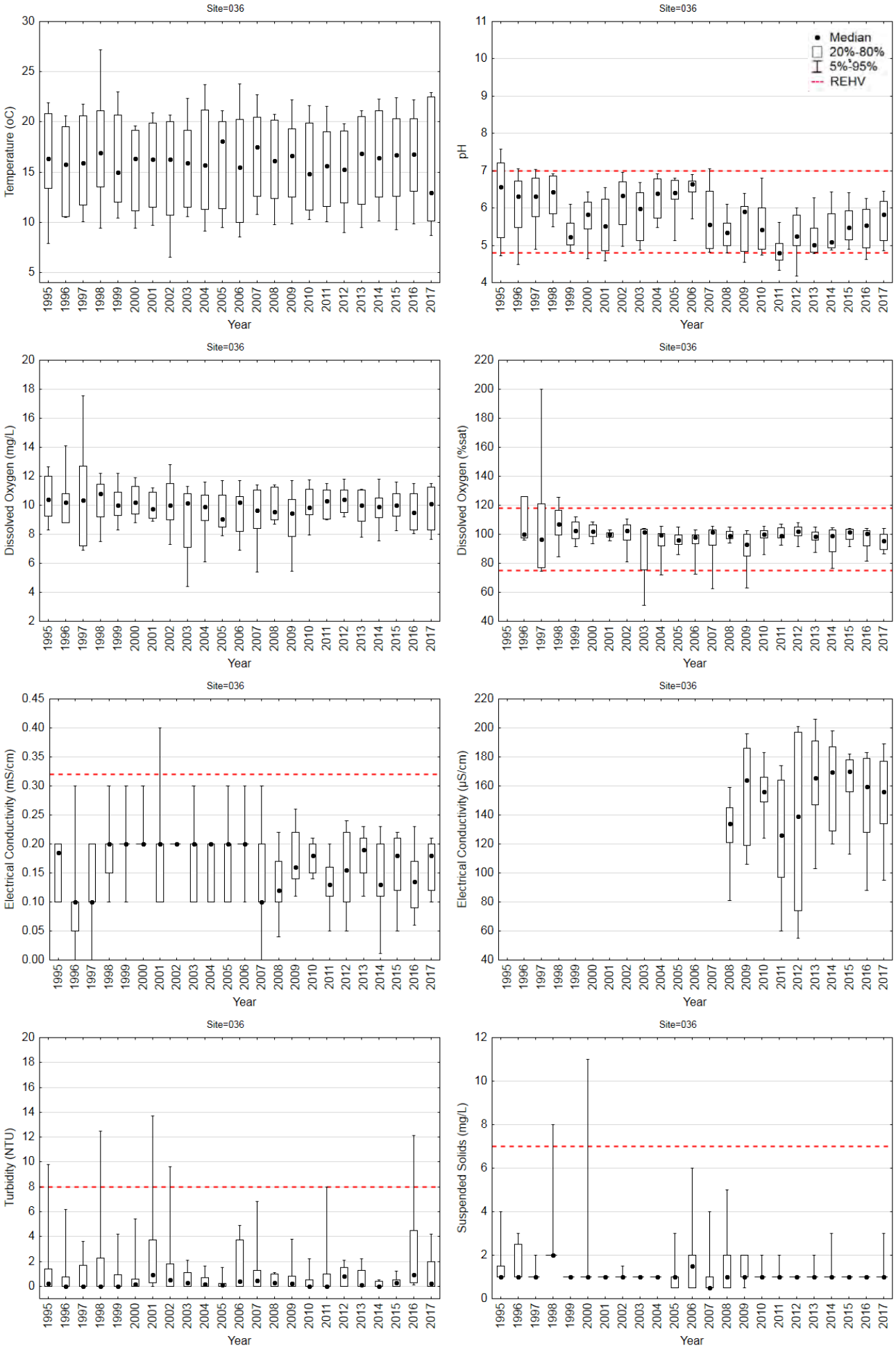
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05
** - trend analysis not appropriate due to change in laboratory detection limit*

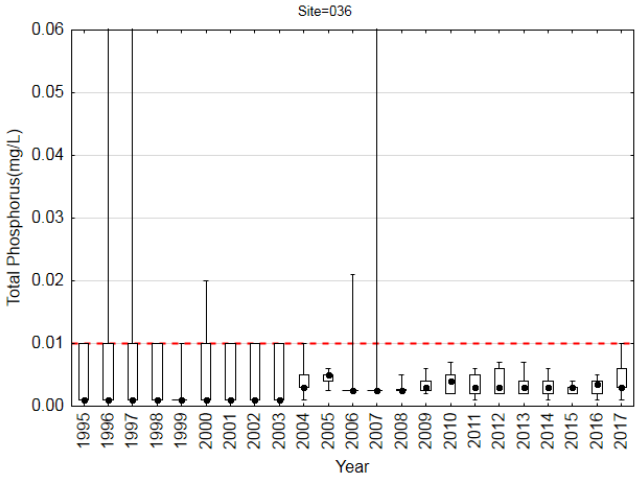
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

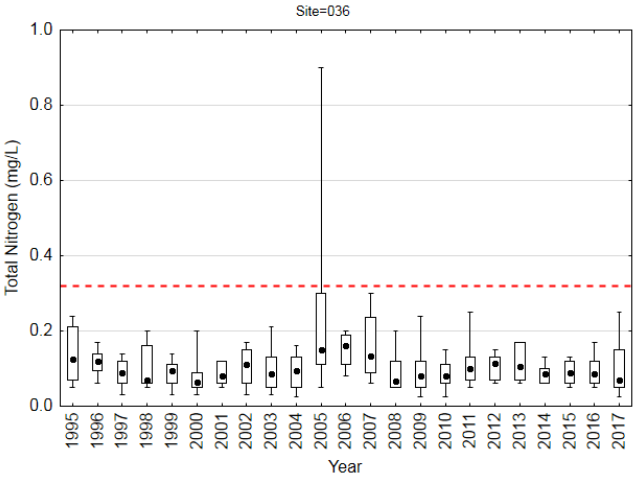
Table 2 Descriptive statistics for variables measured at Site 036 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	269	15.86	16.15	6.50	27.15	11.51	20.07	4.155
pH	270	5.77	5.78	4.18	7.58	5.03	6.46	0.724
DO (mg/L)	266	9.94	10.00	4.40	17.55	8.95	11.07	1.482
DO (%sat)	249	98.80	99.90	50.90	200.00	93.81	103.60	11.326
EC (mS/cm)	269	0.16	0.19	0.00	0.40	0.10	0.20	0.060
EC (µS/cm)	112	150.49	157.00	55.00	206.00	121.00	179.00	33.601
Turbidity (NTU)	270	1.0	0.2	0.0	13.7	0.0	1.3	2.03
TSS (mg/L)	270	1	1	1	11	1	1	1.0
TP (mg/L)	271	0.005	0.003	0.001	0.203	0.001	0.006	0.0156
TN (mg/L)	271	0.108	0.100	0.025	0.900	0.060	0.140	0.0702
NH_3-N (mg/L)	271	0.010	0.010	0.003	0.200	0.005	0.010	0.0161
NOx-N (mg/L)	271	0.009	0.010	0.001	0.206	0.005	0.010	0.0135
F.Cols (CFU/100ml)	271	50	6	0	2400	1	42	199.5
E.Coli (CFU/100ml)	19	25	11	1	95	1	62	30.5
Entero (CFU/100ml)	33	34	7	1	600	1	32	103.1

Boxplots showing annual variability for each variable measured




Site=036
Total Phosphorus(mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=036
Total Nitrogen (mg/L)
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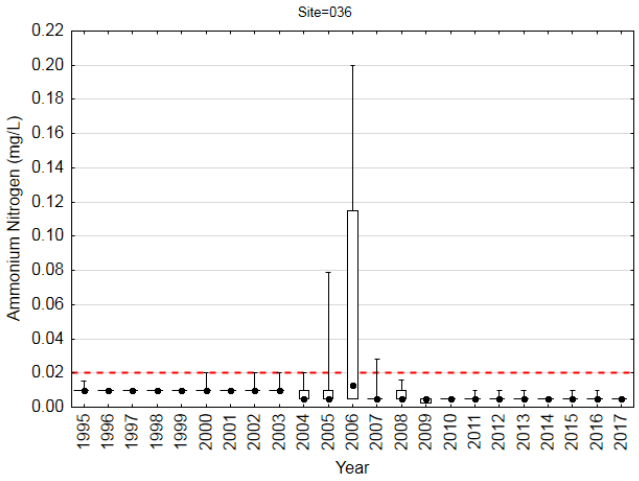
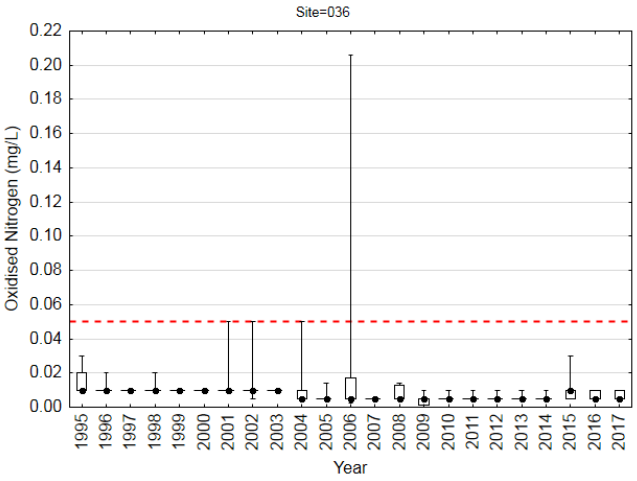
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=036
Ammonium Nitrogen (mg/L)
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=036
Oxidised Nitrogen (mg/L)
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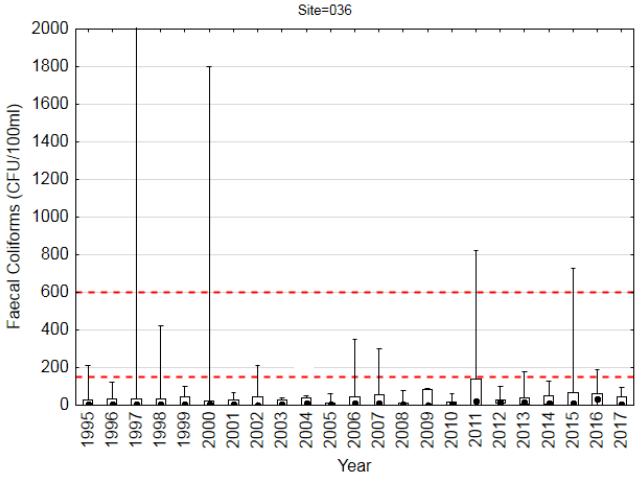
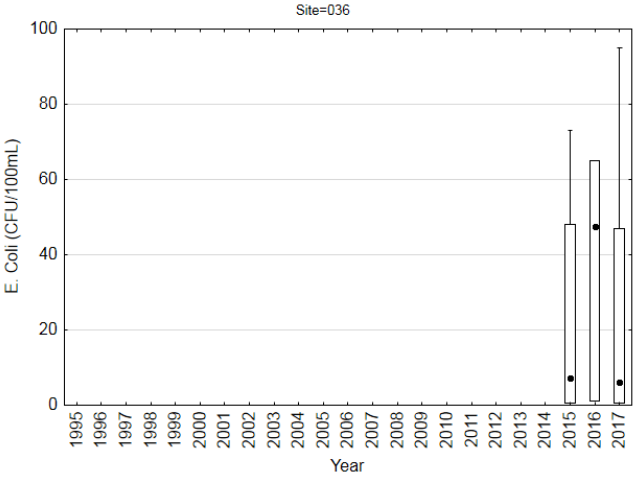
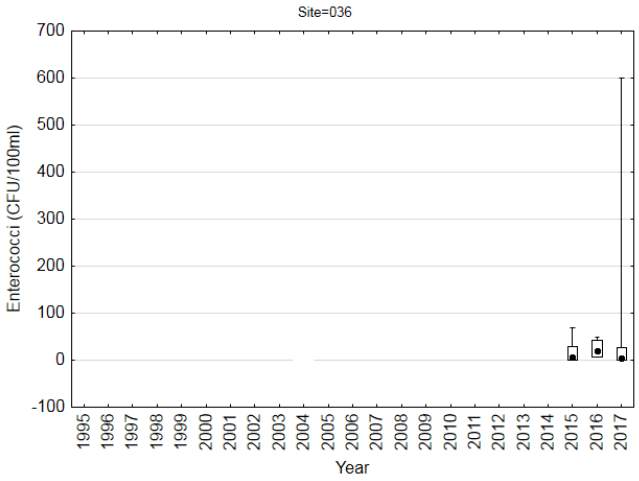
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=036
Faecal Coliforms (CFU/100ml)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=036
E. Coli (CFU/100mL)
100
80
60
40
20
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=036
Enterococci (CFU/100ml)
700
600
500
400
300
200
100
0
-100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 037 – Smugglers Creek, Marramarra National Park

Freshwater (Reference) Site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (037)	Jan 1995 – Sept 2017	Monthly
Ecohealth (SMUG1)	Oct 2017 - ongoing	Quarterly
Reference (SMUG1)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH, EC and DO consistently comply with REHVs. A long-term increasing trend is evident for pH. Clarity: Turbidity and TSS low and consistently comply with REHVs. Nutrients: Nutrient levels are low and consistently comply with REHVs. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Long-term reference site due to undisturbed bushland catchment
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Continued monitoring for local reference conditions – Further investigation of the influence of key SE Australian climate drivers on local reference conditions – Review of REHVs and suitability of long-term reference sites using targeted short-term reference site data

Site Photos

Smugglers Creek looking upstream during high flow

Smugglers Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 037

037	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	264	16.12	NA	NS	61	16.69	NA	NS
pH	4.8-7	264	5.47	6	↑	61	5.57	7	↑
DO (%sat)	75-118	238	101.47	7	NS	61	102.40	0	↑
EC (mS/cm)	0.32	263	0.20	4	↓	61	0.21	3	↓
Turbidity (NTU)	8	264	0.6	5	↑	61	0.8	3	NS
TSS (mg/L)	7	270	1	4	↓	61	1	0	↑
TP (mg/L)	0.01	271	0.004	4	↑	61	0.004	5	NS
TN (mg/L)	0.32	271	0.120	4	NS	61	0.110	2	NS
NH_3-N (mg/L)	0.02	271	0.010	3	*	61	0.005	0	NS
NO_x-N (mg/L)	0.05	271	0.010	3	*	61	0.005	2	↑
F.Cols (CFU/100ml)	150	270	12	9	↑	61	14	13	NS

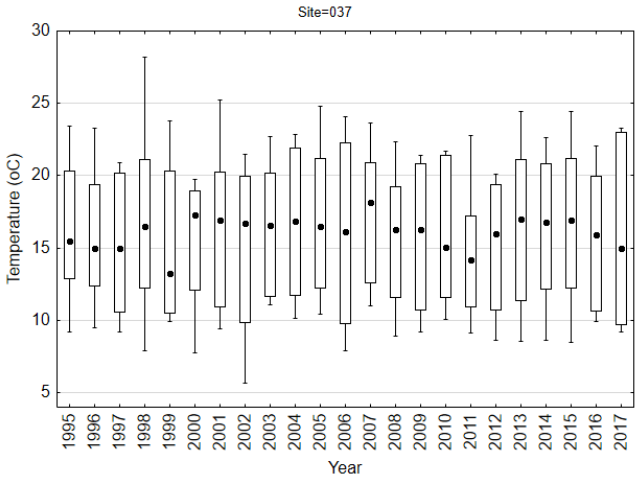
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05
** - trend analysis not appropriate due to variation in laboratory detection limit*

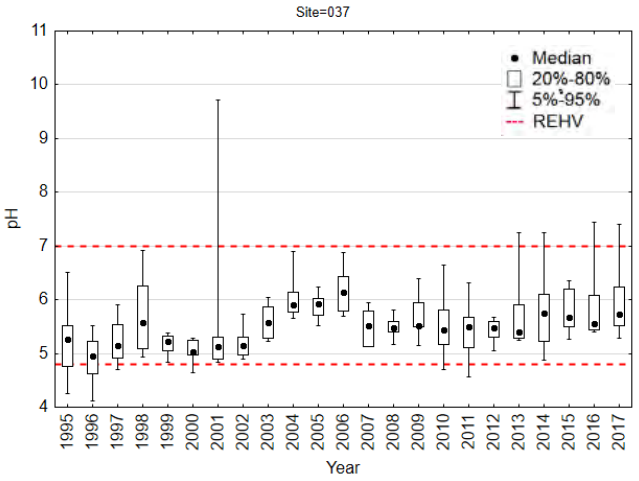
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

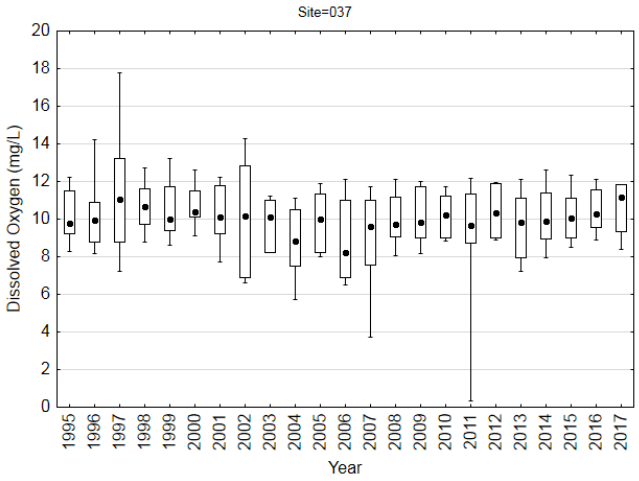
Table 2 Descriptive statistics for variables measured at Site 037 from January 1995 to September 2017

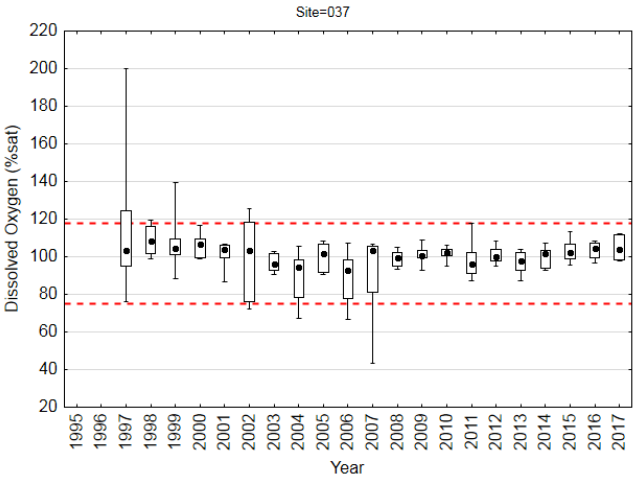
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	264	15.98	16.12	5.68	28.20	11.29	20.76	4.581
pH	264	5.54	5.47	4.12	9.71	5.13	5.90	0.582
DO (mg/L)	261	10.08	10.00	0.32	17.80	8.85	11.50	1.755
DO (%sat)	238	100.64	101.47	43.30	200.00	95.00	106.00	11.998
EC (mS/cm)	263	0.22	0.20	0.00	0.40	0.17	0.30	0.079
EC (µS/cm)	116	201.04	209.00	56.00	315.00	148.00	250.00	58.643
Turbidity (NTU)	264	1.6	0.6	0.0	33.0	0.0	2.2	3.36
TSS (mg/L)	270	2	1	1	47	1	2	3.8
TP (mg/L)	271	0.006	0.004	0.001	0.307	0.001	0.010	0.0191
TN (mg/L)	271	0.148	0.120	0.025	1.870	0.080	0.200	0.1527
NH_3-N (mg/L)	271	0.009	0.010	0.003	0.108	0.005	0.010	0.0095
NOx-N (mg/L)	271	0.013	0.010	0.001	0.240	0.005	0.010	0.0208
F.Cols (CFU/100ml)	270	71	12	0	1700	1	68	202.2
E.Coli (CFU/100ml)	20	85	10	1	590	3	74	169.7
Entero (CFU/100ml)	31	48	25	1	370	1	50	82.2

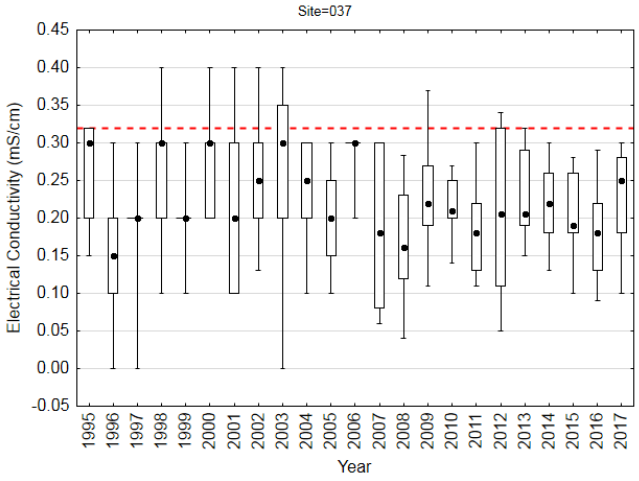
Boxplots showing annual variability for measured variables

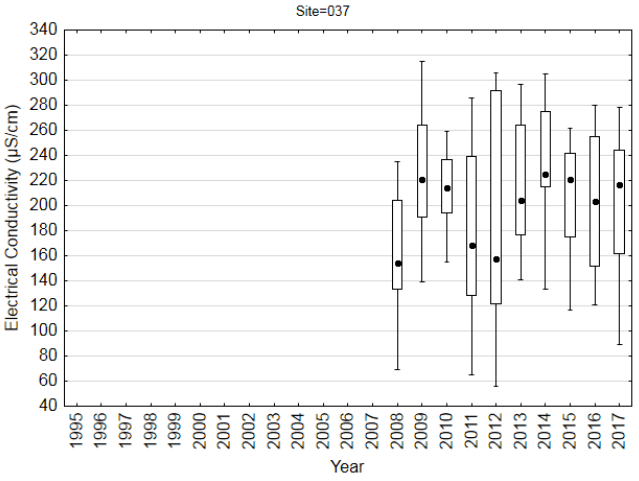


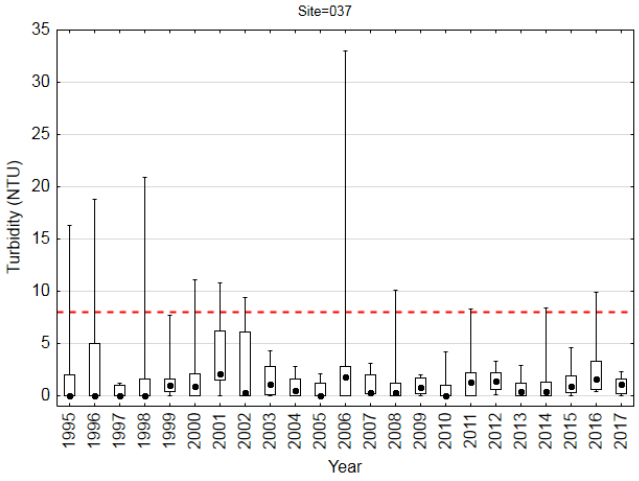


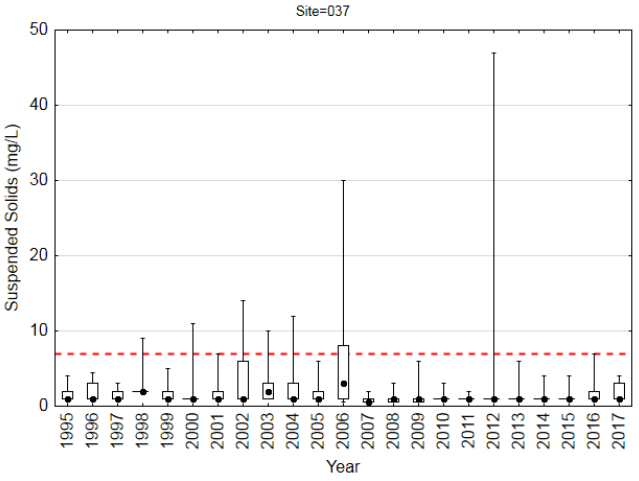


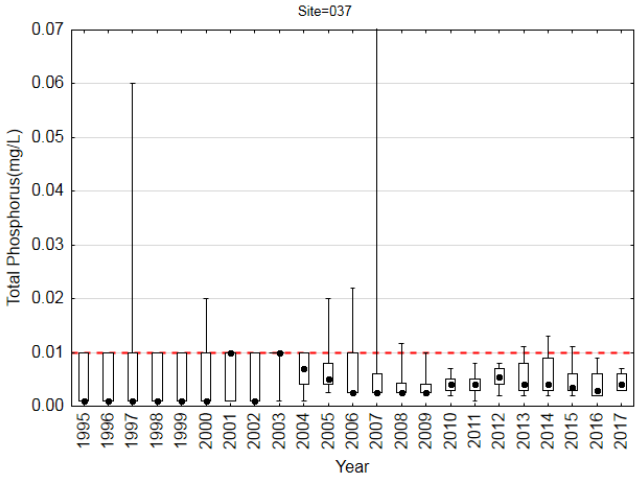


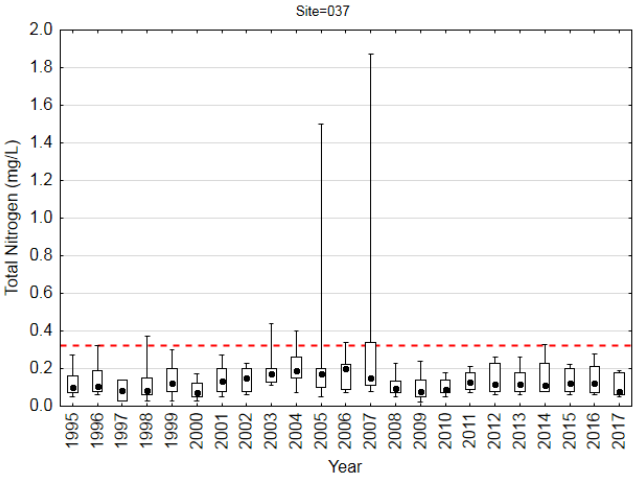


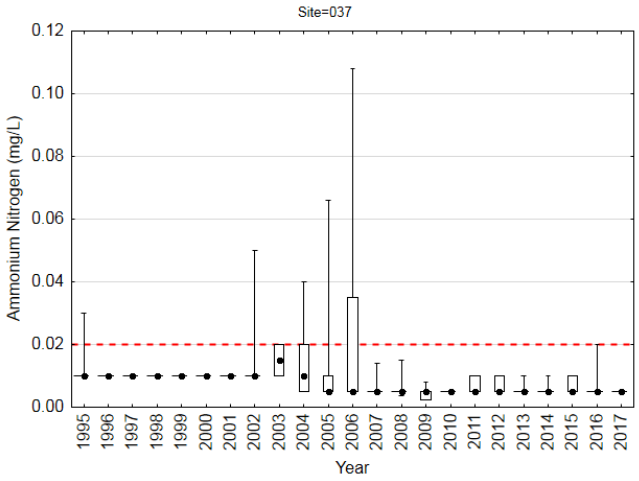


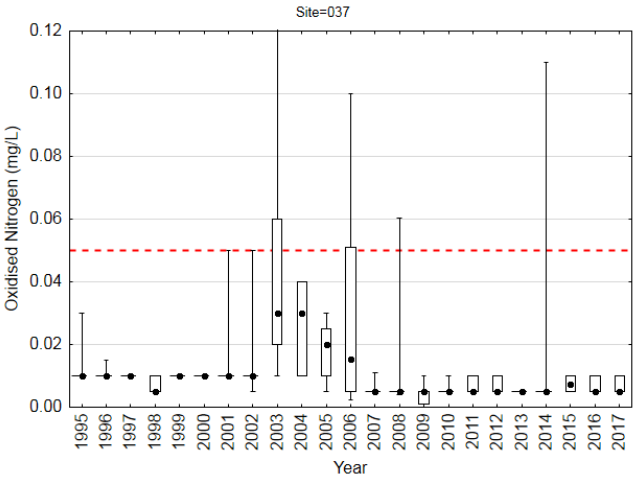


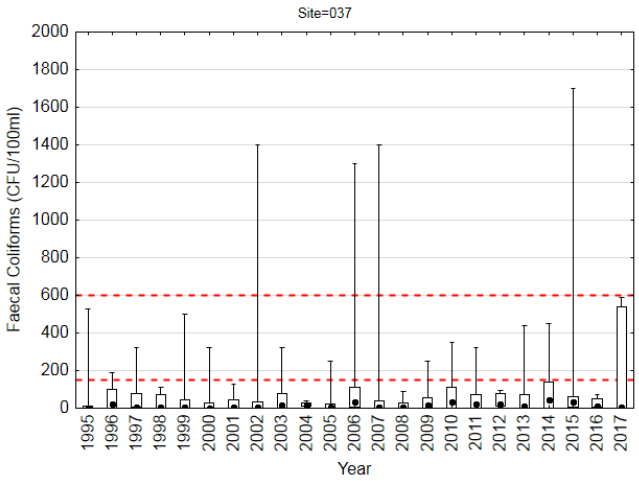


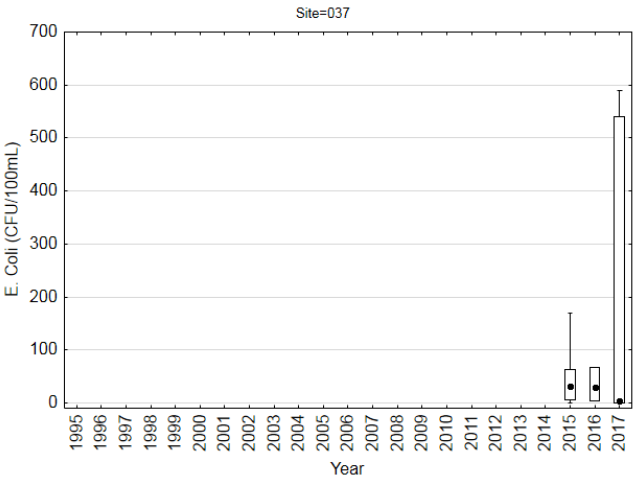

Site=037
Total Phosphorus(mg/L)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

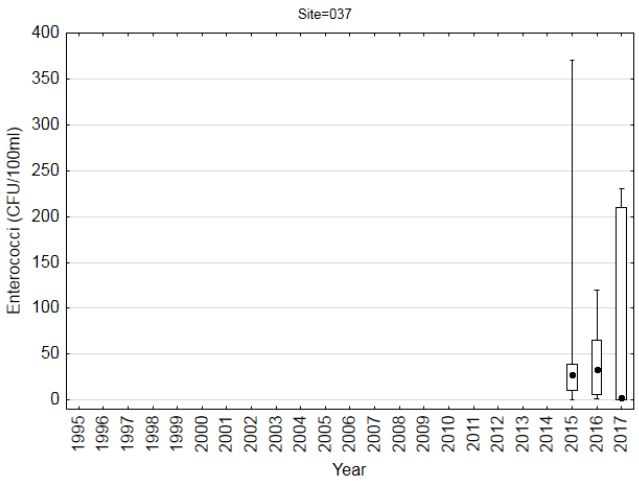

Site=037
Total Nitrogen (mg/L)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=037
Ammonium Nitrogen (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=037
Oxidised Nitrogen (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=037
Faecal Coliforms (CFU/100ml)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=037
E. Coli (CFU/100mL)
700
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=037
Enterococci (CFU/100ml)
400
350
300
250
200
150
100
50
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 038 – Sandbrook Inlet, Hawkesbury River

Estuarine site
Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (038)	Oct 1994 – Sept 2017	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO consistently comply with REHVs. A long-term decreasing trend in salinity is evident. Clarity: Turbidity results are variable and exceed REHVs approximately 50% of the time. TSS is elevated and exceeds REHVs approximately 80% of the time. Biological: Chl-a is generally low, however results are variable exceeding the REHV approximately 40% of the time. Nutrients: Nutrients are low and generally comply with REHVs, with the exception of NOx-N, which is variable and exceeds REHVs approximately 40% of the time. A long-term increasing trend in TN is evident. Bacteria: Bacterial levels are low and consistently comply with REHVs.
Issues	– Influenced by urban development in the catchment – Influenced by local commercial marina operations and boat use – Influenced by local riverside settlements – Possible reduction in tidal flushing/incursion through time
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Education and collaboration with marina operators and boat users to minimise impacts from these activities – Education and collaboration with riverside residents to minimise impacts from these settlements

Site Photos

Sandbrook Inlet, Brooklyn looking east

Sandbrook Inlet, Brooklyn looking west

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 038

038	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	264	20.30	NA	NS	60	20.99	NA	NS
pH	7-8.5	265	7.78	0	↑	61	7.88	0	NS
DO (%sat)	80-110	245	95.60	11	NS	61	95.10	8	NS
Salinity (ppt)	NA	263	29.50	NA	↓	60	28.16	NA	NS
Turbidity (NTU)	10	265	9.9	48	↑	61	10.3	51	↑
TSS (mg/L)	6	266	11	83	NS	60	10	77	NS
Chlorophyll-a (ug/L)	4	264	3.0	31	↑	61	3.9	48	NS
TP (mg/L)	0.03	267	0.020	7	NS	61	0.020	5	NS
TN (mg/L)	0.3	240	0.240	19	↑	61	0.280	33	↑
NH_3-N (mg/L)	0.015	240	0.010	20	↓	61	0.010	5	NS
NOx-N (mg/L)	0.015	267	0.013	49	NS	61	0.010	41	↑
F.Coliforms (CFU/100ml)	150	267	2	1	NS	61	3	2	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Enterococci (CFU/100ml)	40	83	26	1	↓	59	22	2	NS

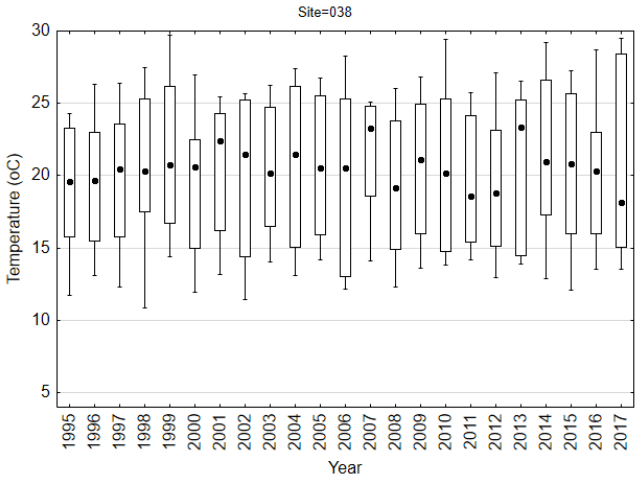
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

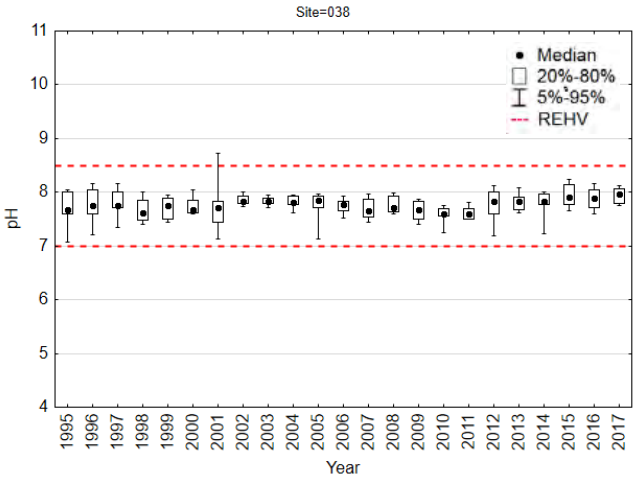
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

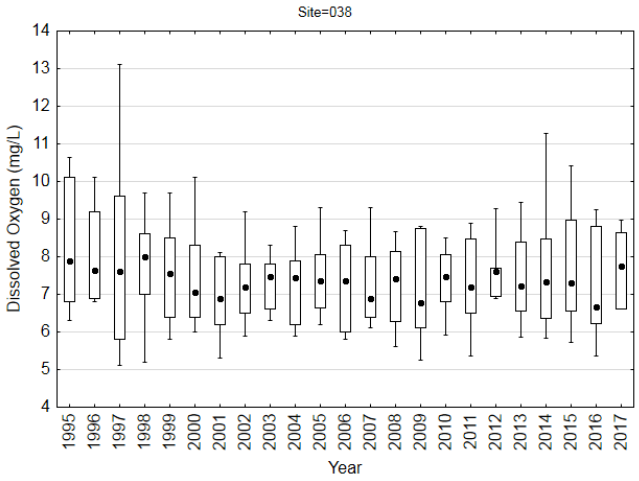
Table 2 Descriptive statistics for variables measured at Site 038 from January 1995 to September 2017

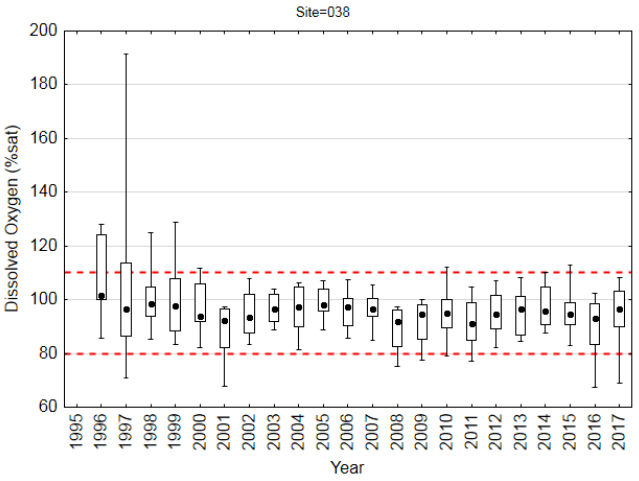
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	264	20.26	20.30	10.85	29.70	15.38	25.23	4.644
pH	265	7.77	7.78	7.07	8.73	7.61	7.92	0.206
DO (mg/L)	262	7.47	7.40	5.10	13.10	6.40	8.47	1.183
DO (%sat)	245	95.83	95.60	67.54	191.45	88.65	102.25	11.366
Salinity (ppt)	263	28.51	29.50	1.49	36.00	25.65	32.45	5.316
Turbidity (NTU)	265	11.1	9.9	0.0	33.4	7.0	14.9	5.66
TSS (mg/L)	266	14	11	1	123	7	17	12.7
Chlorophyll-a (µg/L)	264	3.7	3.0	0.3	28.2	2.0	5.2	2.69
TP (mg/L)	267	0.020	0.020	0.001	0.080	0.010	0.025	0.0113
TN (mg/L)	240	0.257	0.240	0.070	1.050	0.180	0.300	0.1090
NH_3-N (mg/L)	240	0.012	0.010	0.003	0.060	0.008	0.020	0.0086
NOx-N (mg/L)	267	0.031	0.013	0.005	0.370	0.005	0.050	0.0410
SRP (mg/L)	28	0.003	0.002	0.001	0.008	0.001	0.005	0.0020
F.Cols (CFU/100ml)	267	8	2	0	240	1	8	21.3
E.Coli (CFU/100ml)	16	3	1	1	15	1	6	4.3
Entero (CFU/100ml)	83	10	3	1	320	1	9	35.3

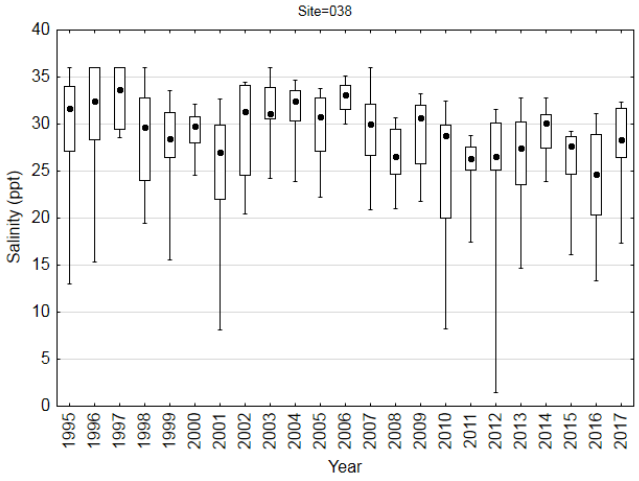
Boxplots showing annual variability for each variable measured

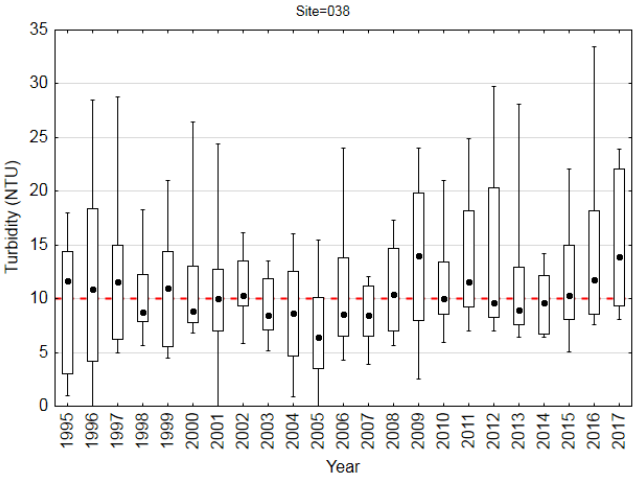


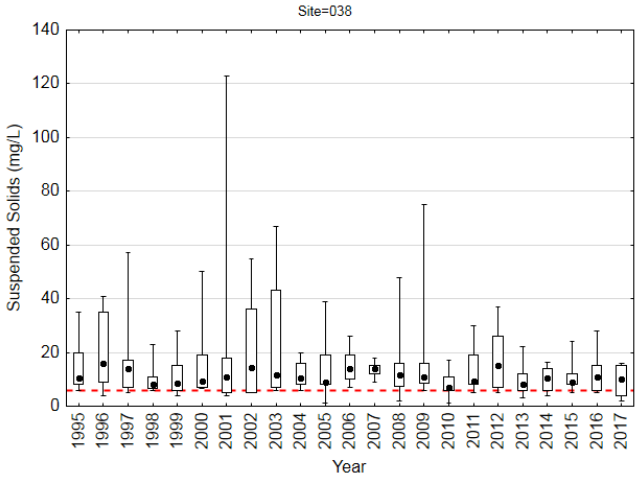


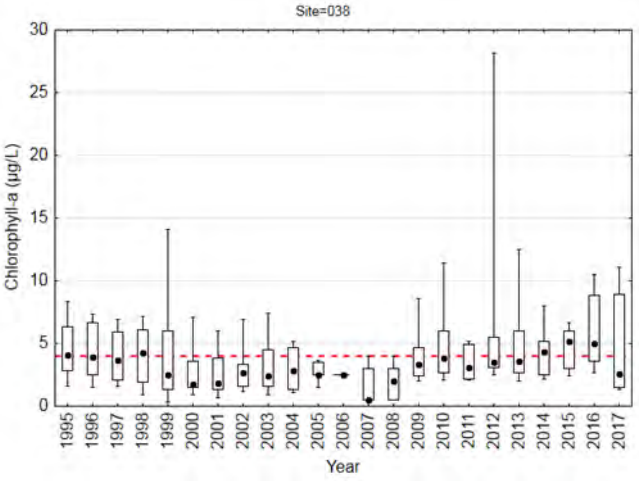


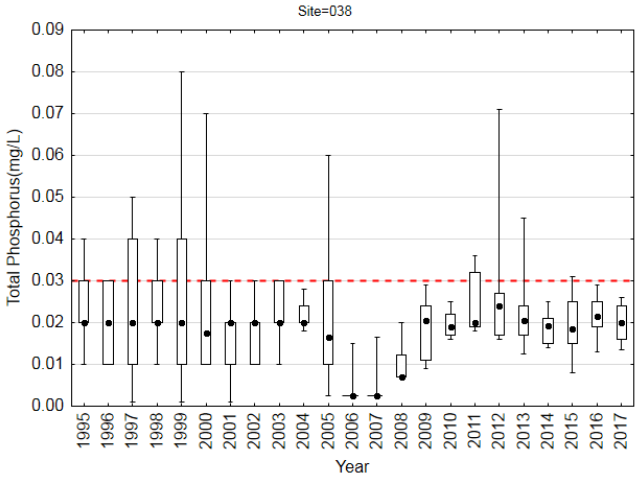








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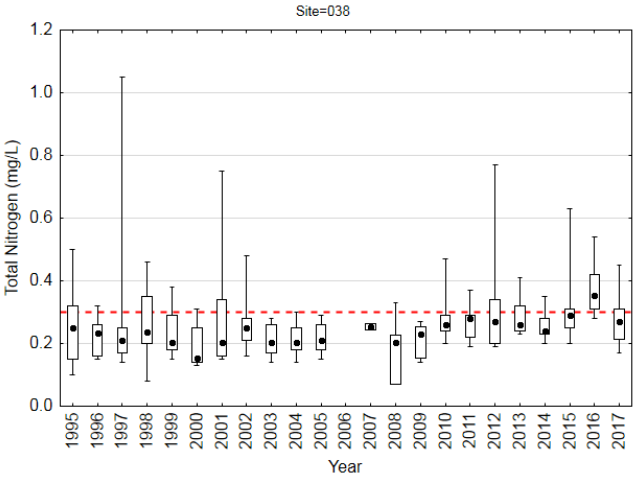
Total Phosphorus(mg/L)
Year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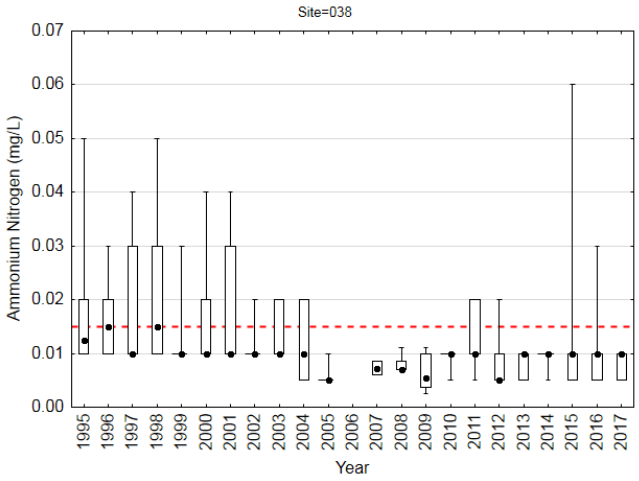
Total Nitrogen (mg/L)
Year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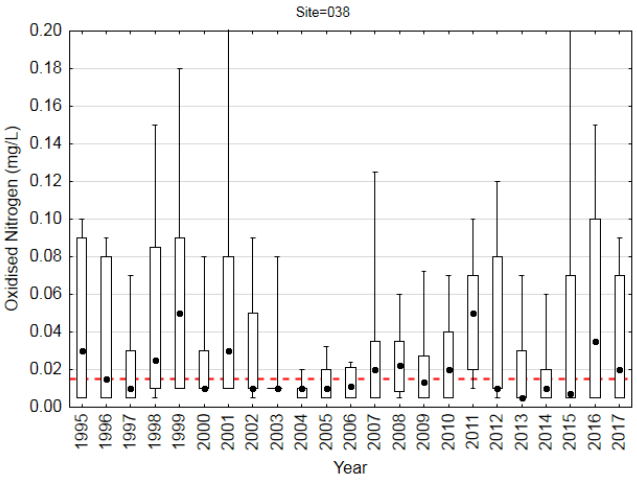
Ammonium Nitrogen (mg/L)
Year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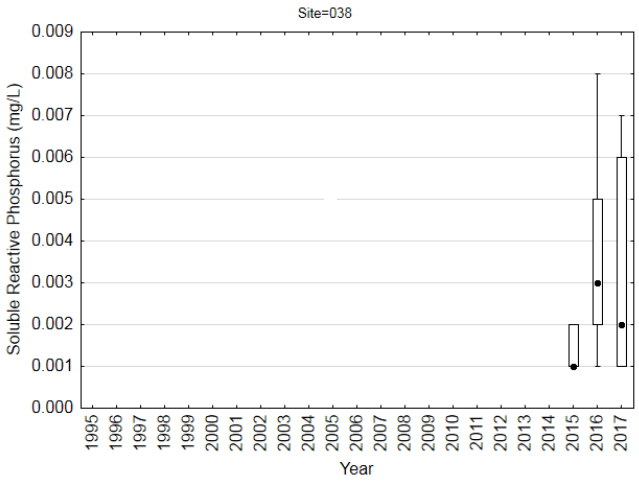
Oxidised Nitrogen (mg/L)
Year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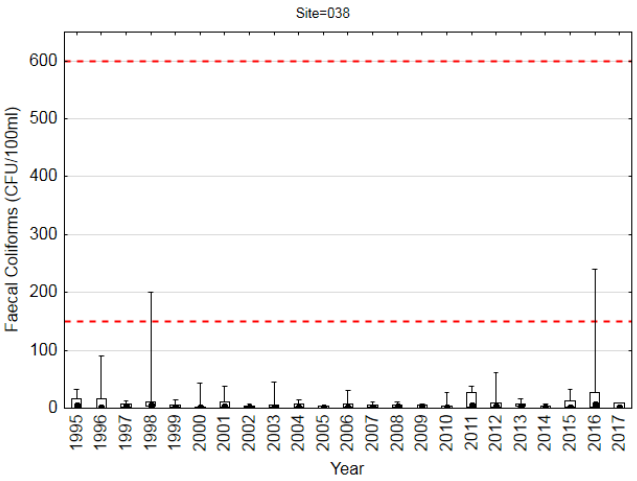
Soluble Reactive Phosphorus (mg/L)
Year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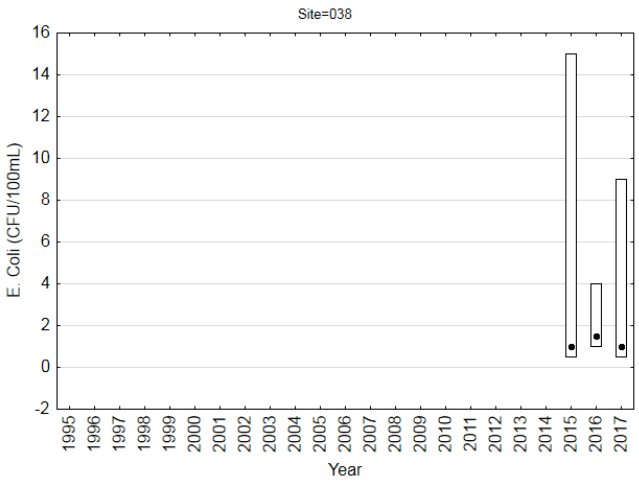
Faecal Coliforms (CFU/100ml)
Year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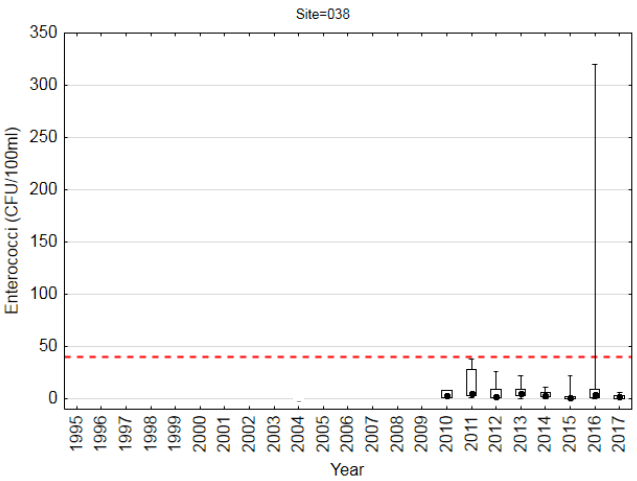
E. Coli (CFU/100mL)
Year


Site=038
Enterococci (CFU/100ml)
Year

Site 039 – Joe Crafts Creek, Berowra Valley National Park

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (039)	Oct 1994 – Sept 2017	Monthly
Ecohealth (JOEC1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH is slightly elevated and exceeds REHV approximately 70% of the time. Clarity: Turbidity and TSS are low and consistently comply with REHVs. Nutrients: Nutrient levels are low and generally comply with REHVs, with the exception of NOx-N, which exceeds the REHV approximately 45% of the time. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Some influence from urban development in the upper catchment – Surrounding bushland and riparian zone are likely to be buffering the impacts of upstream land-use
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment (particularly NOx-N) – Identify further opportunities for WSUD in the upper catchment – Protection of the bushland and riparian zone in the catchment to maintain buffering

Site Photos

Joe Crafts Creek looking downstream during high flow

Joe Crafts Creek looking downstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 039

039	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	258	15.65	NA	NS	60	15.55	NA	NS
pH	4.8-7	258	7.15	73	↓	60	7.12	72	↑
DO (%sat)	75-118	239	93.20	15	↓	60	91.75	12	NS
EC (mS/cm)	0.32	257	0.21	10	↓	60	0.23	3	NS
Turbidity (NTU)	8	258	1.3	12	NS	60	1.3	7	NS
TSS (mg/L)	7	265	1	4	↓	59	1	2	NS
TP (mg/L)	0.01	266	0.009	17	↓	60	0.008	20	NS
TN (mg/L)	0.32	266	0.230	20	NS	60	0.230	25	NS
NH_3-N (mg/L)	0.02	266	0.010	4	↓	60	0.005	2	NS
NO_x-N (mg/L)	0.05	266	0.050	43	NS	60	0.050	45	NS
F.Cols (CFU/100ml)	150	266	18	14	NS	60	17	15	NS

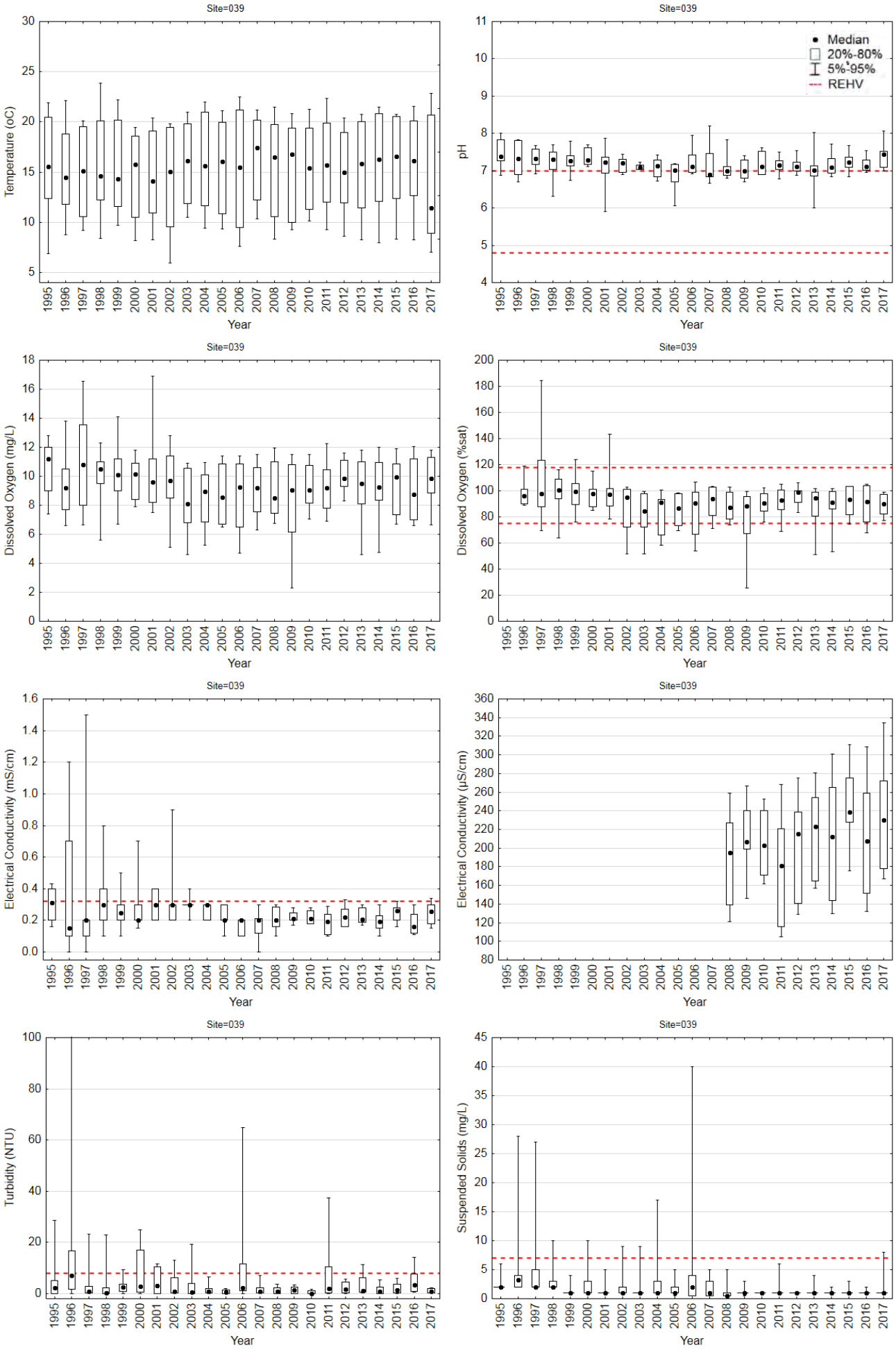
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

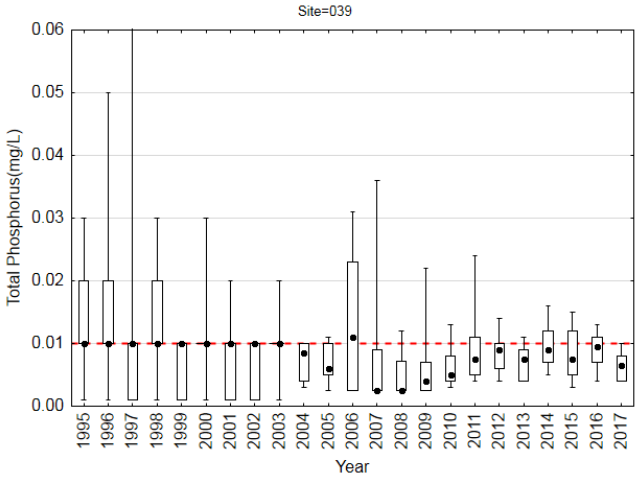
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 039 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	258	15.35	15.65	5.98	23.85	10.92	19.83	4.288
pH	258	7.18	7.15	5.90	8.21	6.95	7.40	0.318
DO (mg/L)	255	9.38	9.50	2.28	16.90	7.65	11.01	2.057
DO (%sat)	239	91.41	93.20	25.50	184.40	81.70	101.10	15.625
EC (mS/cm)	257	0.25	0.21	0.00	1.50	0.18	0.30	0.151
EC (µS/cm)	110	209.14	212.00	105.00	334.00	162.00	254.50	50.710
Turbidity (NTU)	258	4.0	1.3	0.0	127.8	0.2	4.2	10.34
TSS (mg/L)	265	2	1	1	40	1	2	3.7
TP (mg/L)	266	0.009	0.009	0.001	0.090	0.004	0.010	0.0080
TN (mg/L)	266	0.276	0.230	0.070	1.590	0.180	0.320	0.1592
NH_3-N (mg/L)	266	0.011	0.010	0.003	0.251	0.005	0.010	0.0173
NOx-N (mg/L)	266	0.084	0.050	0.005	1.470	0.023	0.108	0.1256
F.Cols (CFU/100ml)	266	135	18	0	4500	4	86	472.1
E.Coli (CFU/100ml)	18	48	14	1	390	1	40	103.8
Entero (CFU/100ml)	31	104	22	1	1800	11	59	324.1

Boxplots showing annual variability for each variable measured

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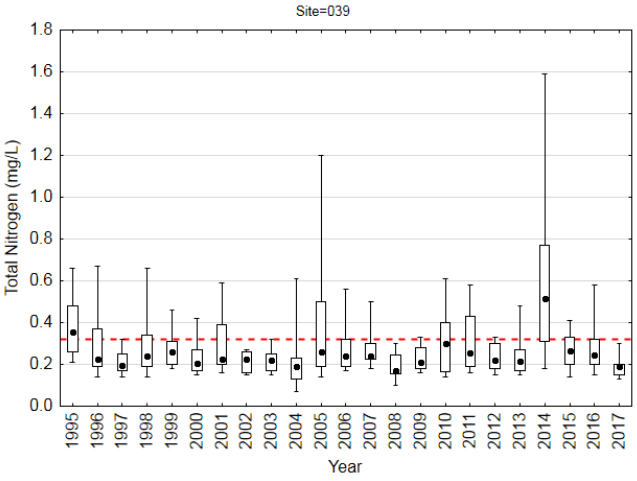
Total Phosphorus(mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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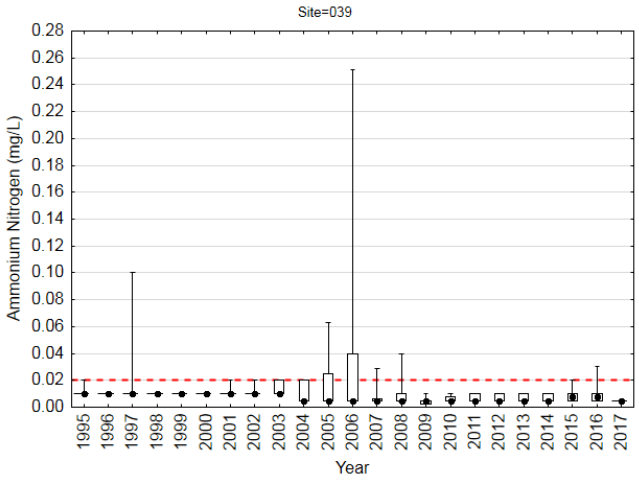
Total Nitrogen (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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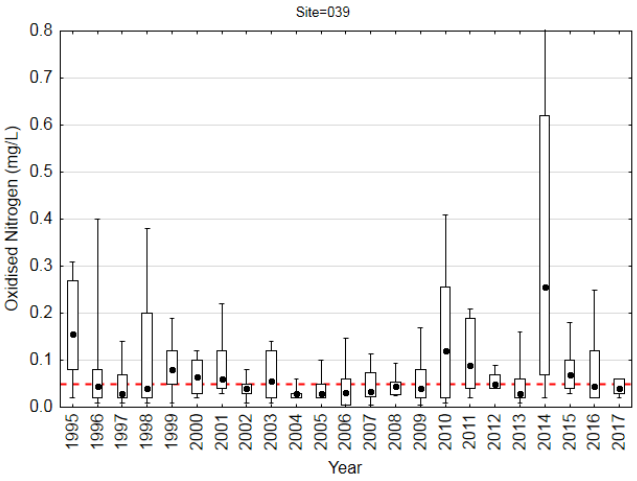
Ammonium Nitrogen (mg/L)
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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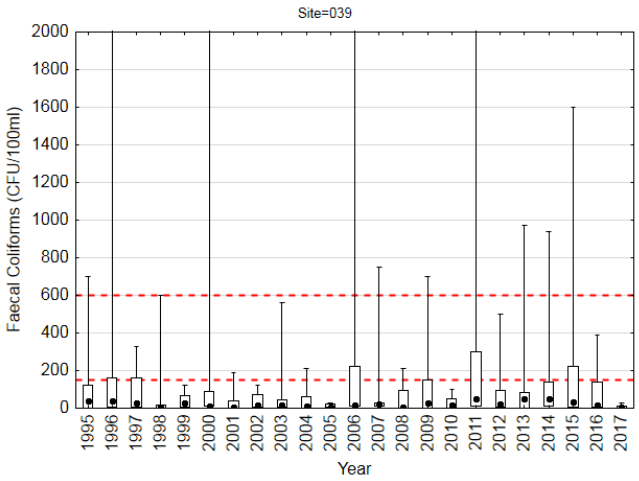
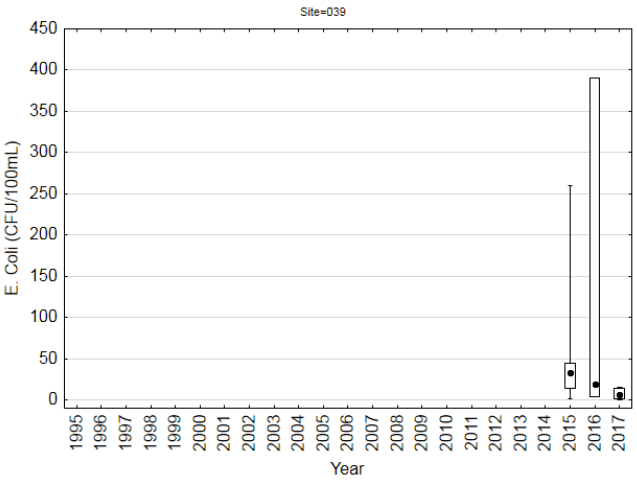
Oxidised Nitrogen (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=039
Faecal Coliforms (CFU/100ml)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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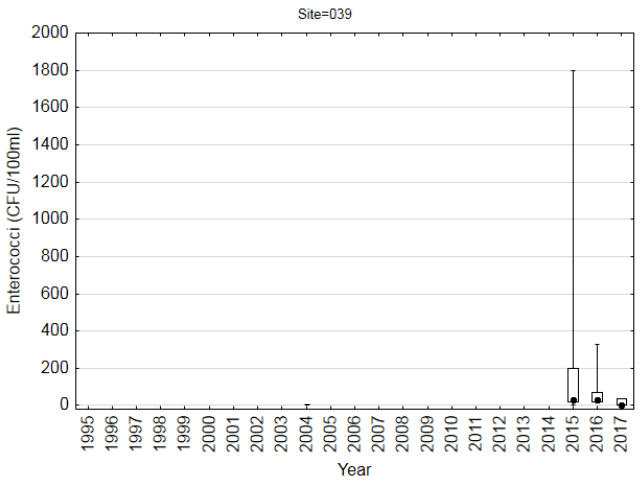
E. Coli (CFU/100mL)
450
400
350
300
250
200
150
100
50
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Enterococci (CFU/100ml)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 042 – Colah Creek, Arcadia

Freshwater site, Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (042)	Oct 1994 – Sept 2017	Monthly
Ecohealth (COLA2)	Oct 2017 ongoing	Quarterly
Targeted assessment (COLA2)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH is slightly elevated with an increase in non-conformance following a long-term increasing trend. EC is elevated and exceeds REHVs approximately 65% of the time. DO is generally compliant with REHVs recovering from a period of low levels between 2000 and 2008. A reduction in data variability is evident post 2008. Clarity: Turbidity and TSS are generally low but variable with turbidity exceeding the REHV approximately 40% of the time. Long-term trends of decrease in TSS are evident. Nutrients: TN and TP are elevated and consistently exceed REHVs despite a long-term decreasing trend. NOx-N is elevated and exceeds REHVs approximately 50% of the time. A long-term decreasing trend in NH_3-N is evident, levels are generally low with less variability post-2009. Bacteria: Bacteria levels are generally low but variable, exceeding the REHV approximately 40% of the time.
Issues	– Influenced by rural land-use in the catchment – Possible impacts from onsite wastewater management systems (OWMS) in the catchment – Possible influence of localised flow conditions
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Targeted monitoring to assess changes after the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality) in 2015 – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with residents to minimise the impacts of OWMS – Education and collaboration with landholders to minimise impacts from rural activities – Investigate the significance of local impacts and subsequently the suitability of the site for catchment health assessment

Site Photos

Colah Creek looking upstream during high flow

Colah Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 042

042	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	267	15.75	NA	NS	60	16.21	NA	NS
pH	4.8-7	265	6.91	36	↑	59	7.06	63	NS
DO (%sat)	75-118	241	77.30	46	↑	60	85.35	15	NS
EC (mS/cm)	0.32	266	0.40	71	↓	60	0.36	65	↓
Turbidity (NTU)	8	266	9.4	58	↓	59	5.7	37	NS
TSS (mg/L)	7	274	5	28	↓	61	2	10	NS
TP (mg/L)	0.01	274	0.037	95	↓	61	0.025	97	NS
TN (mg/L)	0.32	274	0.580	88	↓	61	0.430	77	NS
NH_3-N (mg/L)	0.02	274	0.020	47	↓	61	0.020	23	NS
NO_x-N (mg/L)	0.05	274	0.120	62	↓	61	0.060	54	NS
F.Cols (CFU/100ml)	150	274	100	40	NS	61	81	39	NS

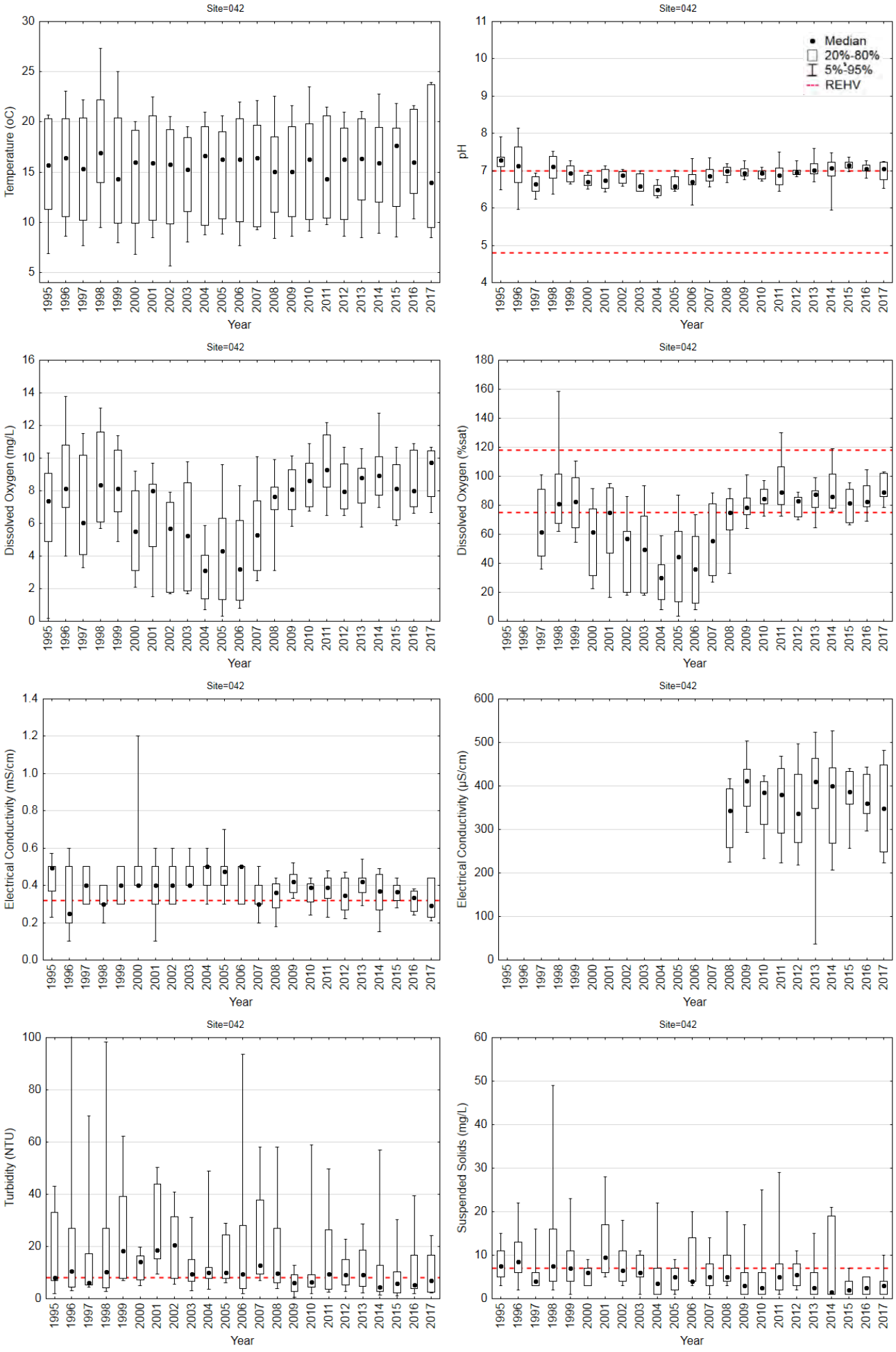
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

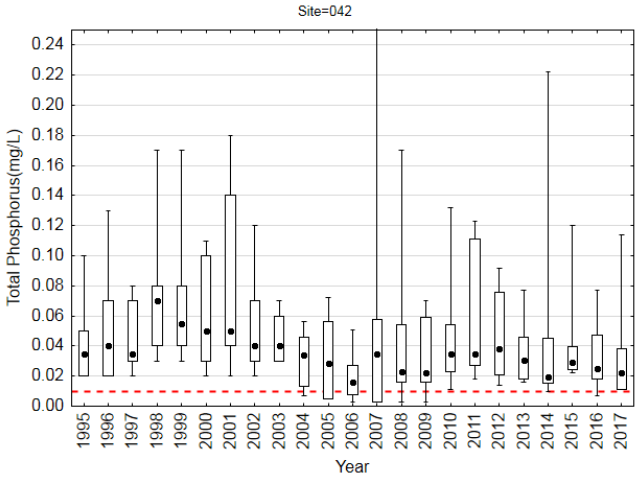
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 042 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	267	15.48	15.75	5.64	27.30	10.45	20.10	4.545
pH	265	6.90	6.91	5.95	8.14	6.65	7.13	0.309
DO (mg/L)	264	7.17	7.58	0.20	13.80	4.70	9.60	2.789
DO (%sat)	241	70.00	77.30	3.30	158.35	47.00	89.20	25.934
EC (mS/cm)	266	0.39	0.40	0.10	1.20	0.30	0.47	0.107
EC (µS/cm)	118	366.02	376.00	36.00	526.00	297.52	428.00	77.591
Turbidity (NTU)	266	15.6	9.4	0.5	180.0	5.0	20.9	18.52
TSS (mg/L)	274	6	5	1	49	2	9	5.9
TP (mg/L)	274	0.046	0.037	0.003	0.350	0.020	0.069	0.0390
TN (mg/L)	274	0.760	0.580	0.200	3.970	0.380	1.065	0.5520
NH_3-N (mg/L)	274	0.034	0.020	0.005	0.350	0.010	0.040	0.0460
NOx-N (mg/L)	274	0.305	0.120	0.005	3.210	0.020	0.550	0.4360
F.Cols (CFU/100ml)	274	688	100	2	33000	44	380	2526.1
E.Coli (CFU/100ml)	19	904	81	5	8000	34	420	2273.7
Entero (CFU/100ml)	31	222	170	4	800	57	320	208.7

Boxplots showing annual variability for each variable measured

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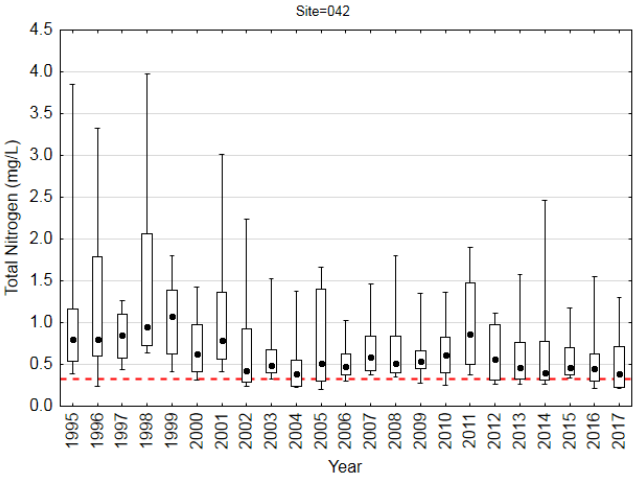
Total Phosphorus(mg/L)
Year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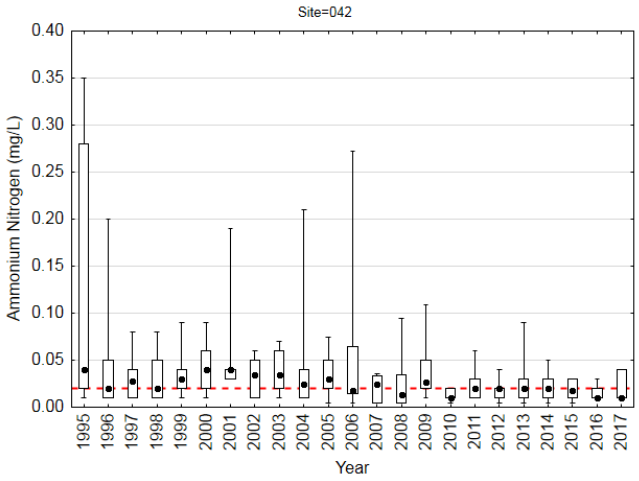
Total Nitrogen (mg/L)
Year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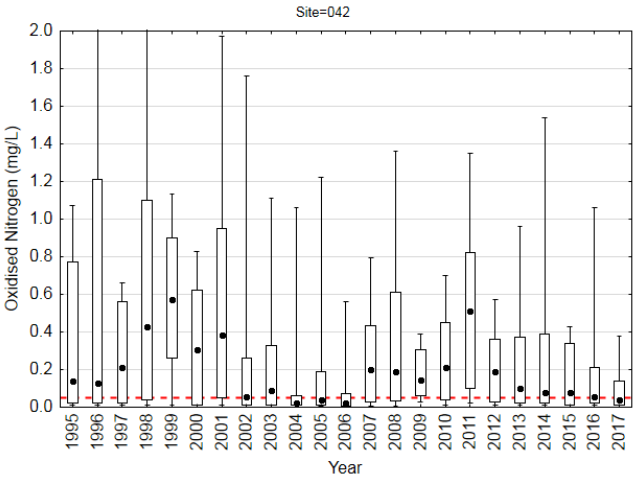
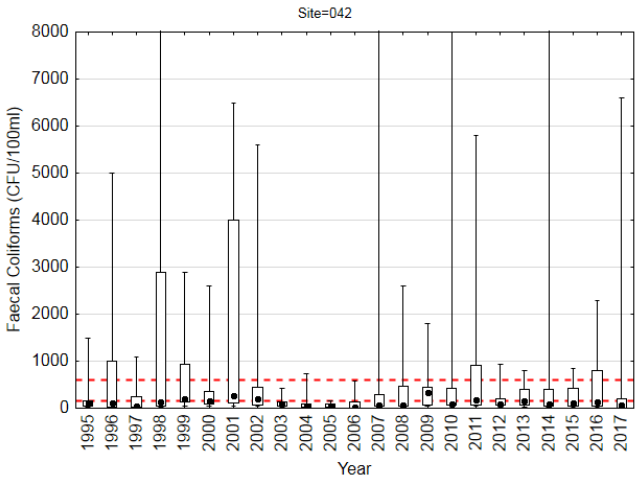
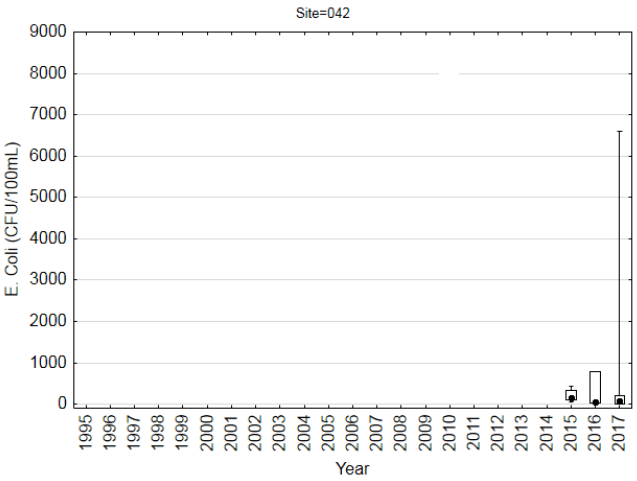
Ammonium Nitrogen (mg/L)
Year


Site=042
Oxidised Nitrogen (mg/L)
Year


Site=042
Faecal Coliforms (CFU/100ml)
Year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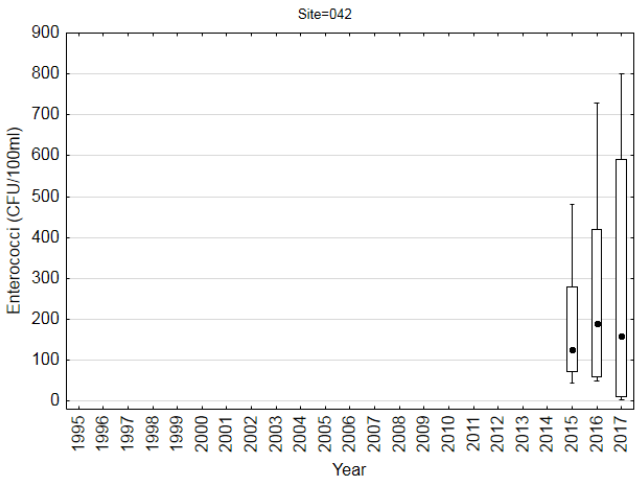
E. Coli (CFU/100mL)
Year


Site=042
Enterococci (CFU/100ml)
Year

Site 043 – Calna Creek, Berowra Valley National Park

Freshwater site
Berowra Creek Catchment

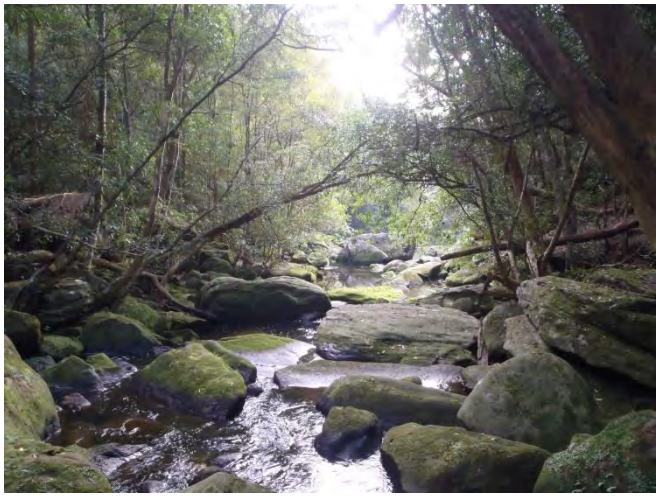
Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (043)	Oct 1994 – Sept 2017	Monthly
Ecohealth (CALN1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated, consistently exceeds the REHV and has long-term trends of increase. EC is elevated and consistently exceeds the REHV despite a long-term trend of decrease. Clarity: Turbidity and TSS are low and consistently comply with REHVs. TSS has a long-term trend of decrease. Nutrients: Nutrient levels are elevated and consistently exceed REHVs despite a significant decrease following WWTP upgrades (post-2003). The exception is NH_3-N which is low and generally complies with the REHV. Bacteria: Bacteria levels are generally low and comply with REHVs.
Issues	– Influenced by an urbanised catchment – Impacted by Hornsby Heights WWTP discharge
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Investigate sources of nutrients in the catchment (other than those from the WWTP)

Site Photos



Calna Creek looking downstream during low flow

Calna Creek looking downstream during high flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 043

043	REHV	Long-term				Post WWTP Upgrades (>2004)				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	264	16.14	NA	NS	160	16.21	NA	NS	59	16.94	NA	NS
pH	4.8-7	262	7.79	98	↑	159	7.88	99	NS	59	7.92	98	NS
DO (%sat)	75-118	246	98.00	4	↓	159	97.30	3	NS	59	97.80	2	NS
EC (mS/cm)	0.32	263	0.65	90	↓	159	0.62	91	↓	59	0.56	93	NS
Turbidity (NTU)	8	263	1.5	16	NS	148	1.4	13	NS	59	1.4	8	NS
TSS (mg/L)	7	269	1	5	↓	162	1	2	NS	59	1	2	↓
TP (mg/L)	0.01	270	0.050	95	NS	163	0.047	91	↑	59	0.077	100	↓
TN (mg/L)	0.32	270	3.915	99	↓	163	2.430	99	NS	59	2.460	98	NS
NH_3-N (mg/L)	0.02	270	0.010	15	↓	163	0.010	10	↑	59	0.010	5	↓
NO_x-N (mg/L)	0.05	270	2.990	99	↓	163	1.890	99	↓	59	1.890	98	NS
F.Cols (CFU/100ml)	150	270	39	22	↓	163	27	19	NS	59	29	19	NS

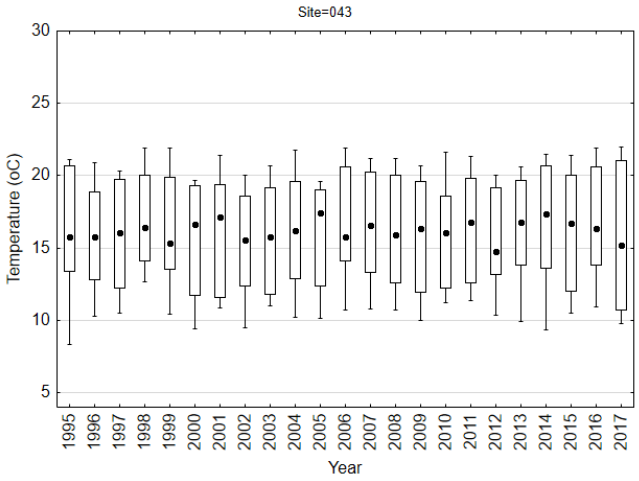
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

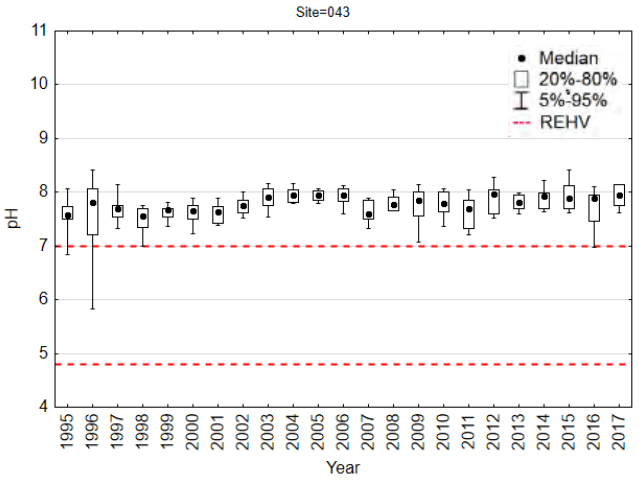
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

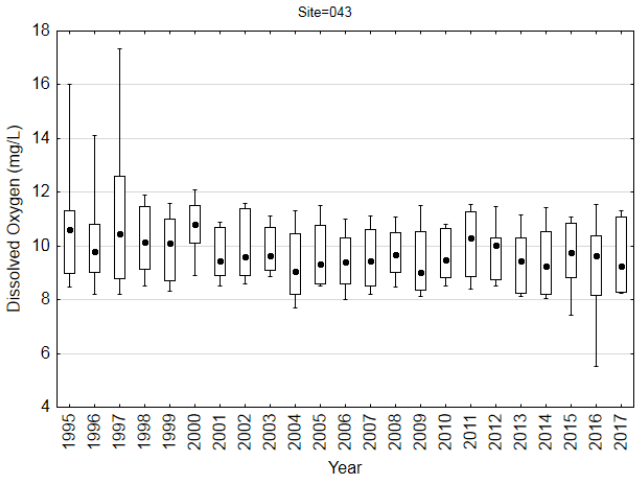
Table 2 Descriptive statistics for variables measured at Site 043 from January 1995 to September 2017

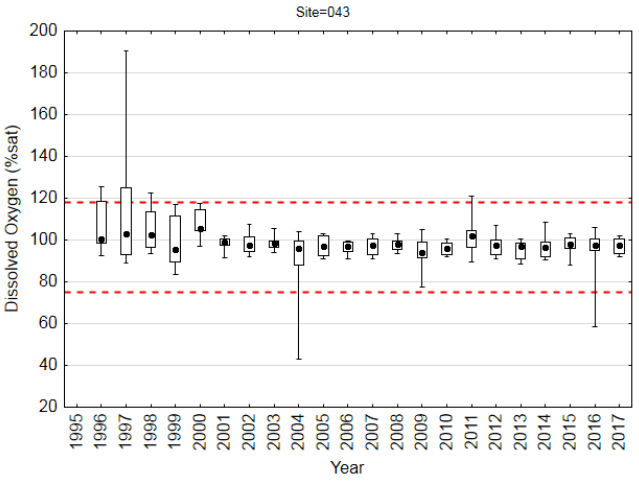
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	264	16.01	16.14	8.30	21.96	12.34	19.67	3.597
pH	262	7.76	7.79	5.82	8.42	7.57	7.98	0.281
DO (mg/L)	262	9.84	9.71	5.52	17.35	8.70	10.80	1.303
DO (%sat)	246	98.70	98.00	43.25	190.45	93.80	102.00	10.086
EC (mS/cm)	263	0.63	0.65	0.12	1.24	0.44	0.80	0.199
EC (µS/cm)	115	559.90	587.00	176.00	858.00	439.50	672.00	153.330
Turbidity (NTU)	263	5.2	1.5	0.0	208.0	0.4	5.6	15.04
TSS (mg/L)	269	3	1	0	86	1	2	6.0
TP (mg/L)	270	0.066	0.050	0.003	0.740	0.030	0.088	0.0670
TN (mg/L)	270	8.757	3.915	0.210	47.500	1.560	18.600	9.9190
NH_3-N (mg/L)	270	0.046	0.010	0.003	3.090	0.010	0.020	0.2330
NOx-N (mg/L)	270	7.612	2.990	0.040	36.800	1.155	16.255	9.0080
F.Cols (CFU/100ml)	270	720	39	1	61000	12	175	5252.7
E.Coli (CFU/100ml)	19	106	35	6	1100	15	94	246.9
Entero (CFU/100ml)	30	144	47	14	1300	31	120	282.4

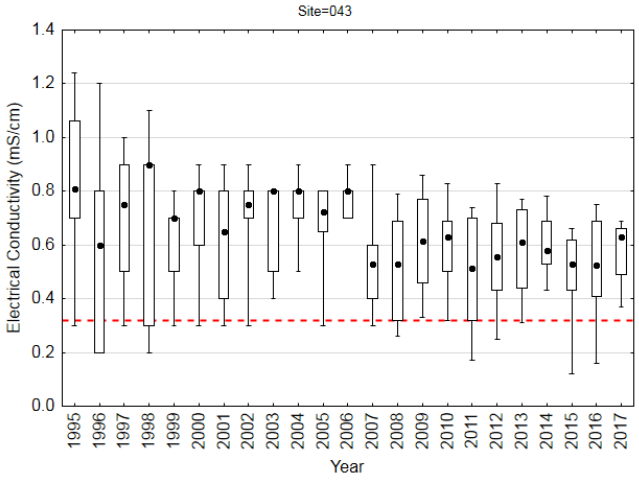
Boxplots showing annual variability for each variable measured

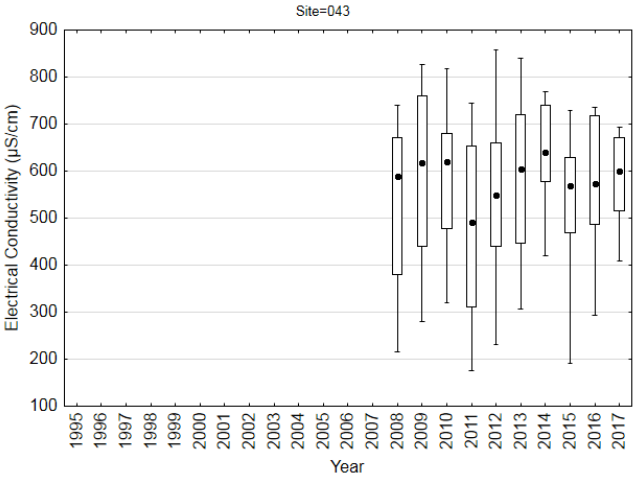


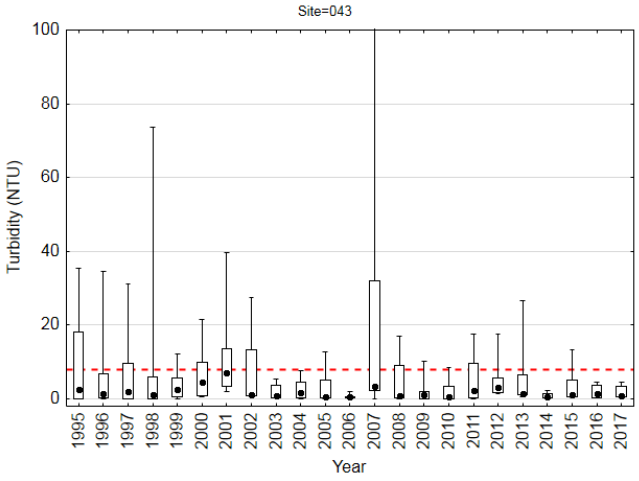


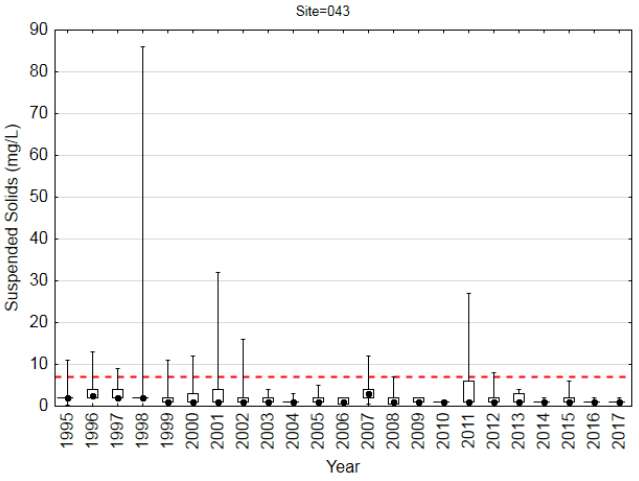


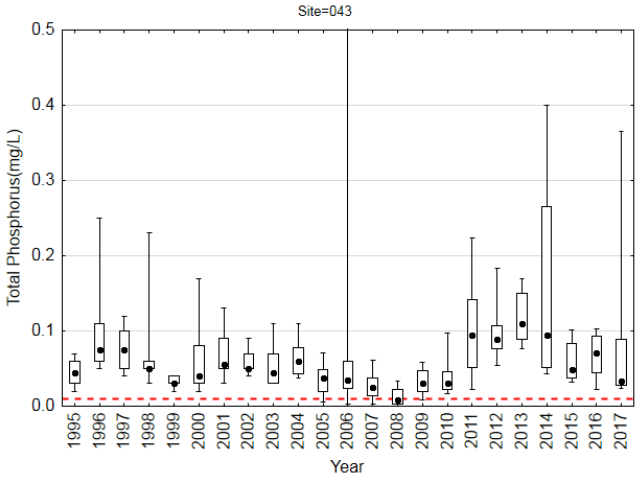








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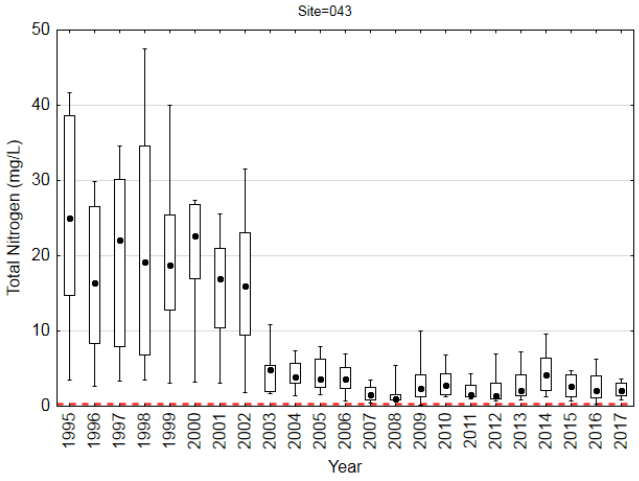
Total Phosphorus(mg/L)
Year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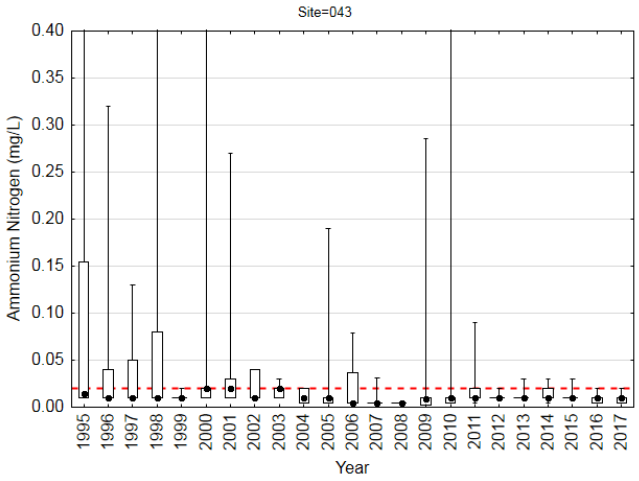
Total Nitrogen (mg/L)
Year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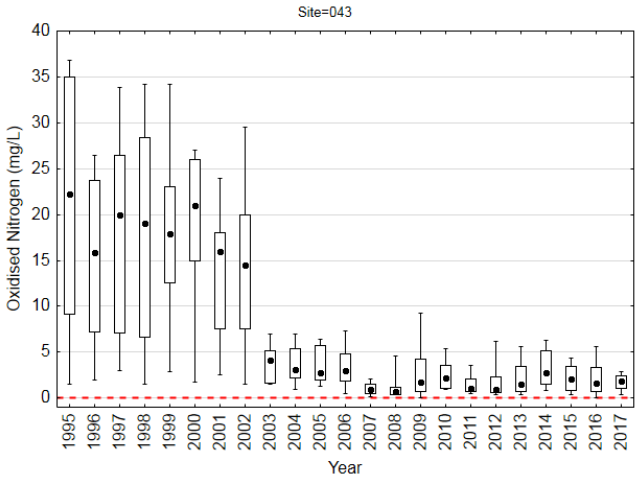
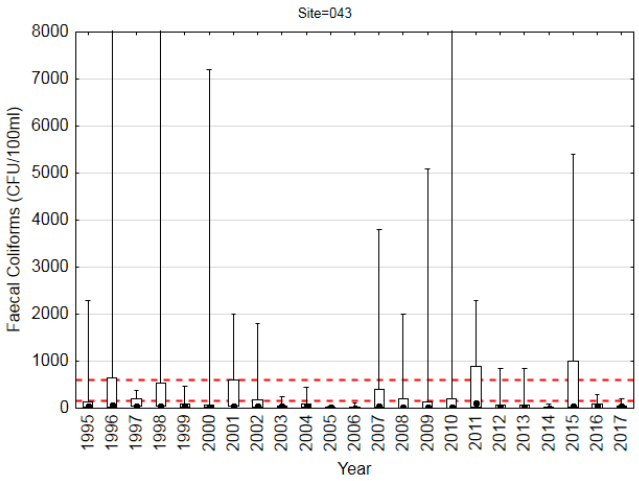
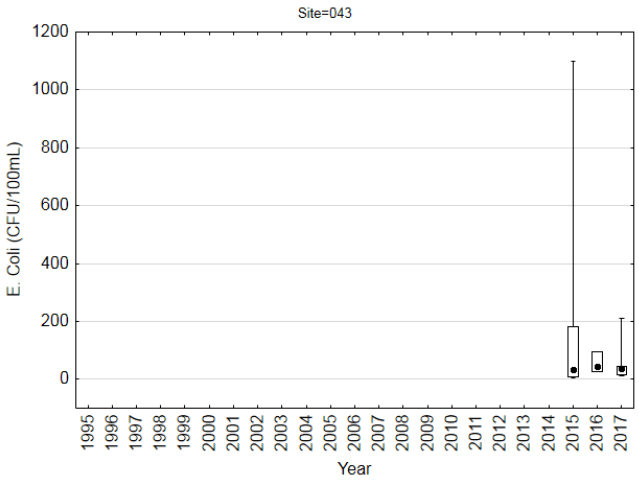
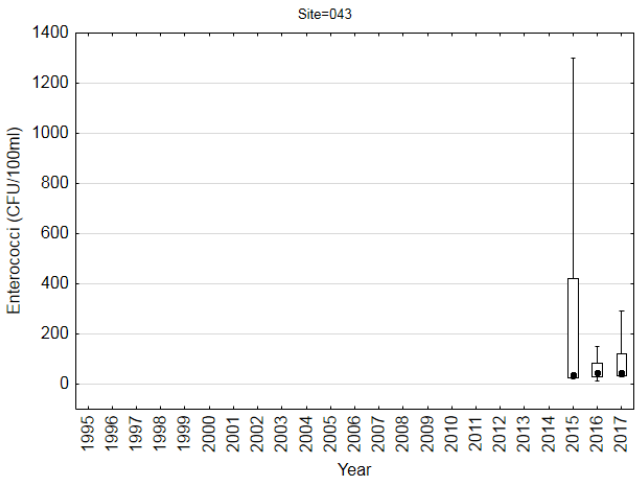
Ammonium Nitrogen (mg/L)
Year


Site=043
Oxidised Nitrogen (mg/L)
Year


Site=043
Faecal Coliforms (CFU/100ml)
Year


Site=043
E. Coli (CFU/100mL)
Year


Site=043
Enterococci (CFU/100ml)
Year

Site 045 – Fishponds, Berowra Creek

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (045)	Oct 1994 – Sept 2017	Monthly
Ecohealth (BERO6)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated, consistently exceeds the REHV and has long-term trends of increase. EC is elevated and consistently exceeds the REHV despite a long-term trend of decrease. Clarity: Turbidity and TSS are low and generally comply with REHVs. Nutrients: Nutrient levels are elevated and consistently exceed REHVs despite a significant decrease following WWTP upgrades (post-2003). The exception is NH_3-N which, following a long-term decrease is low and generally complies with the REHV. Bacteria: Bacteria results are highly variable and exceed REHVs approximately 50% of the time.
Issues	– Influenced by a large diverse catchment including urban and industrial land-uses – Impacted by West Hornsby WWTP discharge – Popular location for passive recreation
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment (other than those from the WWTP) – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with Sydney Water to improve the management of wastewater – Monitoring and assessment of bacteria levels to identify and manage risks in recreational waters

Site Photos

Fishponds looking upstream during high flow

Fishponds looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 045

045	REHV	Long-term				Post WWTP Upgrades (>2004)				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	277	18.51	NA	NS	173	18.51	NA	NS	61	19.73	NA	NS
pH	4.8-7	274	7.68	100	↑	171	7.71	100	↑	60	7.83	100	↑
DO (%sat)	75-118	255	99.80	2	↓	171	98.50	1	↑	61	101.20	0	NS
EC (mS/cm)	0.32	276	0.61	94	↓	172	0.60	92	↓	61	0.56	90	NS
Turbidity (NTU)	8	276	1.7	21	↓	150	1.1	15	NS	61	1.3	15	NS
TSS (mg/L)	7	279	1	11	↓	172	1	8	NS	60	1	10	NS
TP (mg/L)	0.01	280	0.055	96	↓	173	0.048	95	NS	60	0.049	100	↓
TN (mg/L)	0.32	280	3.610	100	↓	173	2.705	100	NS	60	2.780	100	NS
NH_3-N (mg/L)	0.02	280	0.020	32	↓	173	0.010	28	↓	60	0.010	12	NS
NO_x-N (mg/L)	0.05	280	3.000	100	↓	173	2.000	100	NS	60	2.113	100	NS
F.Cols (CFU/100ml)	150	280	150	49	NS	173	165	52	NS	60	135	50	NS

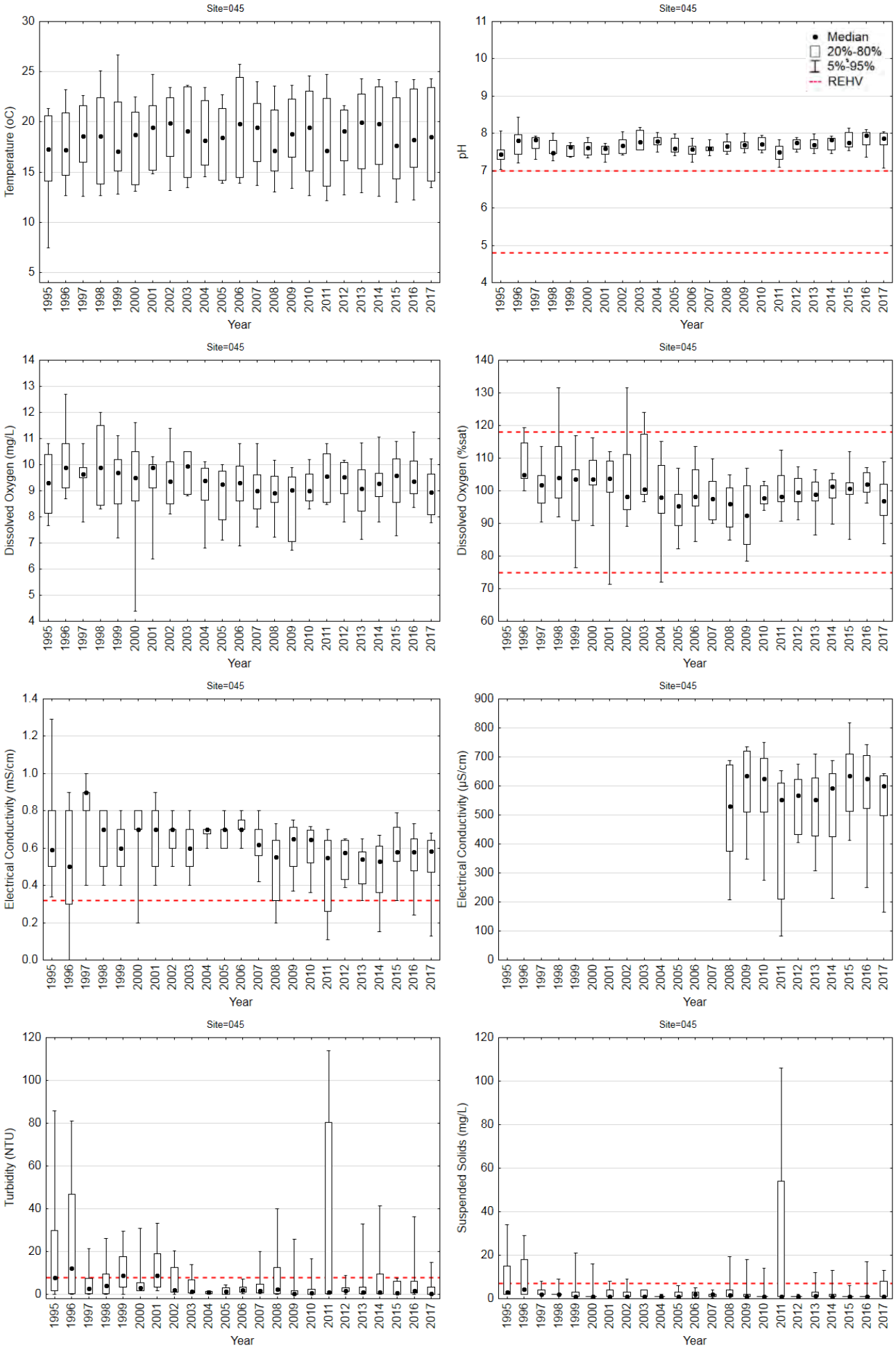
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

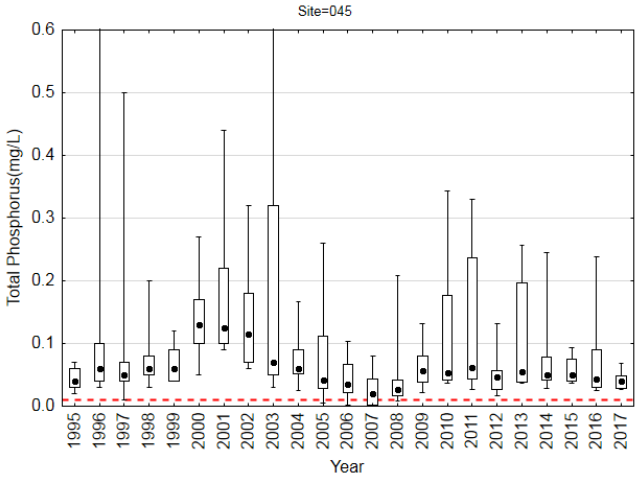
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 045 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	277	18.56	18.51	7.50	26.70	15.10	22.28	3.620
pH	274	7.68	7.68	7.04	8.40	7.50	7.87	0.210
DO (mg/L)	273	9.30	9.40	4.40	12.70	8.50	10.14	1.090
DO (%sat)	255	99.74	99.80	71.30	131.60	94.50	104.95	8.330
EC (mS/cm)	276	0.61	0.61	0.00	1.30	0.50	0.70	0.170
EC (µS/cm)	131	557.07	582.00	83.00	818.00	473.00	670.00	141.350
Turbidity (NTU)	276	7.2	1.7	0.0	114.0	0.5	8.6	14.96
TSS (mg/L)	279	4	1	1	106	1	3	9.5
TP (mg/L)	280	0.092	0.055	0.003	2.400	0.037	0.110	0.1700
TN (mg/L)	280	6.268	3.610	0.560	33.500	2.110	9.800	6.0800
NH_3-N (mg/L)	280	0.113	0.020	0.003	9.400	0.010	0.040	0.6300
NOx-N (mg/L)	280	5.264	3.000	0.180	29.000	1.538	8.460	5.5500
F.Cols (CFU/100ml)	280	3174	150	0	340000	51	525	22391.9
E.Coli (CFU/100ml)	17	395	110	31	3500	44	280	828.9
Entero (CFU/100ml)	86	990	53	16	32000	29	210	4310.4

Boxplots showing annual variability for each variable measured

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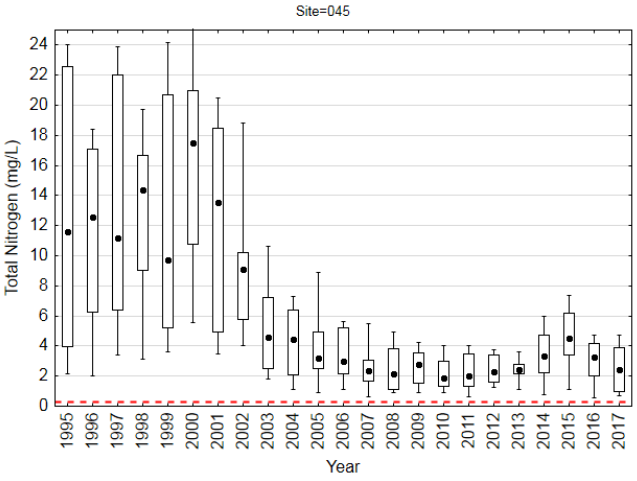
Total Phosphorus(mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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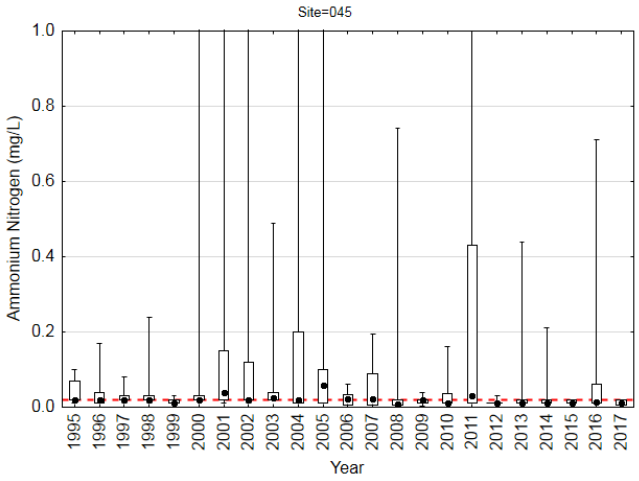
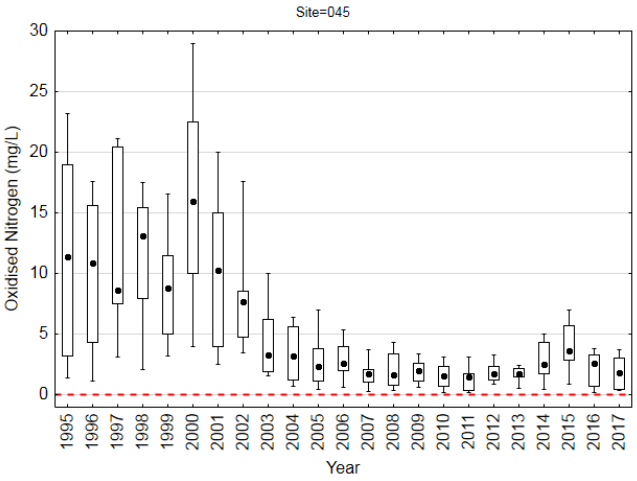
Total Nitrogen (mg/L)
0
2
4
6
8
10
12
14
16
18
20
22
24
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=045
Ammonium Nitrogen (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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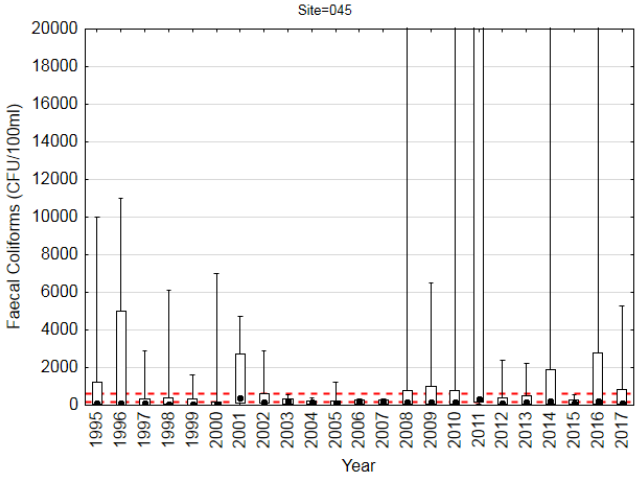
Oxidised Nitrogen (mg/L)
0
5
10
15
20
25
30
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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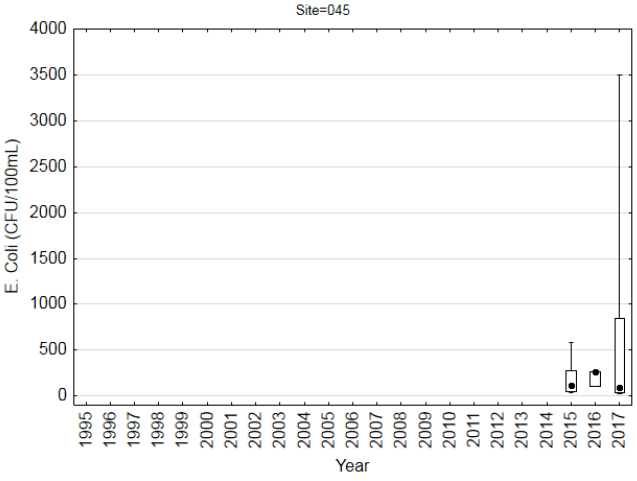
Faecal Coliforms (CFU/100ml)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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E. Coli (CFU/100mL)
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500
1000
1500
2000
2500
3000
3500
4000
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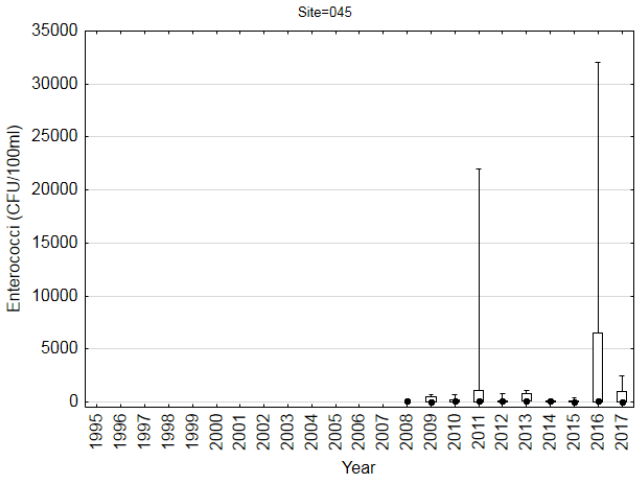
Year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Enterococci (CFU/100ml)
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10000
15000
20000
25000
30000
35000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 048 – Marramarra Creek, Marramarra National Park

Estuarine site
Berowra Creek Catchment

Monitoring Program Timelines

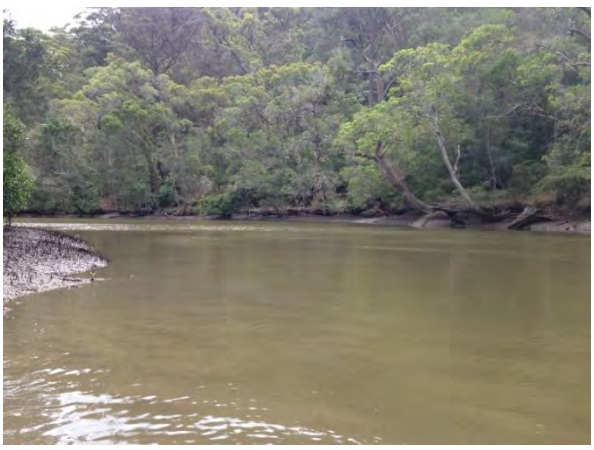
Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (048)	Oct 1994 – Sept 2017	Monthly
Ecohealth (MARR1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH generally complies with the REHV. DO is slightly suppressed complying with the REHV approximately 50% of the time. A weak, long-term decreasing trend in DO and salinity is evident. Clarity: Turbidity and TSS are elevated and exceed the REHVs approximately 55% and 70% of the time, respectively. Biological: Chl-a is generally low although variable, exceeding the REHV approximately 40% of the time. Nutrients: N-based nutrient levels are elevated and often exceed the REHVs. Bacteria: Bacterial levels are low and consistently comply with REHVs. Entero levels are generally low, although variable.
Issues	– Influenced by rural land-use in the upper catchment – Possible reduction in tidal flushing/incursion through time – Popular location for camping and recreation
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate sources of nutrients and bacteria in the catchment – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps

Site Photos

Marramarra Ck looking downstream during low tide



Marramarra Ck looking upstream during low tide

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 048

048	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	275	18.70	NA	NS	63	17.65	NA	NS
pH	7-8.5	275	7.20	20	NS	63	7.27	16	NS
DO (%sat)	80-110	249	81.80	49	↓	63	76.60	57	NS
Salinity (ppt)	NA	271	22.40	NA	↓	62	21.04	NA	NS
Turbidity (NTU)	10	275	11.4	57	NS	63	11.2	56	NS
TSS (mg/L)	6	275	12	80	NS	63	13	71	NS
Chl-a (ug/L)	4	270	2.7	36	NS	62	2.9	39	NS
TP (mg/L)	0.03	275	0.023	30	NS	63	0.022	30	NS
TN (mg/L)	0.3	249	0.340	65	↑	63	0.370	78	NS
NH_3-N (mg/L)	0.015	249	0.030	76	NS	63	0.020	79	NS
NOx-N (mg/L)	0.015	275	0.020	60	NS	63	0.020	67	NS
F.Cols (CFU/100ml)	150	275	14	8	↑	63	15	6	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	83	150	14	NS	62	150	10	NS

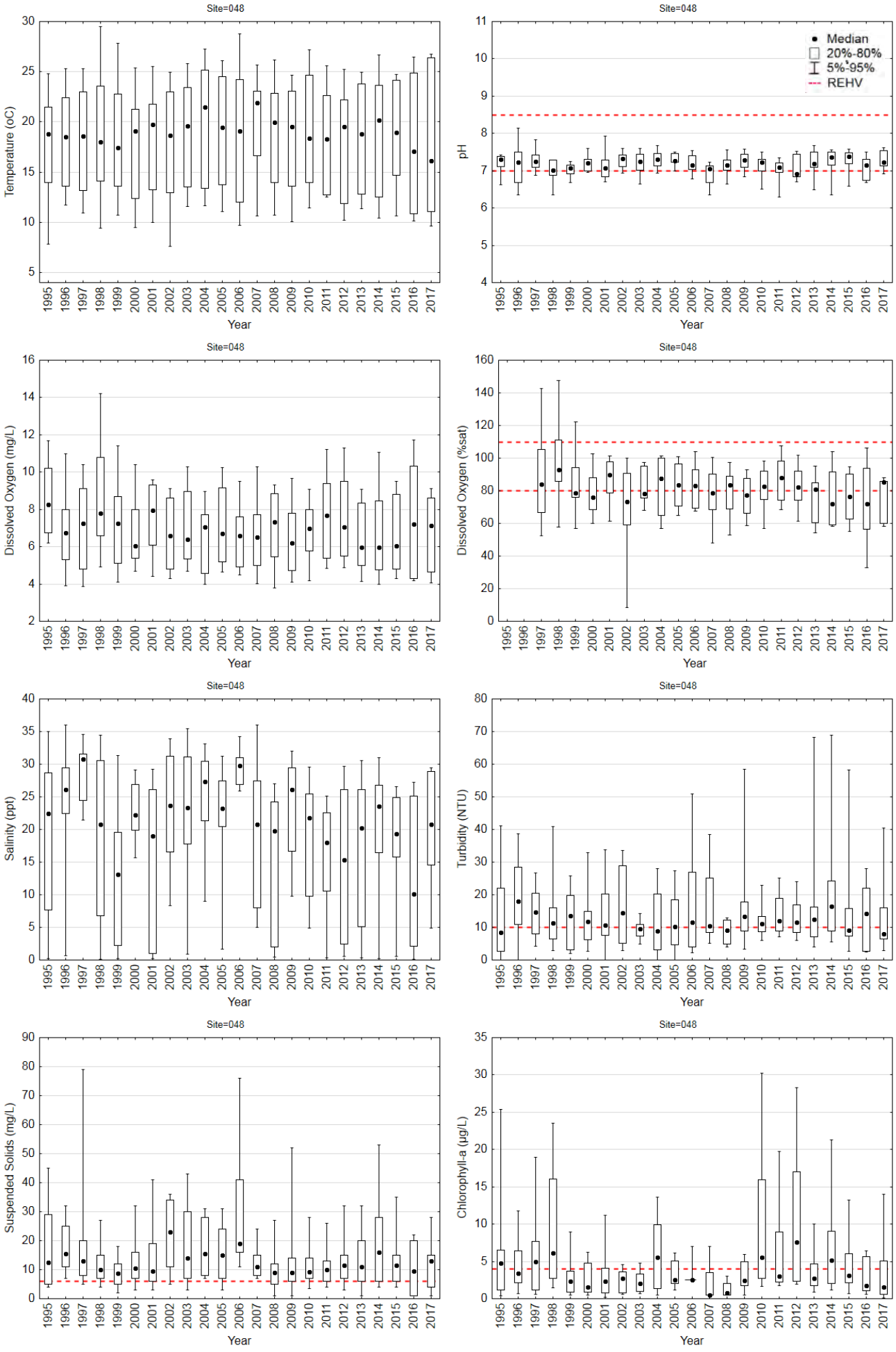
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

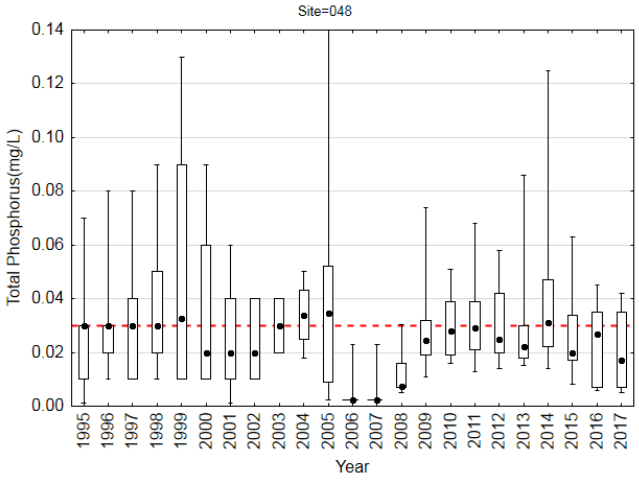
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 048 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	275	18.50	18.70	7.60	29.50	13.22	23.51	5.129
pH	275	7.18	7.20	6.30	8.14	6.98	7.40	0.283
DO (mg/L)	273	7.03	7.00	3.80	14.20	5.10	8.83	1.980
DO (%sat)	249	80.70	81.80	8.60	147.50	67.50	93.10	16.003
Salinity (ppt)	271	20.23	22.40	0.10	36.00	11.14	28.68	9.669
Turbidity (NTU)	275	13.8	11.4	0.0	68.8	6.2	19.9	10.33
TSS (mg/L)	275	15	12	1	79	7	21	11.4
Chlorophyll-a (µg/L)	270	4.5	2.7	0.1	30.3	1.2	6.4	4.86
TP (mg/L)	275	0.027	0.023	0.001	0.140	0.010	0.040	0.0211
TN (mg/L)	249	0.382	0.340	0.030	1.550	0.250	0.470	0.1954
NH_3-N (mg/L)	249	0.032	0.030	0.005	0.160	0.010	0.050	0.0248
NOx-N (mg/L)	275	0.058	0.020	0.004	1.050	0.010	0.060	0.1245
SRP (mg/L)	31	0.004	0.004	0.001	0.010	0.002	0.006	0.0025
F.Cols (CFU/100ml)	275	122	14	0	6800	4	43	591.7
E.Coli (CFU/100ml)	16	20	11	4	65	5	33	18.5
Entero (CFU/100ml)	83	158	11	1	8200	5	26	927.0

Boxplots showing annual variability for each variable measured

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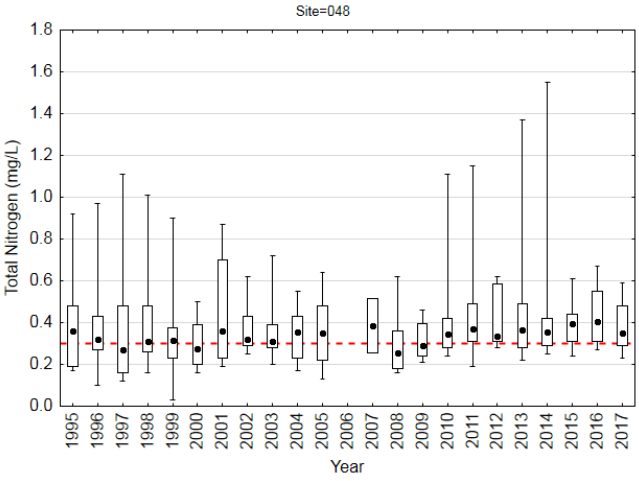
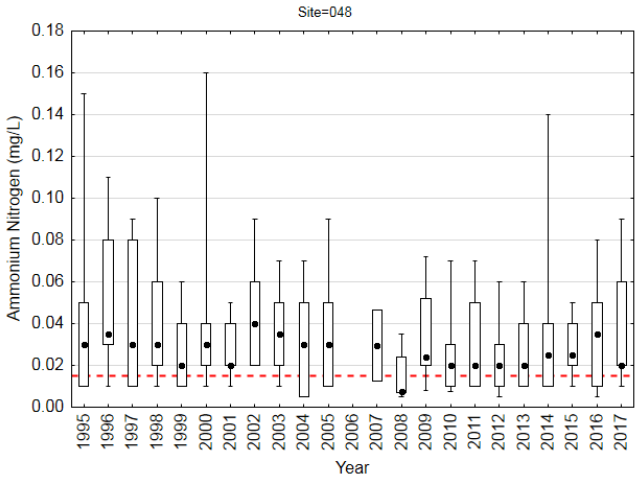
Total Phosphorus(mg/L)
Year


Site=048
Total Nitrogen (mg/L)
Year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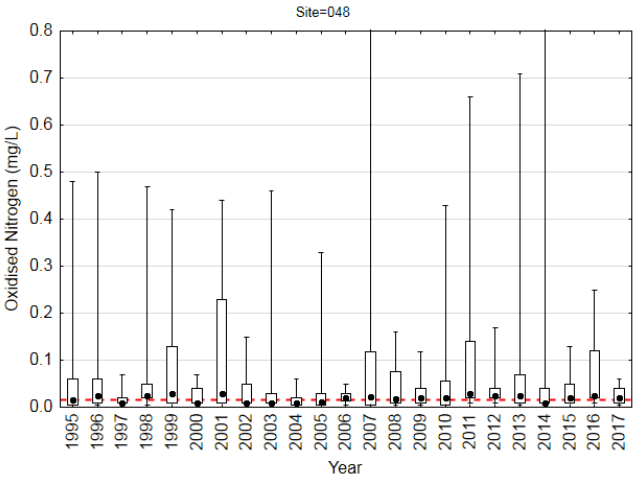
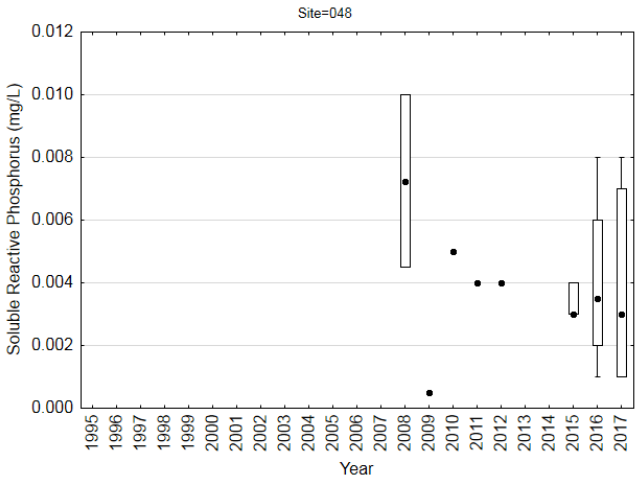
Ammonium Nitrogen (mg/L)
Year


Site=048
Oxidised Nitrogen (mg/L)
Year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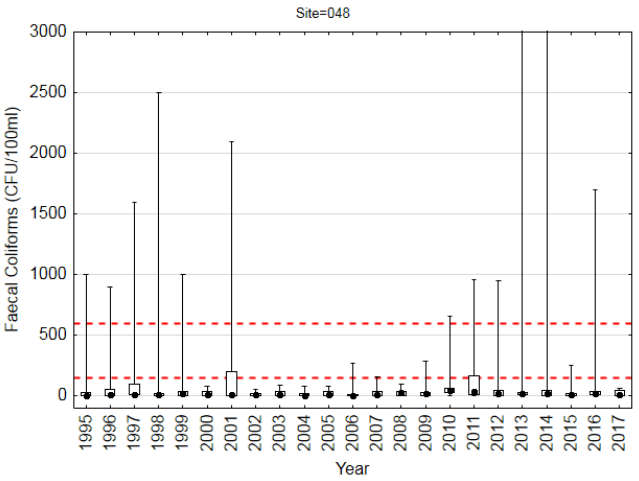
Soluble Reactive Phosphorus (mg/L)
Year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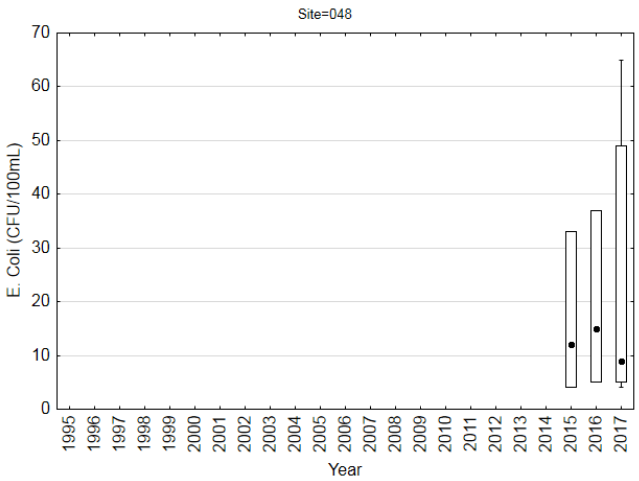
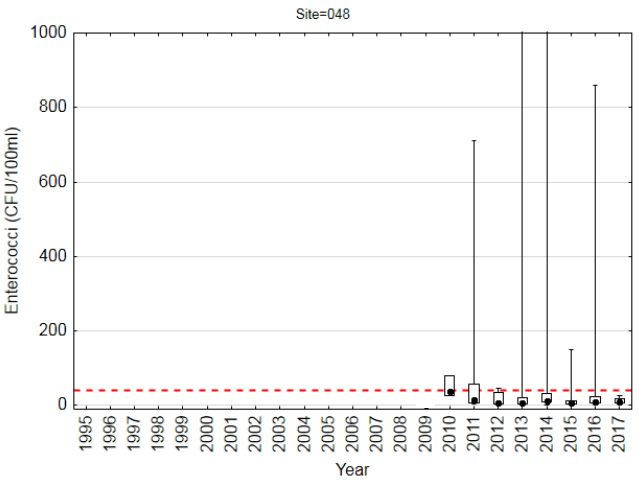
Faecal Coliforms (CFU/100ml)
Year


Site=048
E. Coli (CFU/100mL)
Year


Site=048
Enterococci (CFU/100ml)
Year

Site 049 – Still Creek, Galston

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (049)	Oct 1994 – Sept 2017	Monthly
Ecohealth (STIL2)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and often exceed REHVs. Clarity: Turbidity and TSS are generally low however turbidity exceeds REHVs approximately 25% of the time. Nutrients: Nutrient levels are elevated and often exceed REHVs, with the exception of NH_3-N, which is low and complies with REHVs. Bacteria: Bacteria levels are generally low but still exceed REHVs approximately 25% of the time.
Issues	– Influenced by rural land-use in the catchment.
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment – Identify further opportunities for WSUD in the catchment

Site Photos

Still Creek looking upstream during high flow

Still Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 049

049	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	267	15.81	NA	NS	59	16.42	NA	NS
pH	4.8-7	265	7.22	82	↓	58	7.11	62	↑
DO (%sat)	75-118	248	97.25	7	↓	59	94.20	2	NS
EC (mS/cm)	0.32	265	0.58	92	↓	59	0.55	90	NS
Turbidity (NTU)	8	266	3.7	26	NS	58	3.1	26	NS
TSS (mg/L)	7	273	2	11	↓	60	1	7	NS
TP (mg/L)	0.01	273	0.020	62	NS	60	0.013	60	NS
TN (mg/L)	0.32	273	0.470	81	↓	60	0.365	63	NS
NH_3-N (mg/L)	0.02	273	0.010	16	↓	60	0.010	12	NS
NO_x-N (mg/L)	0.05	273	0.100	69	NS	60	0.070	73	NS
F.Cols (CFU/100ml)	150	273	55	23	NS	60	41	25	NS

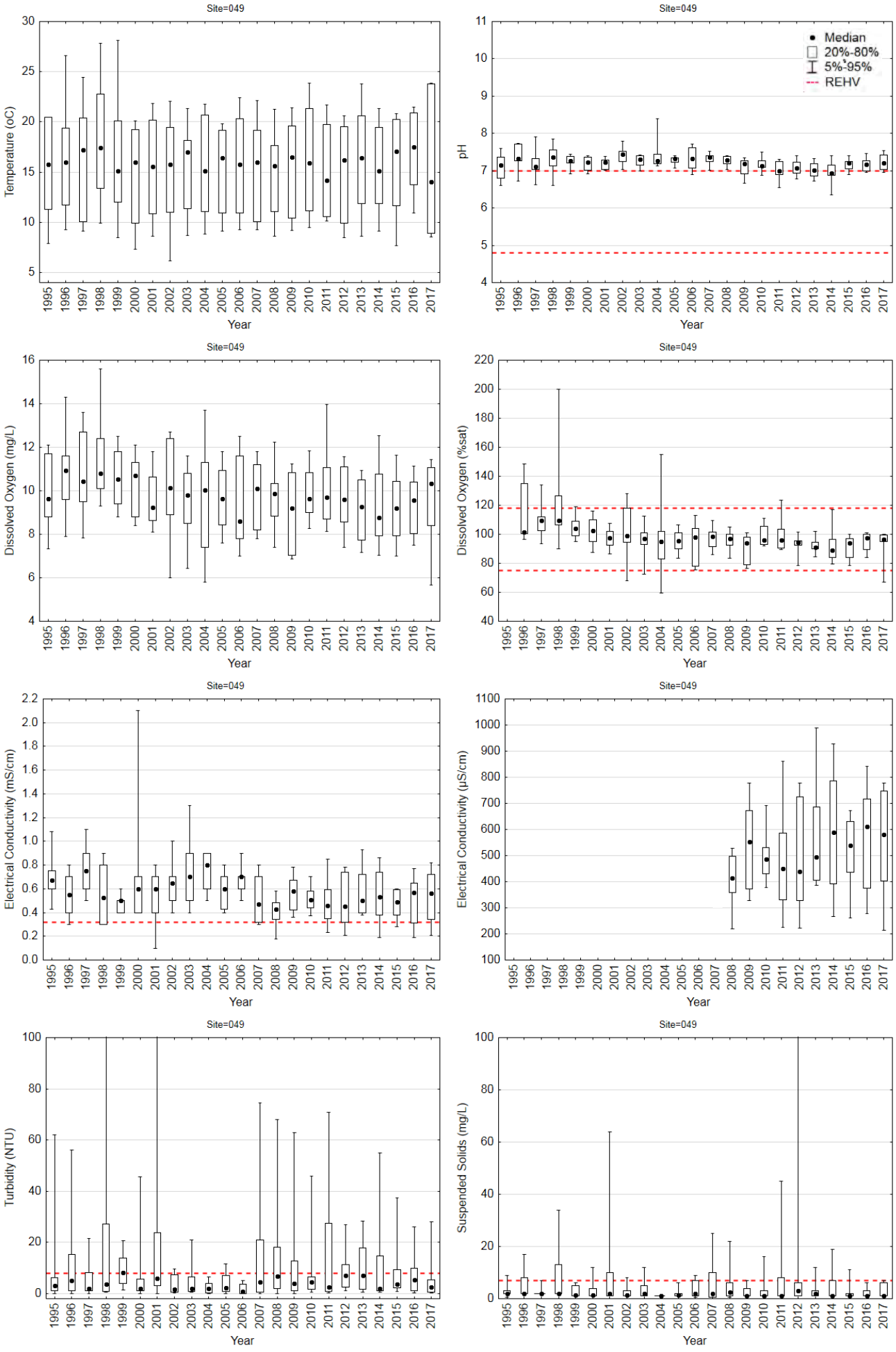
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

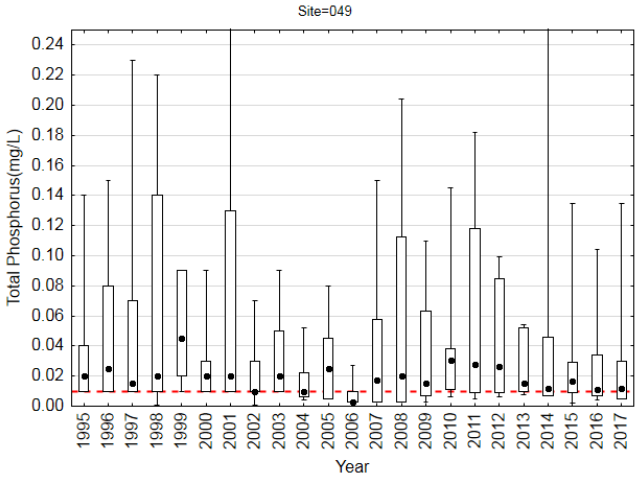
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 049 from January 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	267	15.67	15.81	6.14	28.10	10.93	20.22	4.600
pH	265	7.21	7.22	6.35	8.40	7.02	7.38	0.243
DO (mg/L)	264	9.88	9.80	5.68	15.60	8.50	11.20	1.604
DO (%sat)	248	98.47	97.25	59.65	200.00	90.80	105.15	13.693
EC (mS/cm)	265	0.58	0.58	0.10	2.10	0.40	0.70	0.208
EC (µS/cm)	117	514.49	485.00	215.00	990.00	377.00	650.00	164.534
Turbidity (NTU)	266	9.2	3.7	0.0	126.1	1.0	10.2	16.72
TSS (mg/L)	273	5	2	0	361	1	5	22.5
TP (mg/L)	273	0.036	0.020	0.001	0.320	0.010	0.052	0.0480
TN (mg/L)	273	0.781	0.470	0.080	18.200	0.330	0.885	1.2600
NH_3-N (mg/L)	273	0.018	0.010	0.003	0.360	0.010	0.020	0.0270
NOx-N (mg/L)	273	0.347	0.100	0.005	17.700	0.030	0.340	1.1670
F.Cols (CFU/100ml)	273	488	55	0	18000	13	210	1613.6
E.Coli (CFU/100ml)	20	702	41	1	6600	9	320	1806.4
Entero (CFU/100ml)	31	151	44	1	1200	8	190	275.1

Boxplots showing annual variability for each variable measured

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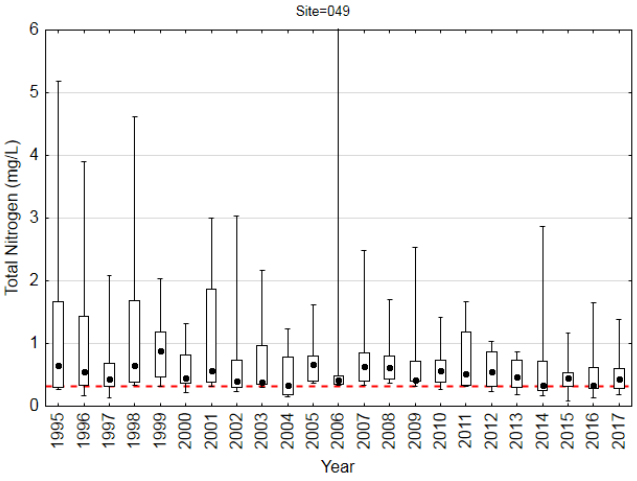
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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1
2
3
4
5
6
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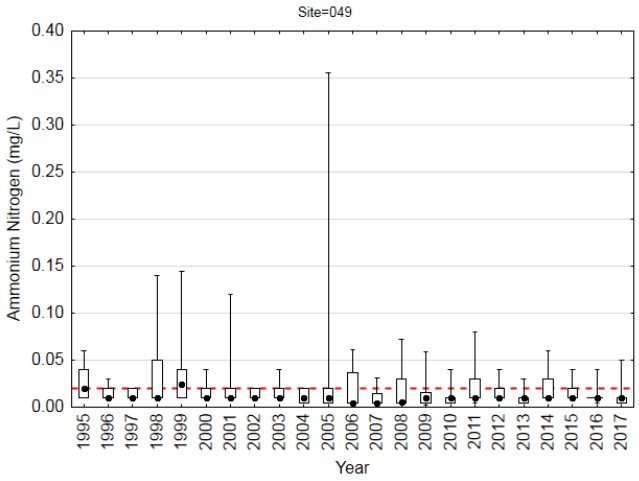
Year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Ammonium Nitrogen (mg/L)
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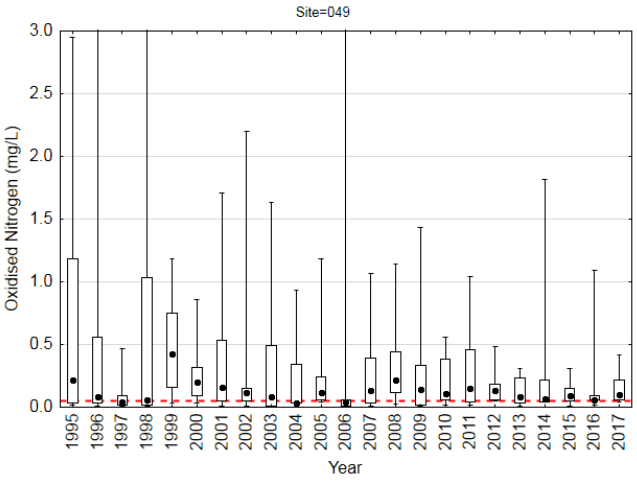
0.10
0.15
0.20
0.25
0.30
0.35
0.40
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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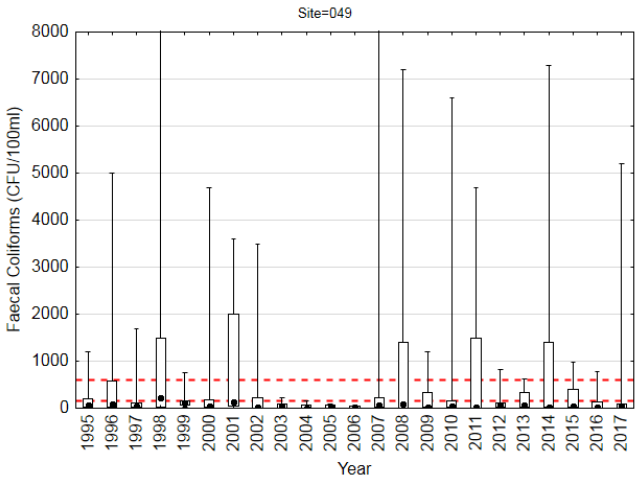
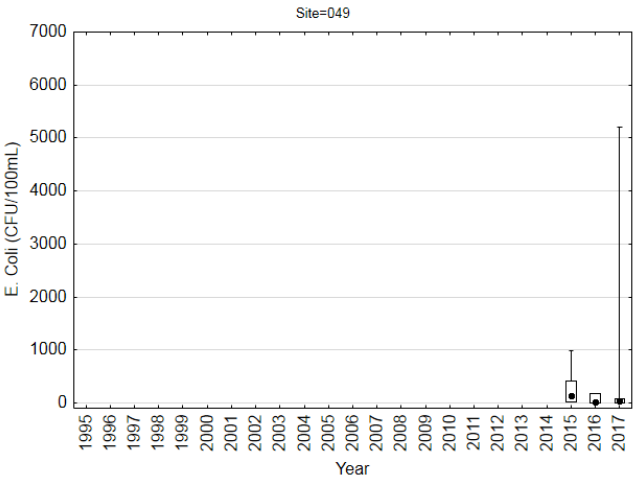
Oxidised Nitrogen (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=049
Faecal Coliforms (CFU/100ml)
0
1000
2000
3000
4000
5000
6000
7000
8000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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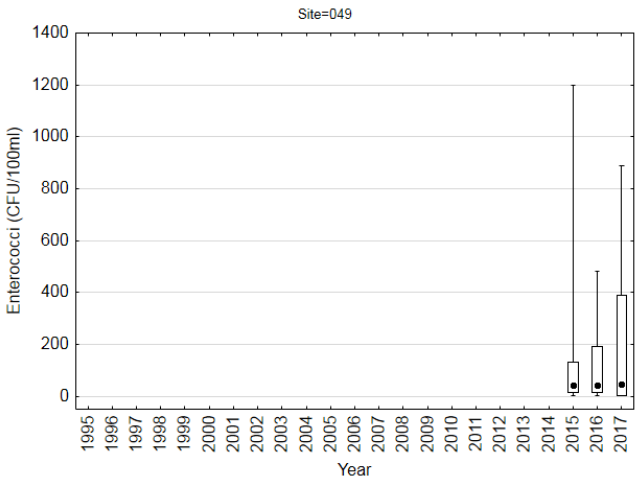
E. Coli (CFU/100mL)
0
1000
2000
3000
4000
5000
6000
7000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Enterococci (CFU/100ml)
0
200
400
600
800
1000
1200
1400
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 052 – Calna Creek, Hornsby Heights

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (052)	Nov 1995 – Sept 2017	Monthly
Ecohealth (CALN2)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated and consistently exceeds REHVs. DO is slightly suppressed and variable, complying with the REHV approximately 60% of the time. Clarity: Turbidity and TSS are low and generally comply with REHVs. Nutrients: TP is elevated and often exceeds the REHV. NOx-N results are variable exceeding the REHV approximately 50% of the time. NH_3-N levels are low and generally comply with the REHV however it has a long-term increasing trend. Bacteria: Bacterial levels variable exceeding REHVs around 50% of the time.
Issues	– Influenced by a relatively small, highly urbanised catchment – Possible pressure from wastewater infrastructure
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients (particularly TP) and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events

Site Photos

Calna Creek looking upstream during low flow

Calna Creek looking downstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 052

052	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	370	15.59	NA	NS	62	15.82	NA	NS
pH	4.8-7	368	7.20	86	↓	62	7.20	82	↑
DO (%sat)	75-118	353	88.60	26	↓	62	78.75	44	NS
EC (mS/cm)	0.32	369	0.30	25	NS	62	0.27	24	NS
Turbidity (NTU)	8	370	4.0	26	NS	62	5.2	19	NS
TSS (mg/L)	7	375	1	9	↓	62	1	5	NS
TP (mg/L)	0.01	375	0.017	62	NS	62	0.022	87	NS
TN (mg/L)	0.32	375	0.290	39	NS	62	0.275	35	NS
NH_3-N (mg/L)	0.02	375	0.010	11	↑	62	0.020	10	↑
NO_x-N (mg/L)	0.05	375	0.075	54	NS	62	0.030	44	NS
F.Cols (CFU/100ml)	150	375	120	45	NS	62	130	48	NS

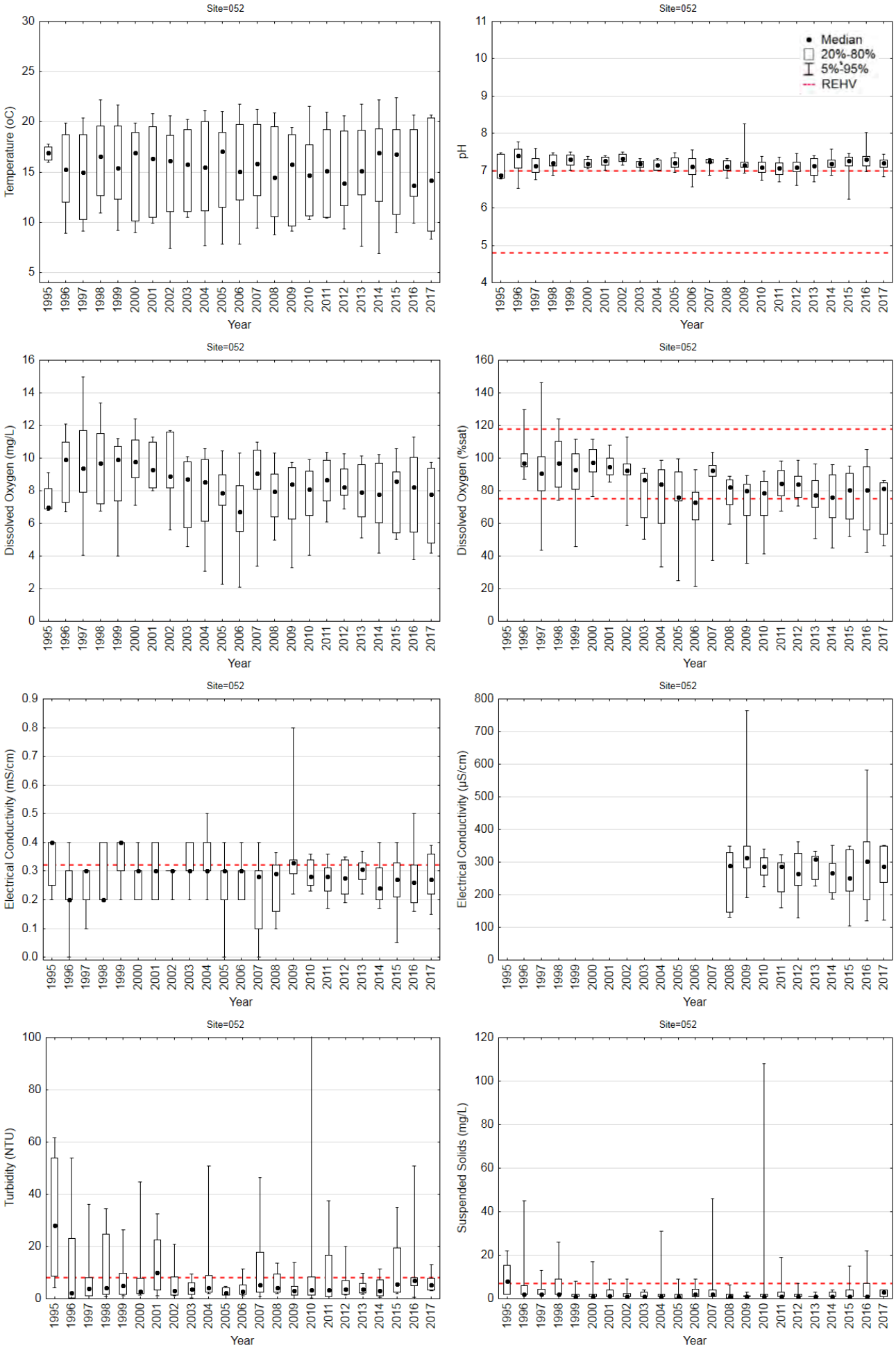
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

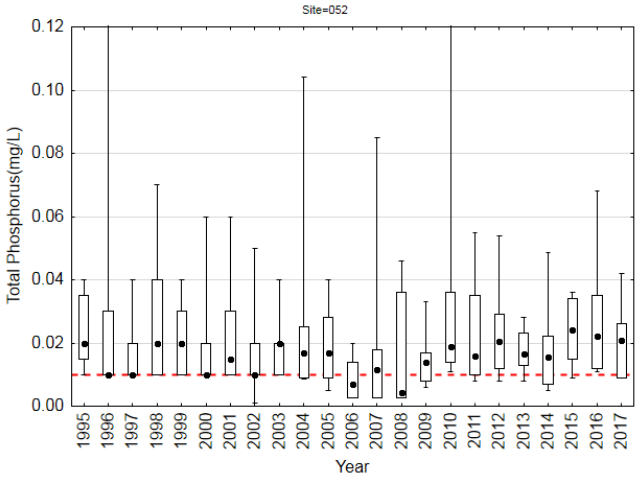
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 052 from November 1995 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	370	15.40	15.59	6.70	23.20	11.26	19.27	3.930
pH	368	7.20	7.20	6.24	8.26	7.05	7.35	0.223
DO (mg/L)	368	8.58	8.78	2.10	17.45	6.93	10.30	2.180
DO (%sat)	353	84.87	88.60	21.30	194.20	73.00	97.10	18.980
EC (mS/cm)	369	0.29	0.30	0.00	1.65	0.20	0.35	0.115
EC (µS/cm)	119	281.96	287.00	104.00	764.00	230.00	327.00	78.993
Turbidity (NTU)	370	9.2	4.0	0.0	268.5	1.8	9.8	19.95
TSS (mg/L)	375	4	1	1	108	1	3	8.4
TP (mg/L)	375	0.022	0.017	0.001	0.420	0.010	0.030	0.0290
TN (mg/L)	375	0.416	0.290	0.050	4.900	0.200	0.488	0.4590
NH_3-N (mg/L)	375	0.028	0.010	0.003	4.400	0.010	0.020	0.2270
NOx-N (mg/L)	375	0.164	0.075	0.005	2.000	0.010	0.207	0.2720
F.Cols (CFU/100ml)	375	834	120	1	22000	55	608	2333.3
E.Coli (CFU/100ml)	19	646	130	25	4900	40	1000	1144.6
Entero (CFU/100ml)	30	495	225	4	3300	42	495	876.6

Boxplots showing annual variability for each variable measured

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Total Phosphorus(mg/L)
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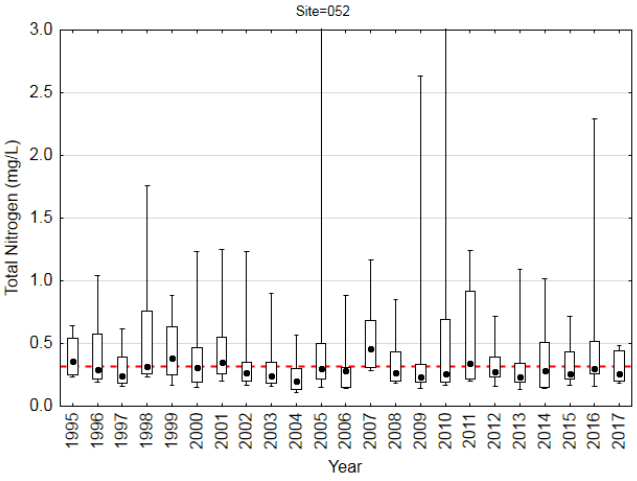
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=052
Total Nitrogen (mg/L)
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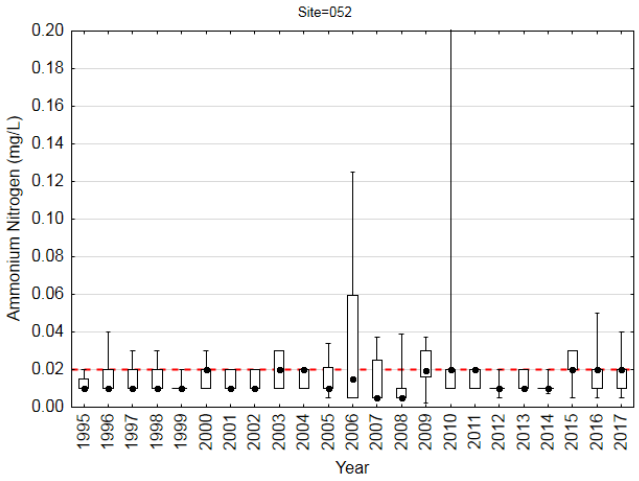
2.5
2.0
1.5
1.0
0.5
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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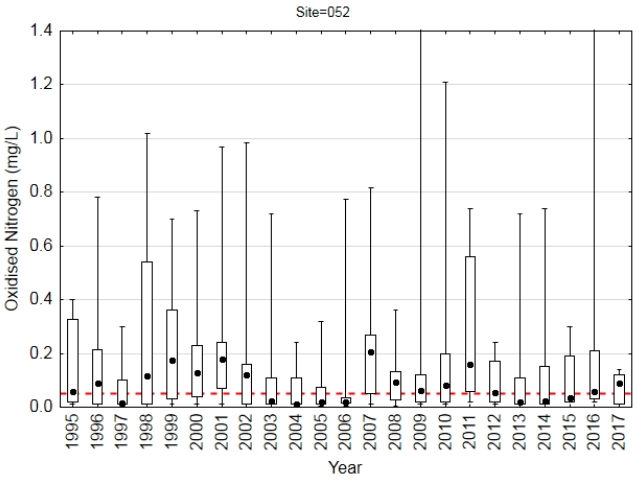
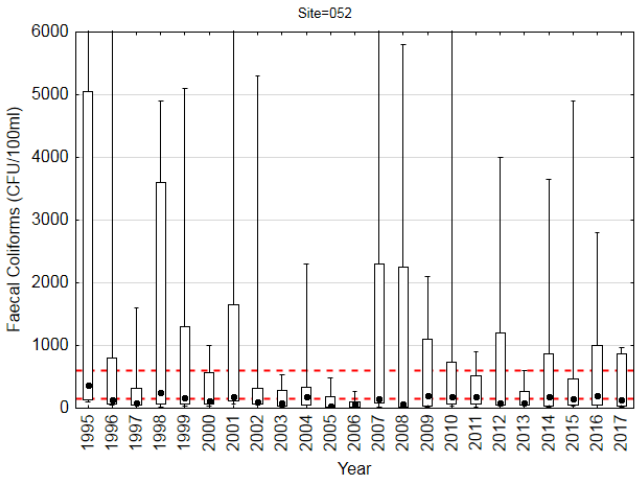
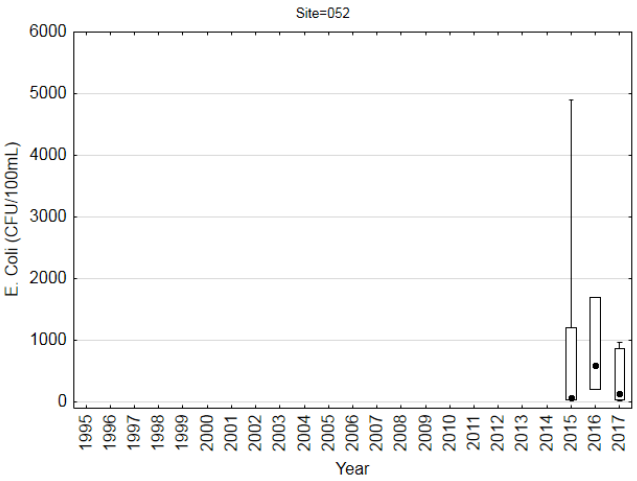
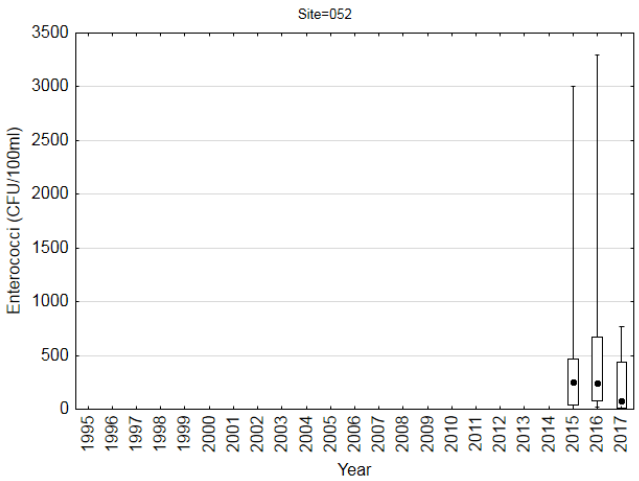
Ammonium Nitrogen (mg/L)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=052
Oxidised Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=052
Faecal Coliforms (CFU/100ml)
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=052
E. Coli (CFU/100mL)
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=052
Enterococci (CFU/100ml)
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 055 – Brooklyn Baths, Hawkesbury River

Estuarine site
Hawkesbury River Catchment

Monitoring Program Timelines

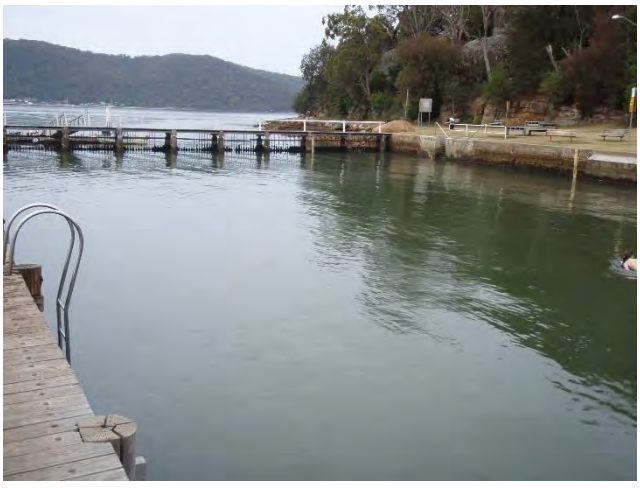
Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (055)	Oct 2013 – Sept 2017	Monthly
Recreational (055)	Dec 2004 – Mar 2011 Nov 2016 – Mar 2017	Weekly during summer months
Event (055)	Dec 2017 ongoing	Following significant rainfall events

Key Findings and Recommendations

Condition	Phys-chem: pH and DO consistently comply with REHVs. Clarity: Turbidity is generally low exceeding the REHV approximately 55% of the time with a long-term increasing trend evident. TSS is elevated and exceeds the REHV approximately 90% of the time. Biological: Chl-a levels are low and consistently comply with the REHV. Nutrients: Nutrient levels are low and generally comply with REHVs, with the exception of NOx-N, which is slightly elevated and exceeds the REHV approximately 60% of the time. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Recreational swimming location – Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment – Possible influence from local commercial marina and boating operations
Recommendations	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate the influence of wet-weather events on local conditions – Investigate sources of increasing nutrients in the Hawkesbury River – Monitoring and assessment of bacteria levels to identify and manage risks in recreational waters – Suitability for recreational use to be advised on Council's web-based swimming maps

Site Photos

Brooklyn Baths looking west



Brooklyn Baths looking east

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 055

055	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	178	23.85	NA	*	58	21.68	NA	NS
pH	7-8.5	177	7.90	0	*	58	8.03	0	NS
DO (%sat)	80-110	178	93.51	6	*	58	95.30	7	↓
Salinity (ppt)	NA	177	33.31	NA	*	57	33.05	NA	↓
Turbidity (NTU)	10	178	8.0	30	*	58	10.1	55	NS
TSS (mg/L)	6	146	9	67	*	44	12	89	NS
Chl-a (ug/L)	4	159	2.0	7	*	57	2.0	4	NS
TP (mg/L)	0.03	159	0.018	5	*	58	0.020	10	↑
TN (mg/L)	0.3	144	0.220	13	*	58	0.240	14	↑
NH_3-N (mg/L)	0.015	145	0.010	37	*	58	0.010	47	NS
NOx-N (mg/L)	0.015	160	0.020	56	*	58	0.020	57	↑
F.Cols (CFU/100ml)	150	159	2	2	*	57	3	2	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	146	18	2	*	53	17	2	NS

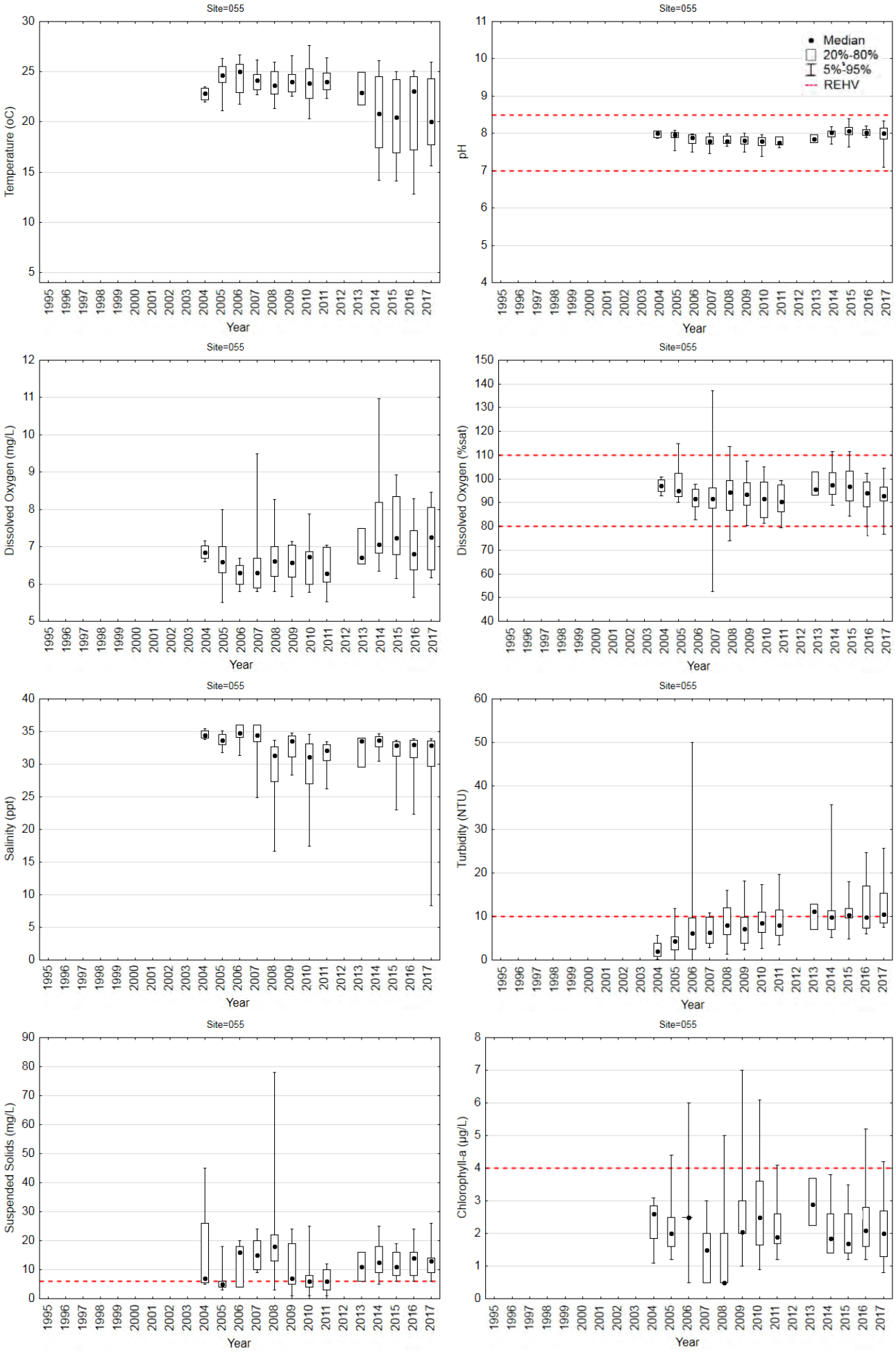
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05
** - trend analysis not appropriate due to a change in sampling effort*

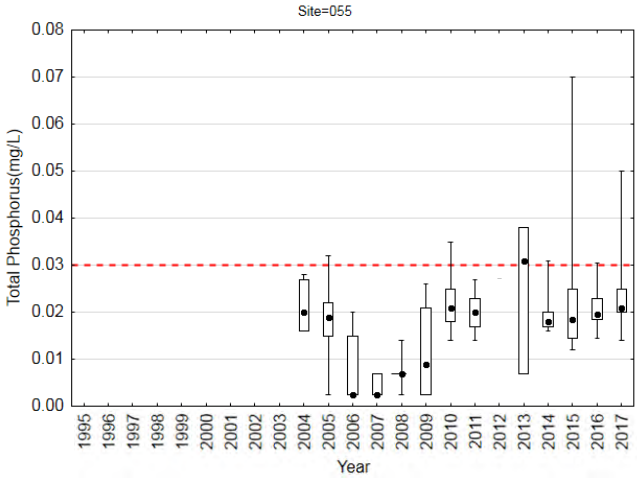
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 055 from December 2004 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	178	23.09	23.85	10.16	27.60	21.91	25.00	2.794
pH	177	7.88	7.90	7.09	8.40	7.75	8.03	0.176
DO (mg/L)	178	6.75	6.60	5.15	10.97	6.20	7.10	0.747
DO (%sat)	178	94.03	93.51	52.50	137.30	89.00	99.00	8.212
Salinity (ppt)	177	32.17	33.31	8.38	36.00	31.12	34.26	3.722
Turbidity (NTU)	178	8.7	8.0	0.0	50.0	4.4	11.2	5.95
TSS (mg/L)	146	12	9	1	78	5	16	9.0
Chlorophyll-a (µg/L)	159	2.2	2.0	0.5	7.0	1.4	2.8	1.15
TP (mg/L)	159	0.017	0.018	0.003	0.070	0.007	0.023	0.0095
TN (mg/L)	144	0.231	0.220	0.050	0.610	0.180	0.270	0.0865
NH_3-N (mg/L)	145	0.015	0.010	0.003	0.080	0.010	0.020	0.0116
NOx-N (mg/L)	160	0.028	0.020	0.003	0.290	0.010	0.040	0.0339
SRP (mg/L)	34	0.007	0.007	0.002	0.017	0.004	0.010	0.0032
F.Cols (CFU/100ml)	159	10	2	0	250	1	8	31.8
E.Coli (CFU/100ml)	25	6	2	1	51	1	8	12.2
Entero (CFU/100ml)	146	9	2	1	400	1	5	39.6

Boxplots showing annual variability for each variable measured

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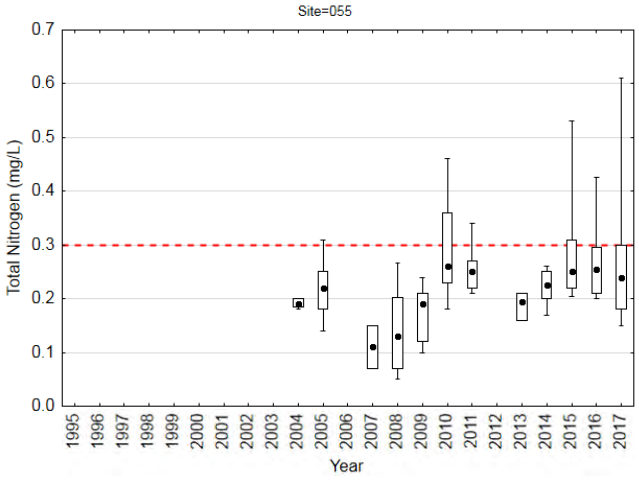
Total Phosphorus(mg/L)
Year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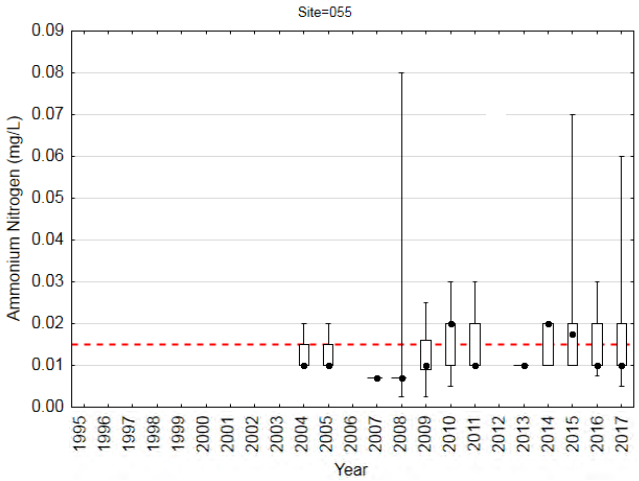
Total Nitrogen (mg/L)
Year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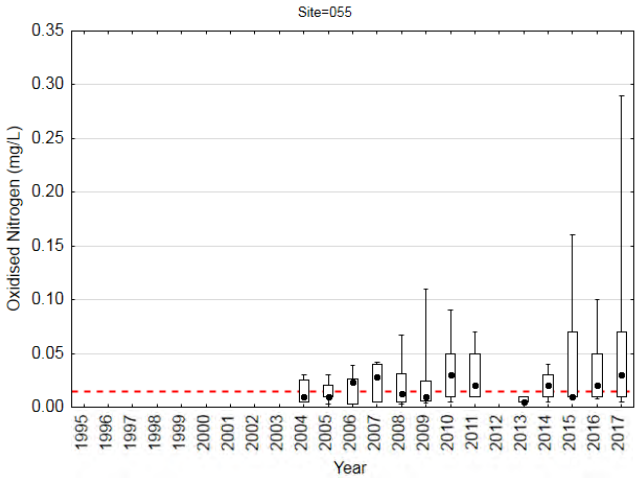
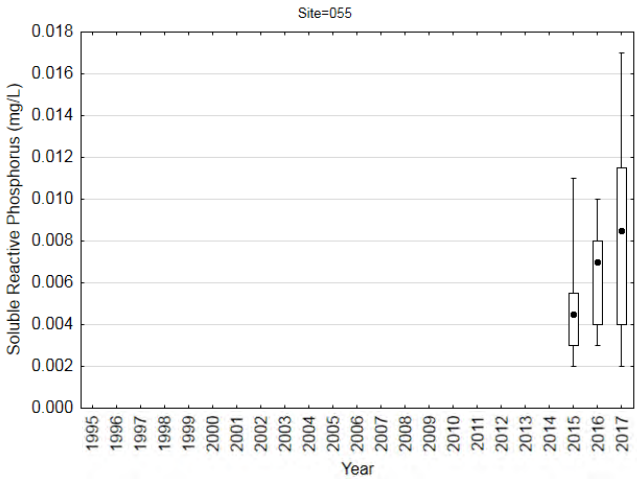
Ammonium Nitrogen (mg/L)
Year


Site=055
Oxidised Nitrogen (mg/L)
Year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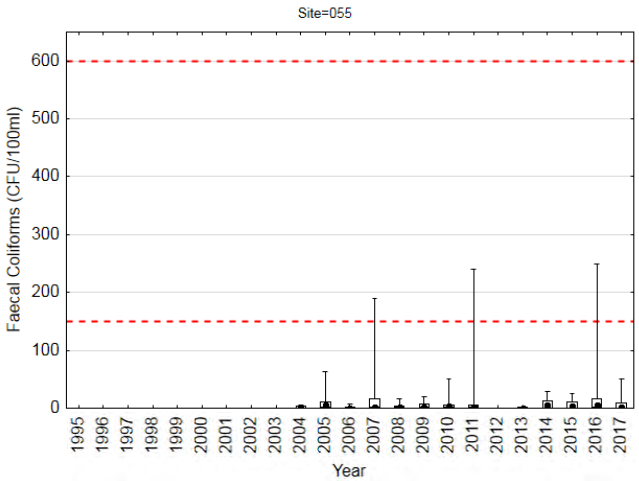
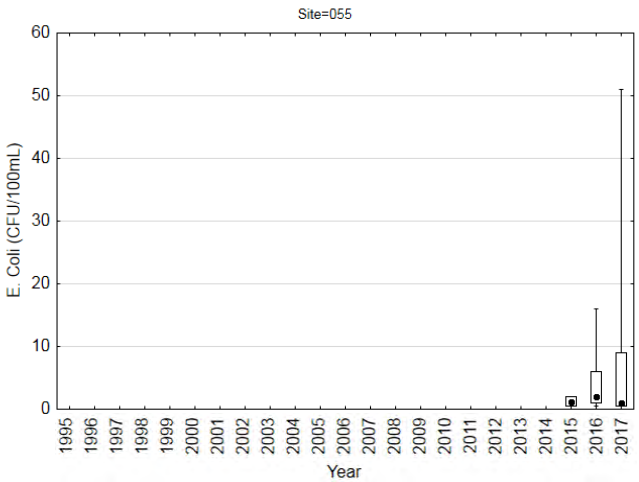
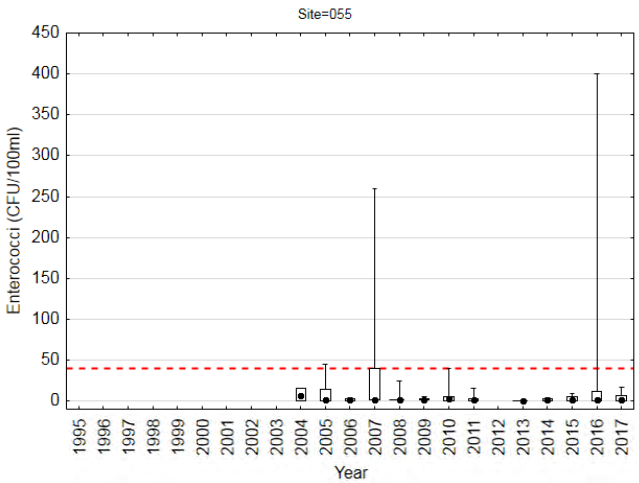
Soluble Reactive Phosphorus (mg/L)
Year


Site=055
Faecal Coliforms (CFU/100ml)
Year


Site=055
E. Coli (CFU/100mL)
Year


Site=055
Enterococci (CFU/100ml)
Year

Site 060 – Berowra Waters, Berowra Creek

Estuarine site, Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (060)	Jan 1997 – Sept 2017	Monthly
Algae (060)	May 2003 – Jun 2018	Monthly
	Jun 2018 – ongoing	In response to elevated algae

Key Findings and Recommendations

Condition	Phys-chem: pH consistently complies with the REHV. DO is slightly suppressed and variable complying with the REHV approximately 50% of the time. A long-term decreasing trend in salinity is evident. Clarity: Turbidity and TSS levels are low and generally comply with REHVs, despite a long-term increasing trend in turbidity. Biological: Chl-a is slightly elevated and exceeds the REHV approximately 55% of the time. Nutrients: N-based nutrients are elevated and generally exceed REHVs despite a significant decrease in nutrients following WWTP upgrades. An increasing trend in TN and TP is evident from 2003 onwards. Bacteria: F.Col levels are low and consistently comply with REHVs. Entero levels are generally low, although variable.
Issues	– Influenced by a large diverse catchment including urban, rural and industrial land-uses – Impacted by Hornsby Heights and West Hornsby WWTP discharge – Influenced by local commercial marina operations and boat use – Influenced by local riverside settlements – Possible reduction in tidal flushing/incursion through time
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Ongoing collaboration with Sydney Water to improve the management of wastewater – Education and collaboration with marina operators and boat users to minimise impacts from these activities – Education and collaboration with riverside residents to minimise impacts from these settlements – Ongoing (response) monitoring to identify and manage risks associated with algal blooms – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Undertake a review of all phytoplankton monitoring data

Site Photos

Berowra Waters marina and ferry crossing from above

Berowra Waters looking west

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 060

060	REHV	Long-term				Post WWTP Upgrades (>2004)				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	247	20.60	NA	NS	165	20.58	NA	NS	60	20.65	NA	NS
pH	7-8.5	247	7.53	5	NS	165	7.50	7	NS	60	7.53	3	NS
DO (%sat)	80-110	245	83.10	45	↓	164	81.46	49	↓	60	80.60	50	NS
Salinity (ppt)	NA	245	23.40	NA	↓	163	22.52	NA	↓	59	22.30	NA	NS
Turbidity (NTU)	10	247	1.3	4	↑	165	1.3	5	↑	60	1.6	8	NS
TSS (mg/L)	6	249	4	33	NS	165	5	31	↓	60	4	22	NS
Chl-a (ug/L)	4	248	4.3	52	NS	165	4.3	52	↑	61	5.4	61	NS
TP (mg/L)	0.03	250	0.024	36	NS	166	0.024	36	↑	61	0.029	49	NS
TN (mg/L)	0.3	223	0.450	83	↓	139	0.390	76	↑	61	0.390	85	↑
NH_3-N (mg/L)	0.015	223	0.020	62	↓	139	0.020	54	NS	61	0.020	54	NS
NOx-N (mg/L)	0.015	250	0.110	84	↓	166	0.060	78	NS	61	0.060	72	NS
F.Cols (CFU/100ml)	150	250	7	10	NS	166	6	10	↑	61	8	10	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	86	680	14	NS	86	680	14	NS	61	610	10	NS

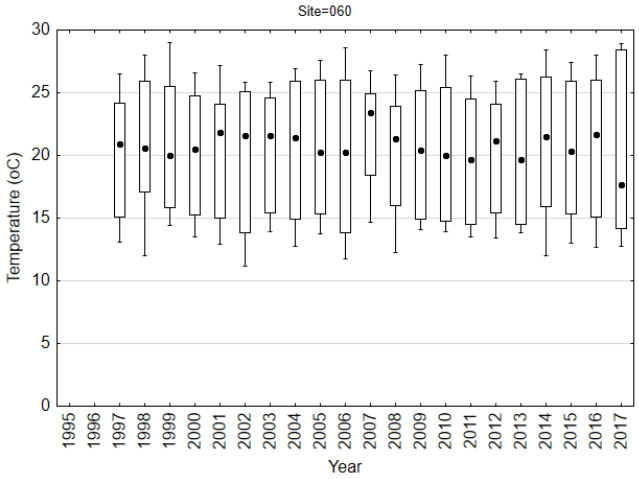
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

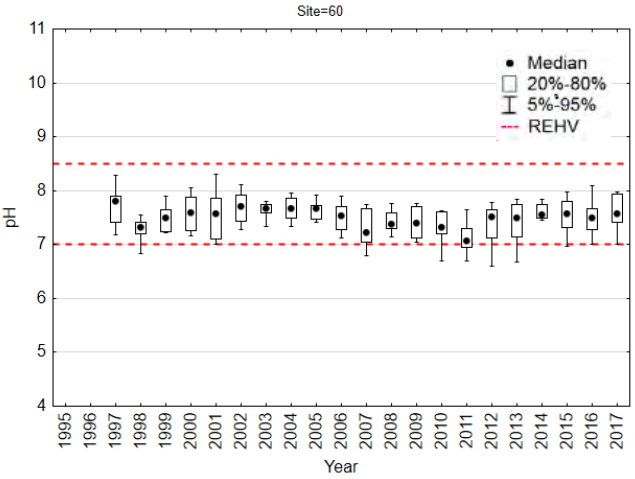
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

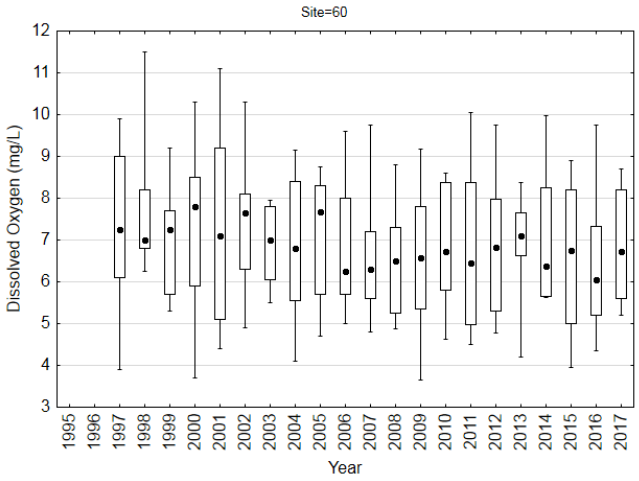
Table 2 Descriptive statistics for variables measured at Site 060 from January 1997 to September 2017

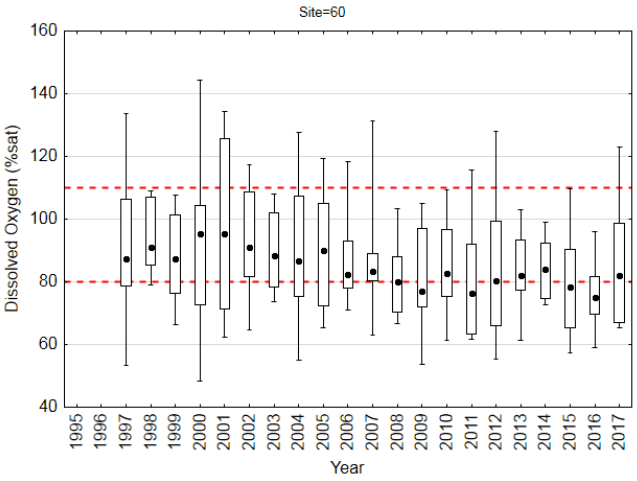
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	247	20.42	20.60	11.15	29.00	15.04	25.37	4.830
pH	247	7.49	7.53	6.60	8.31	7.21	7.75	0.299
DO (mg/L)	245	6.93	6.82	3.65	11.50	5.60	8.25	1.493
DO (%sat)	245	86.33	83.10	48.20	144.50	73.00	99.10	16.809
Salinity (ppt)	245	22.06	23.40	1.20	33.86	17.30	27.49	6.680
Turbidity (NTU)	247	2.5	1.3	0.0	62.7	0.5	2.4	5.37
TSS (mg/L)	249	6	4	1	84	2	8	8.2
Chlorophyll-a (µg/L)	248	7.5	4.3	0.3	85.5	2.3	10.8	9.47
TP (mg/L)	250	0.029	0.024	0.001	0.120	0.013	0.040	0.0210
TN (mg/L)	223	0.663	0.450	0.060	14.500	0.320	0.820	1.0980
NH_3-N (mg/L)	223	0.038	0.020	0.003	0.650	0.010	0.060	0.0530
NOx-N (mg/L)	250	0.275	0.110	0.003	12.100	0.020	0.400	0.8090
SRP (mg/L)	140	0.009	0.008	0.001	0.050	0.002	0.014	0.0070
F.Cols (CFU/100ml)	250	263	7	0	21000	1	29	1561.4
E.Coli (CFU/100ml)	17	11	6	1	54	1	15	14.1
Entero (CFU/100ml)	86	115	3	1	2800	1	11	418.7

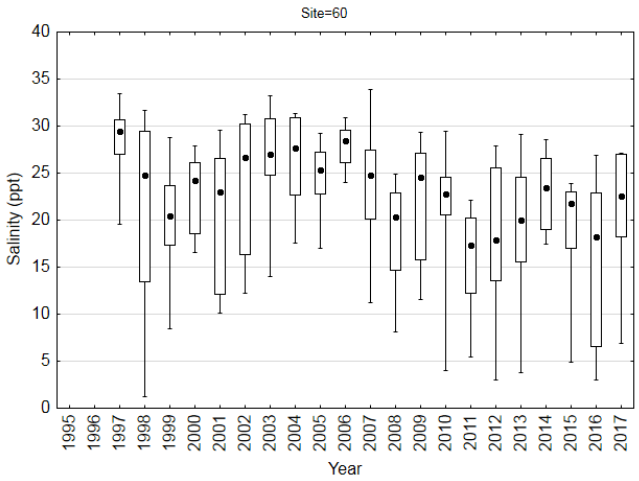
Boxplots showing annual variability for each variable measured

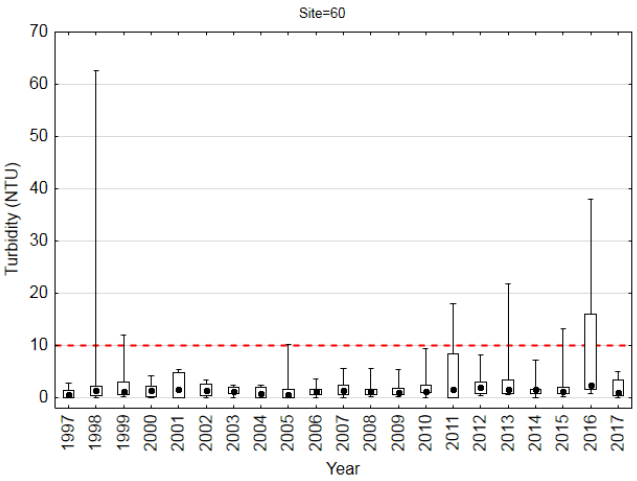


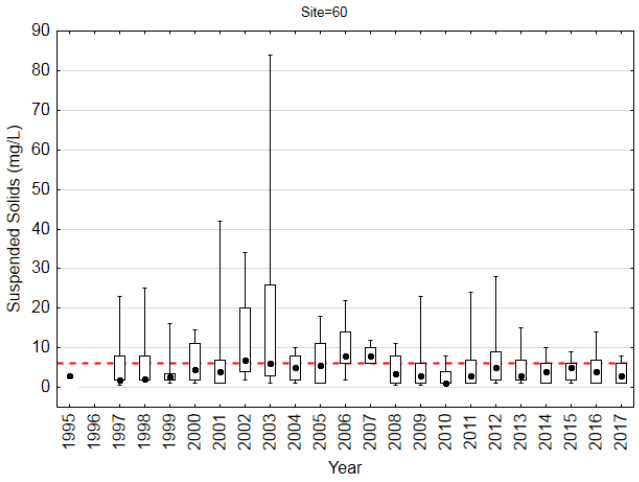


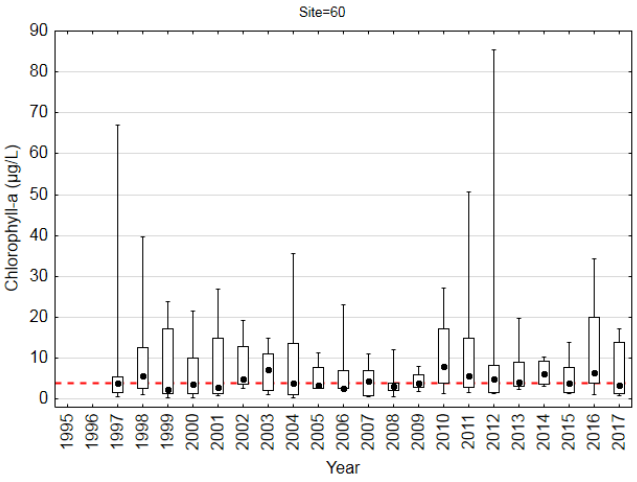


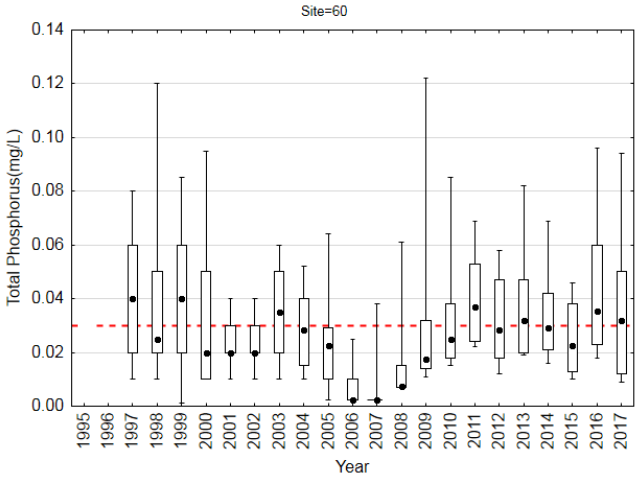


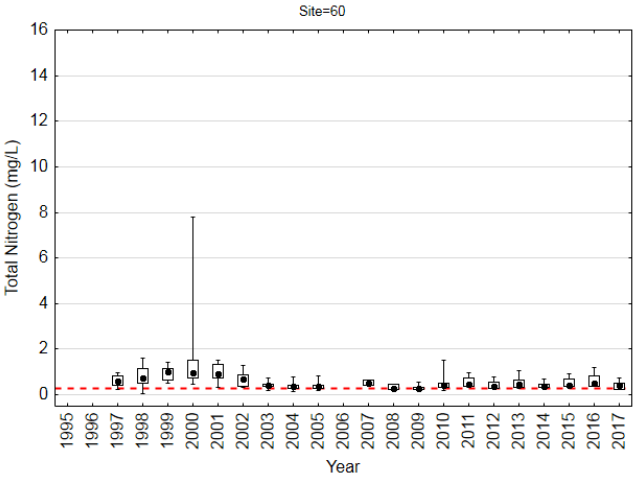


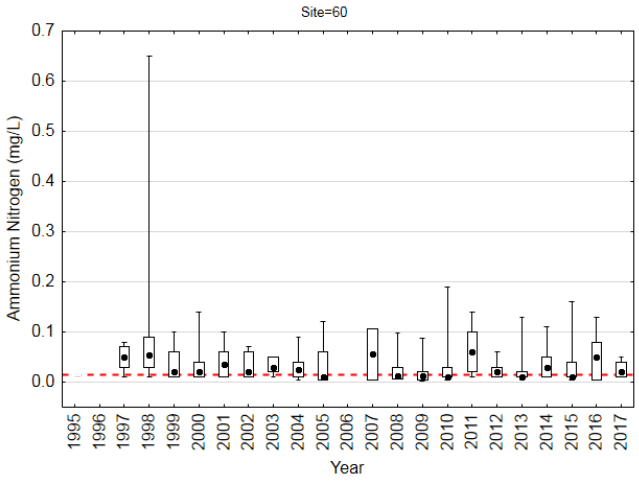


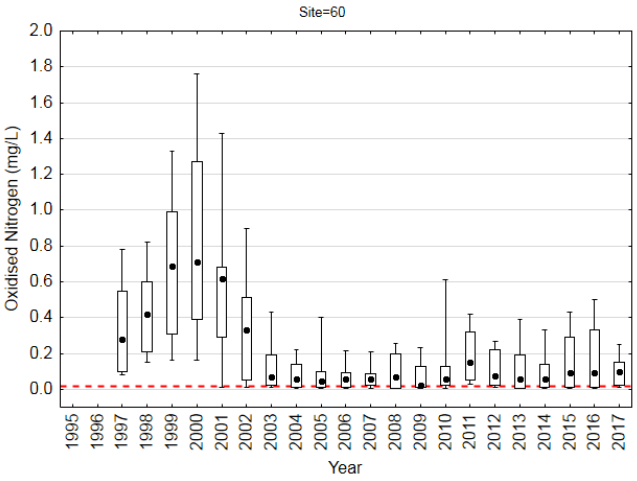


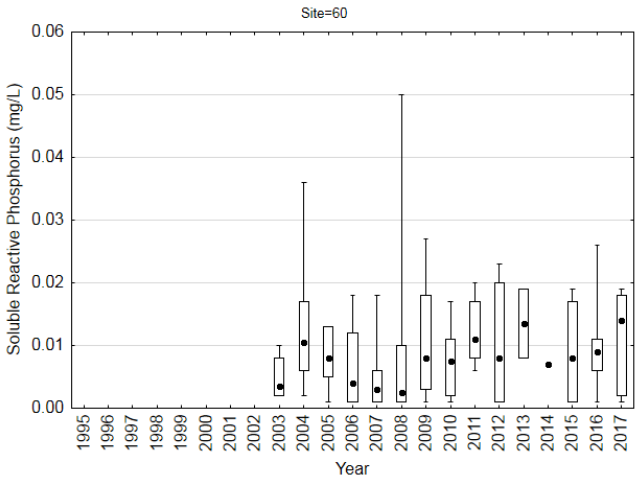


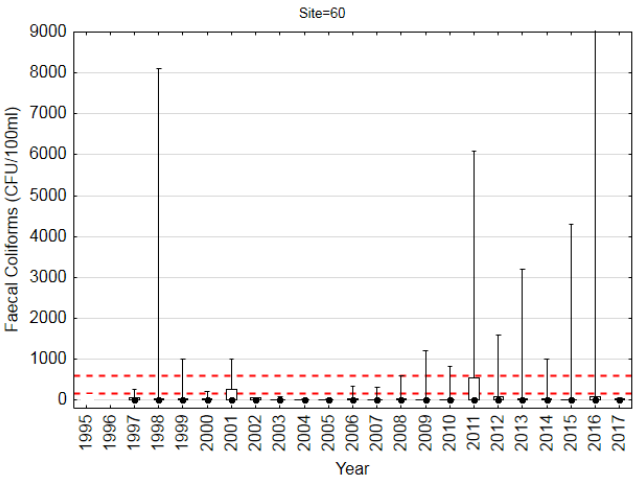

Site=60
Total Phosphorus(mg/L)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

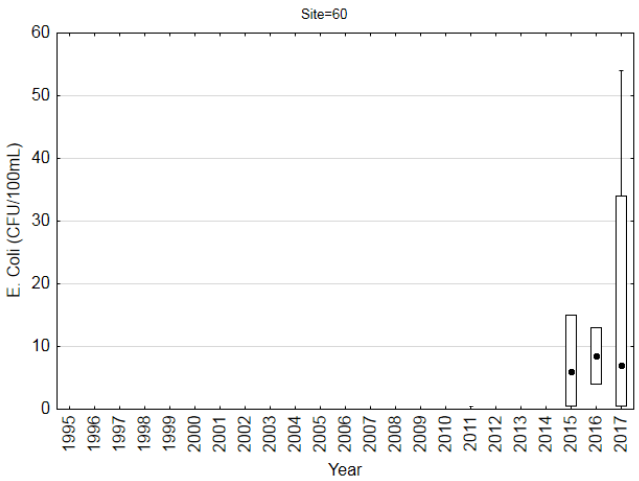

Site=60
Total Nitrogen (mg/L)
16
14
12
10
8
6
4
2
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

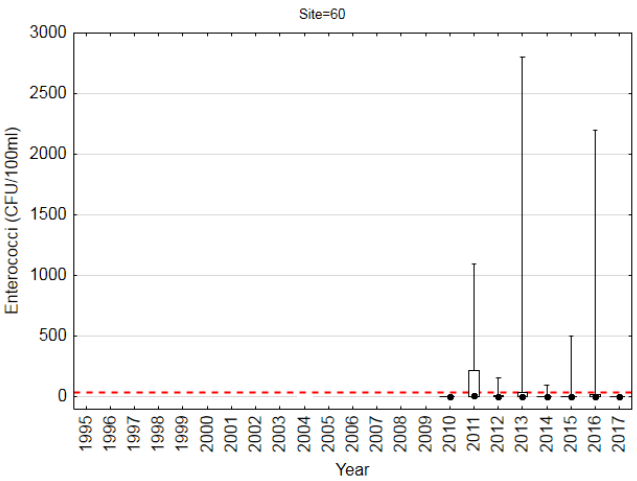

Site=60
Ammonium Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=60
Oxidised Nitrogen (mg/L)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=60
Soluble Reactive Phosphorus (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=60
Faecal Coliforms (CFU/100ml)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=60
E. Coli (CFU/100mL)
60
50
40
30
20
10
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=60
Enterococci (CFU/100ml)
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 061 – Calabash Point, Berowra Creek

Estuarine site, Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Remote (061)	Jun 2004 ongoing	Temperature (°C), salinity (ppt), turbidity (NTU) and chlorophyll-a (µg/L) recorded continuously at 15-minute intervals (data not analysed in this report)
Long-term (061)	Mar 1997 – Sept 2017	Monthly
Algae (061)	Apr 2003 – Sept 2017	Monthly from July to September, every 3 weeks for the remainder of the year
	Oct 2017 ongoing	~ Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO generally comply with REHVs. A weak, long-term decreasing trend in salinity is evident. Clarity: Turbidity and TSS are low and generally comply with REHVs. Biological: Chl-a levels are elevated and exceed the REHV approximately 75% of the time. Nutrients: TN and NOx-N are elevated and generally exceed the REHVs despite a significant decrease following WWTP upgrades. An increasing trend in TN is evident from 2003 onwards. TP is generally low and complies with the REHV approximately 50% of the time although a long-term increasing trend is evident. Bacteria: F.Col levels are low and consistently comply with REHVs. Entero levels are generally low, although variable.
Issues	– Influenced by a large diverse catchment including urban, rural and industrial land-uses – Impacted by Hornsby Heights and West Hornsby WWTP discharge – Unique bathymetry with a deep hole (~15m) that limits tidal flushing and potentially increases the opportunity for algal production – Influenced by local riverside settlements – Possible reduction in tidal flushing/incursion through time
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Ongoing collaboration with Sydney Water to improve the management of wastewater – Education and collaboration with riverside residents to minimise impacts from these settlements – Ongoing monitoring to identify and manage risks associated with algae blooms – Ongoing remote monitoring of estuarine conditions – Undertake a review of all phytoplankton monitoring data

Site Photos

Calabash Point looking south west

Calabash Point looking north

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 061

061	REHV	Long-term				Post WWTP Upgrades (>2004)				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	354	21.04	NA	NS	272	21.10	NA	NS	139	21.59	NA	NS
pH	7-8.5	351	7.67	3	NS	269	7.67	4	↑	138	7.72	2	NS
DO (%sat)	80-110	349	95.50	34	↓	268	94.35	32	NS	138	95.75	29	NS
Salinity (ppt)	NA	352	23.11	NA	↓	270	22.35	NA	↓	138	22.71	NA	↓
Turbidity (NTU)	10	351	1.4	5	↑	269	1.5	6	↑	138	1.8	7	↑
TSS (mg/L)	6	315	4	35	↓	233	4	31	↓	120	4	23	NS
Chl-a (ug/L)	4	311	8.0	73	NS	232	7.8	74	↑	120	9.1	80	NS
TP (mg/L)	0.03	321	0.027	40	↑	239	0.026	41	↑	124	0.030	49	NS
TN (mg/L)	0.3	291	0.430	84	↓	209	0.390	80	↑	124	0.410	90	↑
NH_3-N (mg/L)	0.015	291	0.010	42	↓	209	0.010	33	NS	124	0.010	32	NS
NOx-N (mg/L)	0.015	321	0.050	66	↓	239	0.031	58	NS	124	0.030	56	↑
F.Cols (CFU/100ml)	150	316	3	8	↑	234	3	9	↑	121	4	8	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	146	120	8	NS	146	120	8	NS	117	98	7	↑

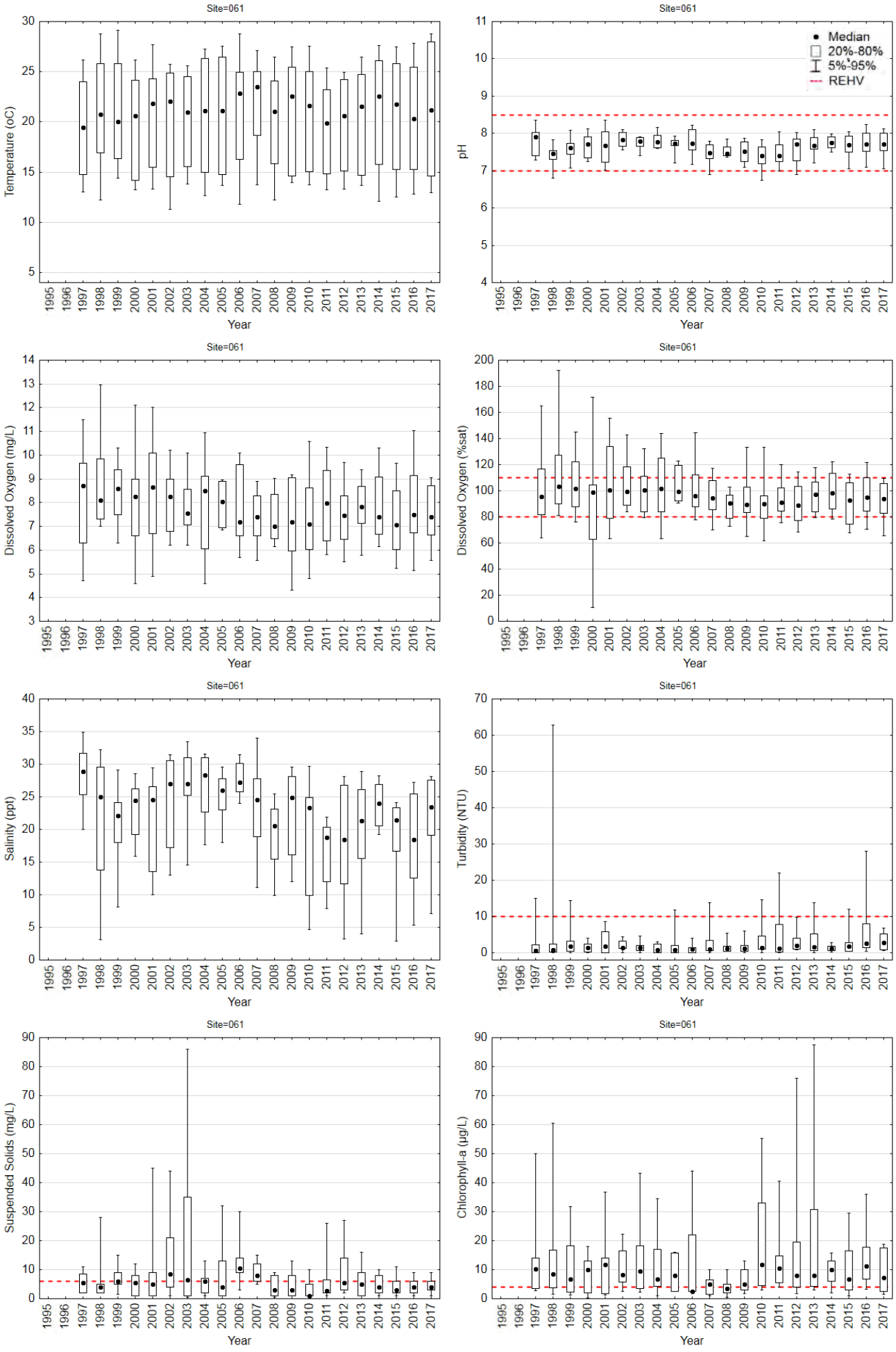
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

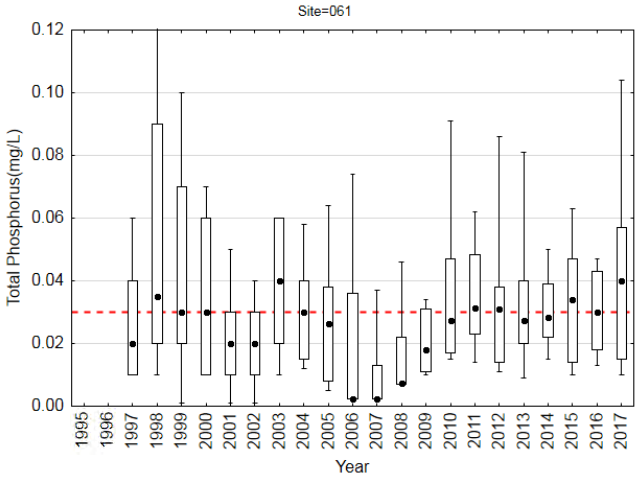
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

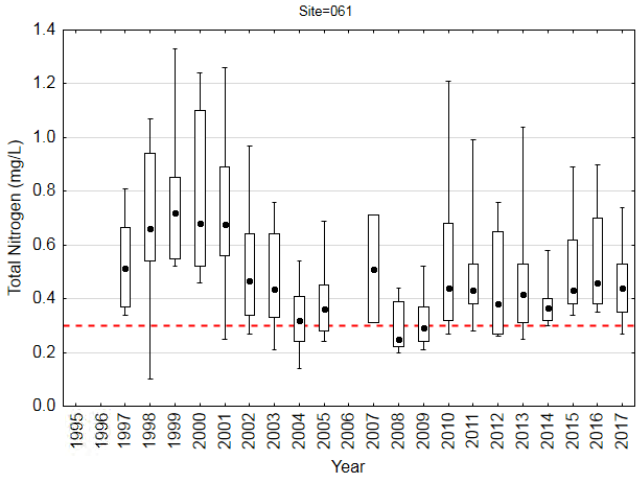
Table 2 Descriptive statistics for variables measured at Site 061 from March 1997 to September 2017

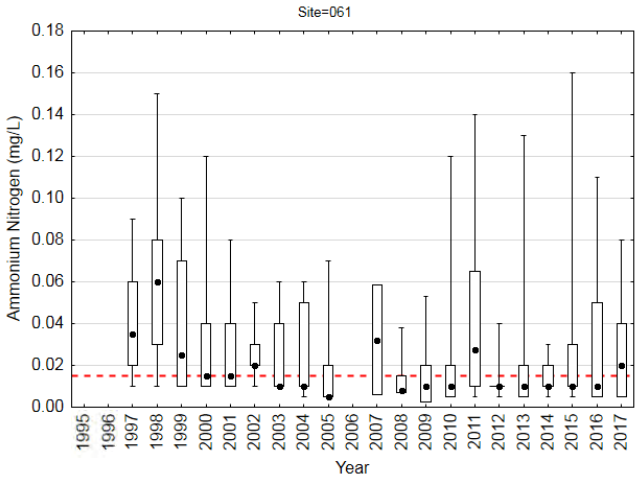
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	354	20.58	21.04	11.29	29.29	15.17	25.48	4.878
pH	351	7.65	7.67	6.75	8.57	7.40	7.88	0.306
DO (mg/L)	349	7.78	7.69	4.02	13.00	6.60	9.00	1.500
DO (%sat)	349	97.17	95.50	10.30	192.00	82.80	109.00	19.823
Salinity (ppt)	352	21.79	23.11	0.61	34.90	17.43	27.43	6.773
Turbidity (NTU)	351	2.9	1.4	0.0	62.8	0.5	3.5	5.31
TSS (mg/L)	315	7	4	1	86	2	9	8.2
Chlorophyll-a (µg/L)	311	11.0	8.0	0.3	87.5	3.0	15.7	11.29
TP (mg/L)	321	0.031	0.027	0.001	0.162	0.014	0.043	0.0221
TN (mg/L)	291	0.495	0.430	0.100	1.330	0.320	0.660	0.2199
NH_3-N (mg/L)	291	0.026	0.010	0.003	0.160	0.010	0.040	0.0304
NOx-N (mg/L)	321	0.129	0.050	0.001	1.100	0.005	0.230	0.1760
SRP (mg/L)	188	0.007	0.005	0.001	0.065	0.001	0.012	0.0081
F.Cols (CFU/100ml)	316	146	3	0	8100	1	12	771.1
E.Coli (CFU/100ml)	34	28	3	1	710	1	12	122.1
Entero (CFU/100ml)	146	74	1	1	3200	1	5	363.3

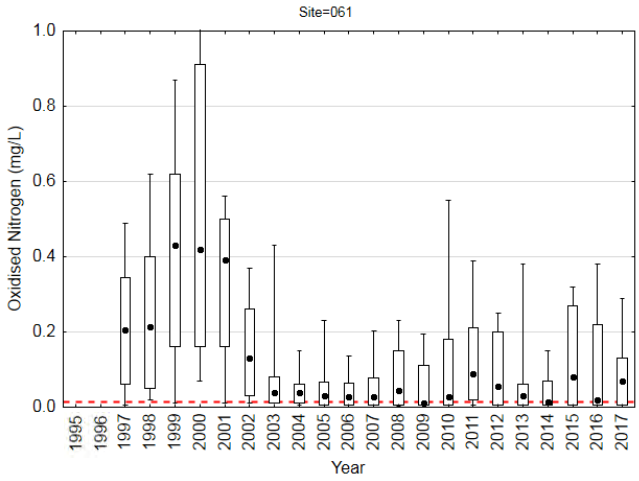
Boxplots showing annual variability for each variable measured

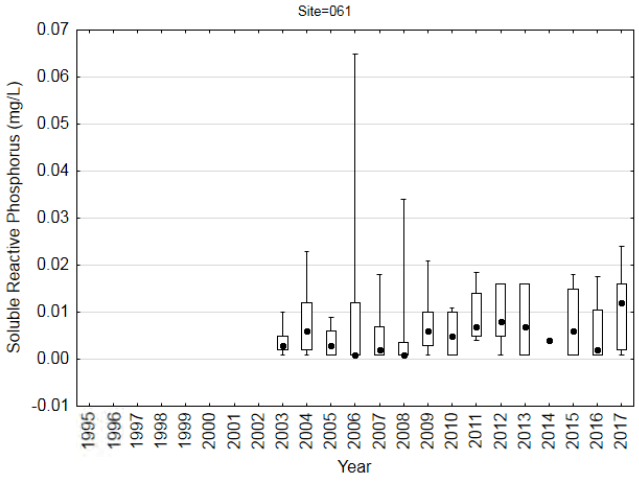


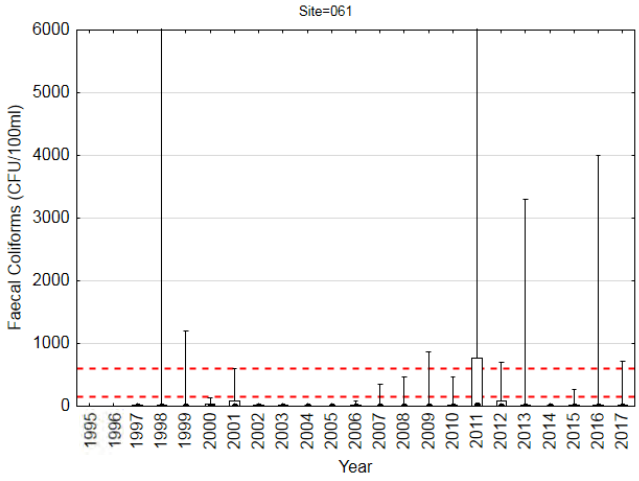

Site=061
Total Phosphorus(mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

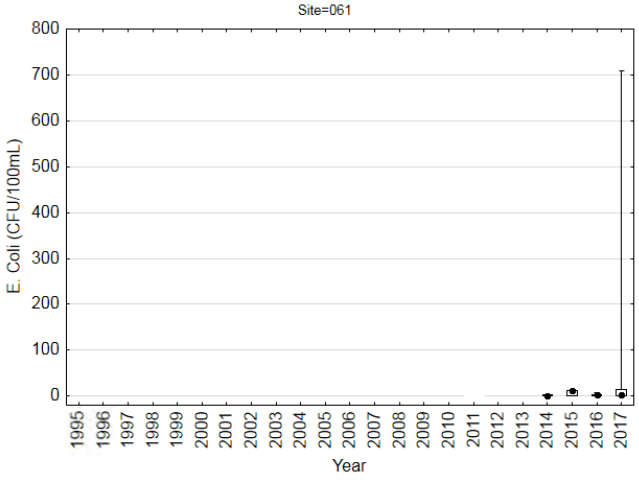

Site=061
Total Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

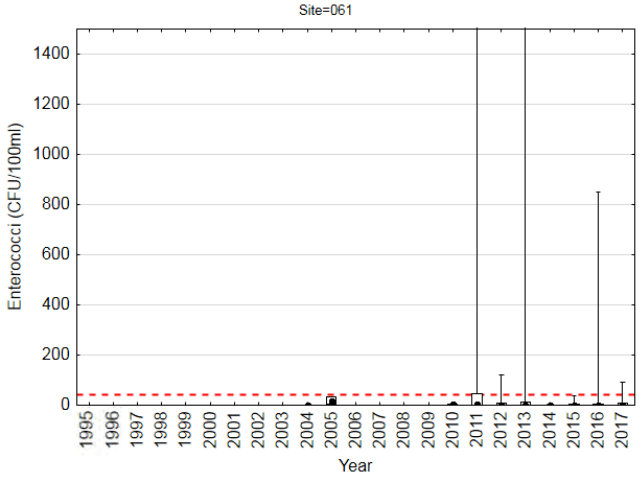

Site=061
Ammonium Nitrogen (mg/L)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=061
Oxidised Nitrogen (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=061
Soluble Reactive Phosphorus (mg/L)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=061
Faecal Coliforms (CFU/100ml)
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=061
E. Coli (CFU/100mL)
800
700
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=061
Enterococci (CFU/100ml)
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 062 – Kimmerikong Creek, Cowan

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (062)	Jul 2002 – Sept 2017	Monthly
Targeted assessment (062)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated and consistently exceeds REHVs. EC is elevated and exceeds REHVs approximately 60% of the time despite a weak long-term decreasing trend. A reduction in data variability for pH and DO is evident post-2010. Clarity: Turbidity and TSS are low and consistently comply with REHVs. Nutrients: Nutrient levels are elevated and often exceed REHVs, with the exception of NH_3-N which exceeds REHVs approximately 50% of the time. A decreasing trend in TN, TP and NH_3-N is evident between 2012 and 2017. Bacteria: Bacteria levels are slightly elevated and variable exceeding REHVs approximately 50% of the time.
Issues	– Influenced by urban land-use in the catchment – Impacted by onsite wastewater management systems (OWMS) in the catchment – Possible influence of localised low flow conditions
Recommendations	– Targeted monitoring to assess changes since the completion of the Cowan Wastewater Scheme (i.e. improved water quality) in 2013 – Identify further opportunities for WSUD in the catchment

Site Photos

Kimmerikong Creek looking upstream during average flow

Kimmerikong Creek looking upstream during dry conditions

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 062

062	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	150	16.38	NA	NS	54	17.49	NA	NS
pH	4.8-7	149	7.34	91	↓	54	7.30	91	↑
DO (%sat)	75-118	148	88.90	16	NS	54	90.15	9	↑
EC (mS/cm)	0.32	149	0.38	69	↓	54	0.35	63	↓
Turbidity (NTU)	8	149	3.0	15	↑	54	3.8	22	NS
TSS (mg/L)	7	157	1	8	NS	54	1	7	↓
TP (mg/L)	0.01	157	0.030	89	↓	54	0.023	93	↓
TN (mg/L)	0.32	157	0.530	87	NS	54	0.430	80	↓
NH_3-N (mg/L)	0.02	157	0.020	39	↑	54	0.025	50	↓
NO_x-N (mg/L)	0.05	157	0.180	73	NS	54	0.120	69	NS
F.Cols (CFU/100ml)	150	157	120	44	NS	54	160	50	NS

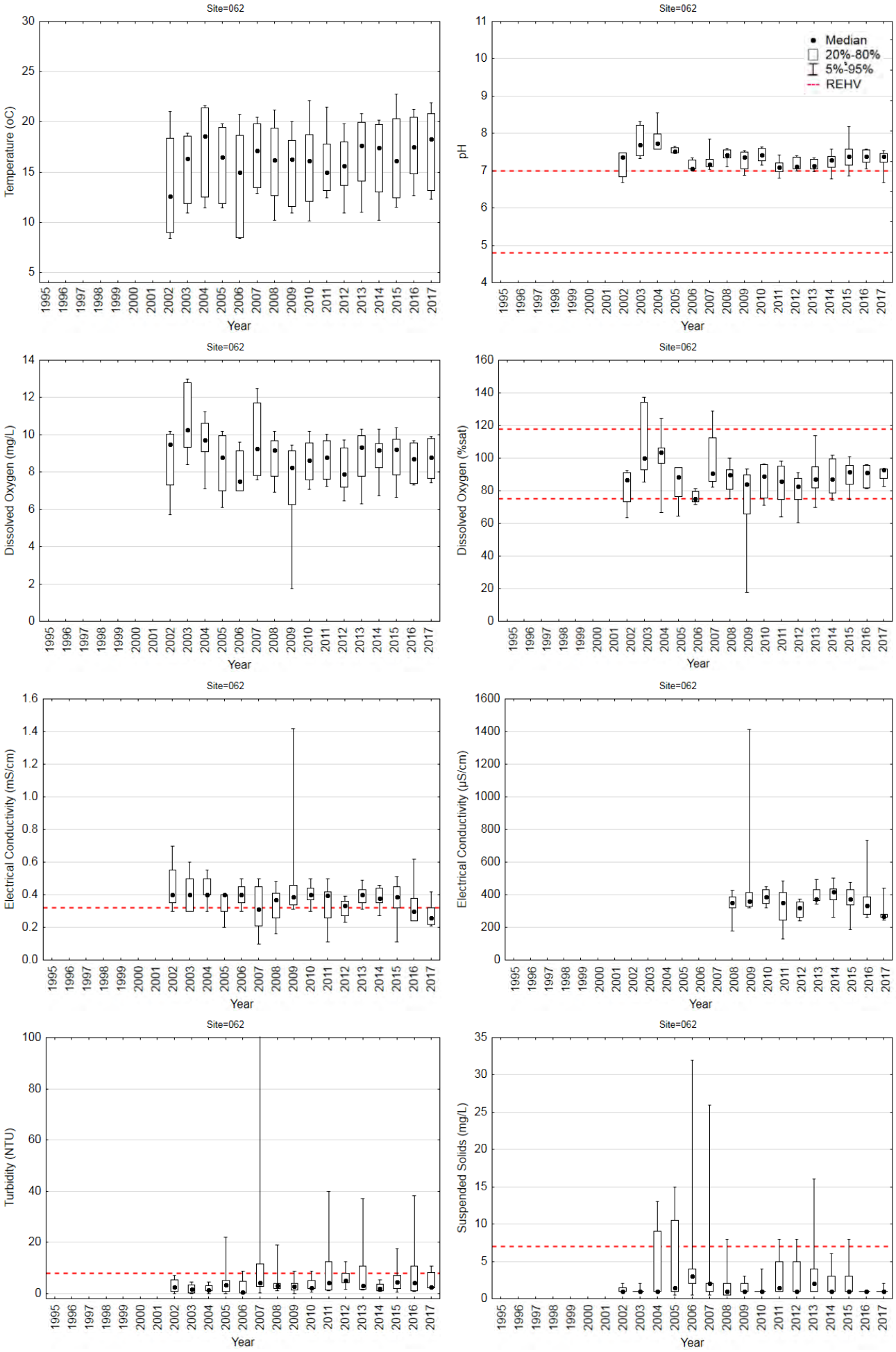
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

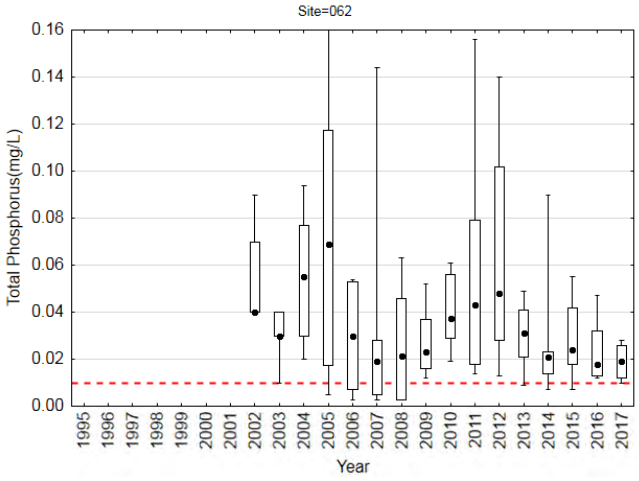
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

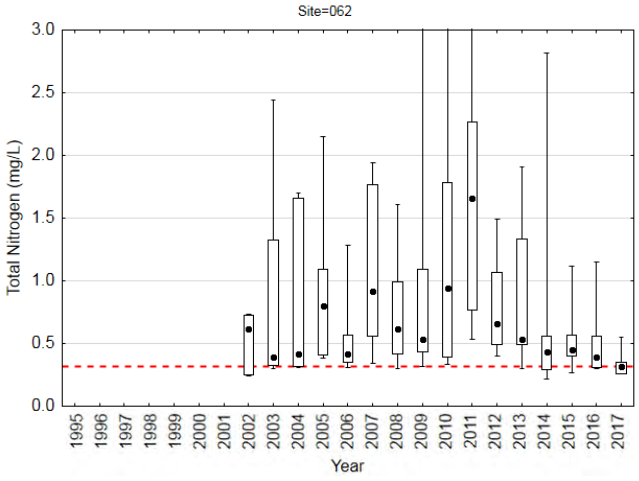
Table 2 Descriptive statistics for variables measured at Site 062 from July 2002 to September 2017

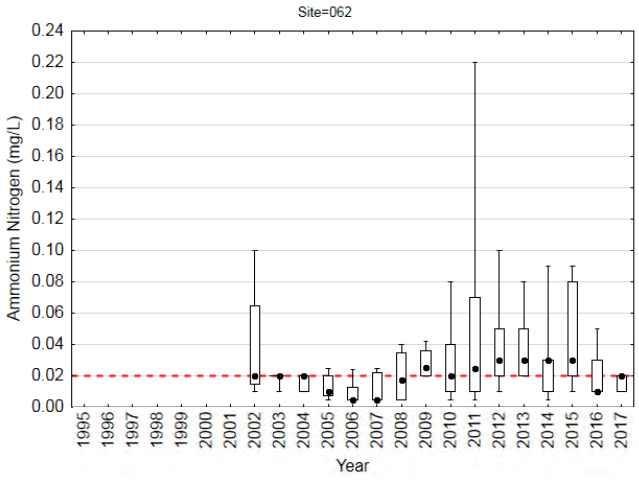
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	150	16.09	16.38	8.38	22.80	12.61	19.82	3.486
pH	149	7.34	7.34	6.68	8.60	7.10	7.56	0.290
DO (mg/L)	148	8.81	9.10	1.74	13.00	7.52	9.81	1.452
DO (%sat)	148	88.61	88.90	18.00	137.40	78.80	96.00	13.582
EC (mS/cm)	149	0.37	0.38	0.10	1.40	0.30	0.42	0.127
EC (µS/cm)	105	367.12	363.00	129.00	1414.00	300.50	418.50	130.077
Turbidity (NTU)	149	5.8	3.0	0.0	124.0	1.4	7.0	11.72
TSS (mg/L)	157	2	1	1	32	1	2	4.0
TP (mg/L)	157	0.038	0.030	0.003	0.200	0.016	0.053	0.0300
TN (mg/L)	157	0.862	0.530	0.220	4.400	0.360	1.200	0.7580
NH_3-N (mg/L)	157	0.026	0.020	0.005	0.200	0.010	0.030	0.0250
NOx-N (mg/L)	157	0.530	0.180	0.005	3.600	0.030	0.965	0.7140
F.Cols (CFU/100ml)	157	1539	120	1	120000	28	560	9875.5
E.Coli (CFU/100ml)	18	766	145	4	6400	21	720	1668.9
Entero (CFU/100ml)	25	721	88	1	7000	28	700	1727.2

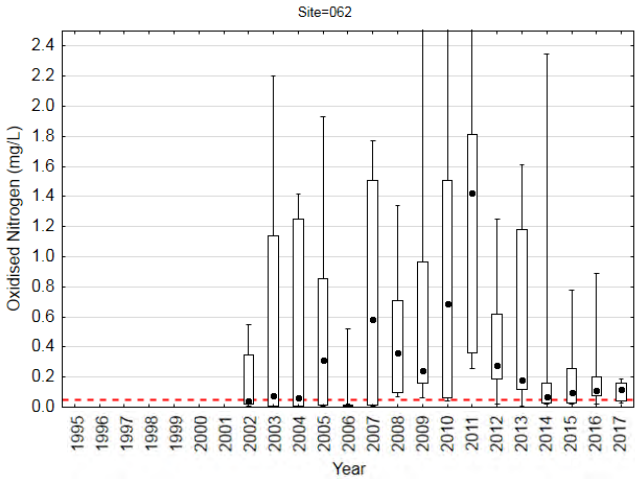
Boxplots showing annual variability for each variable measured

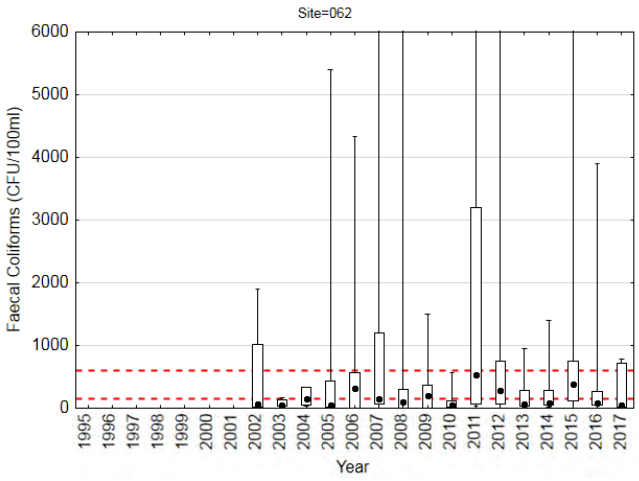


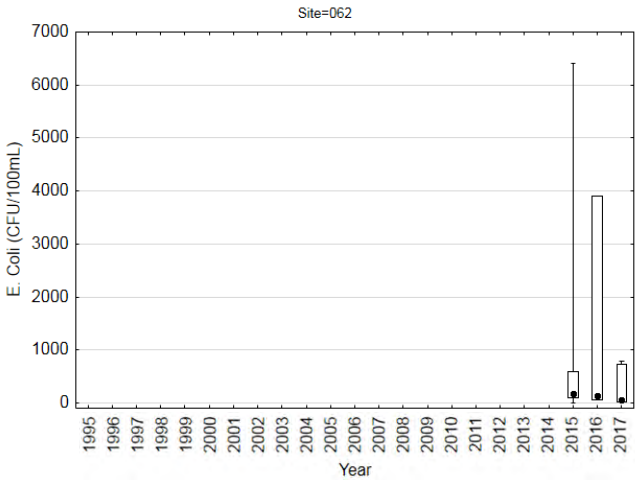

Site=062
Total Phosphorus(mg/L)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=062
Total Nitrogen (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=062
Ammonium Nitrogen (mg/L)
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=062
Oxidised Nitrogen (mg/L)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=062
Faecal Coliforms (CFU/100ml)
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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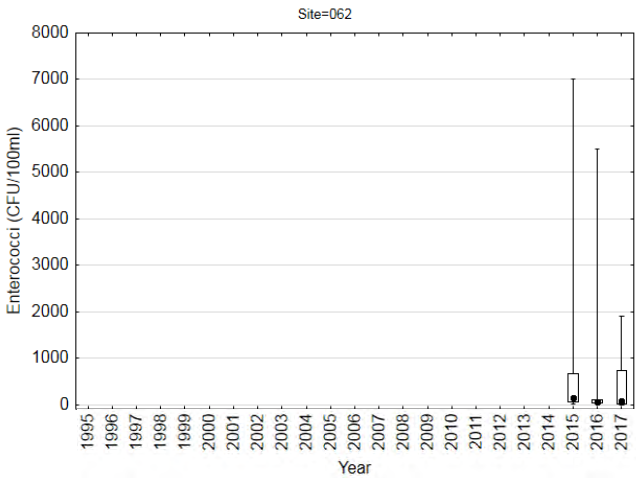
E. Coli (CFU/100mL)
7000
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Enterococci (CFU/100ml)
8000
7000
6000
5000
4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 063 – Colah Creek, Glenorie

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (063)	Jul 2002 – Sept 2017	Monthly
Ecohealth (COLA1)	Oct 2017 ongoing	Quarterly

Key Findings and Recommendations

Condition	Phys-chem: EC is elevated and consistently exceeds REHVS. pH is slightly elevated exceeding REHVs approximately 50% of the time. Clarity: Turbidity and TSS are low and consistently comply with REHVs. Nutrients: TP is elevated and exceeds the REHV approximately 80% of the time. TN and NOx-N are slightly elevated and exceed REHVs approximately 50% of the time. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Some influence from rural land-use in the upper catchment – Surrounding bushland and riparian zone are likely to be buffering the impacts of upstream land-use
Recommendations	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment – Protection of the bushland and riparian zone in the catchment to maintain buffering – Identify further opportunities for WSUD in the upper catchment – Education and collaboration with landholders to minimise impacts from rural activities

Site Photos

Colah Creek looking upstream during high flow

Colah Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 063

063	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	169	14.10	NA	NS	54	13.80	NA	NS
pH	4.8-7	167	7.02	53	↑	53	7.04	57	NS
DO (%sat)	75-118	168	84.70	30	NS	54	83.50	28	NS
EC (mS/cm)	0.32	168	0.44	83	↓	54	0.44	87	↓
Turbidity (NTU)	8	168	3.8	21	NS	53	3.4	15	NS
TSS (mg/L)	7	176	1	6	NS	56	1	9	NS
TP (mg/L)	0.01	176	0.020	74	NS	56	0.018	88	NS
TN (mg/L)	0.32	176	0.390	66	NS	56	0.350	55	NS
NH_3-N (mg/L)	0.02	176	0.010	11	↓	56	0.010	2	NS
NO_x-N (mg/L)	0.05	176	0.070	55	NS	56	0.040	41	NS
F.Cols (CFU/100ml)	150	176	52	16	NS	56	52	18	↓

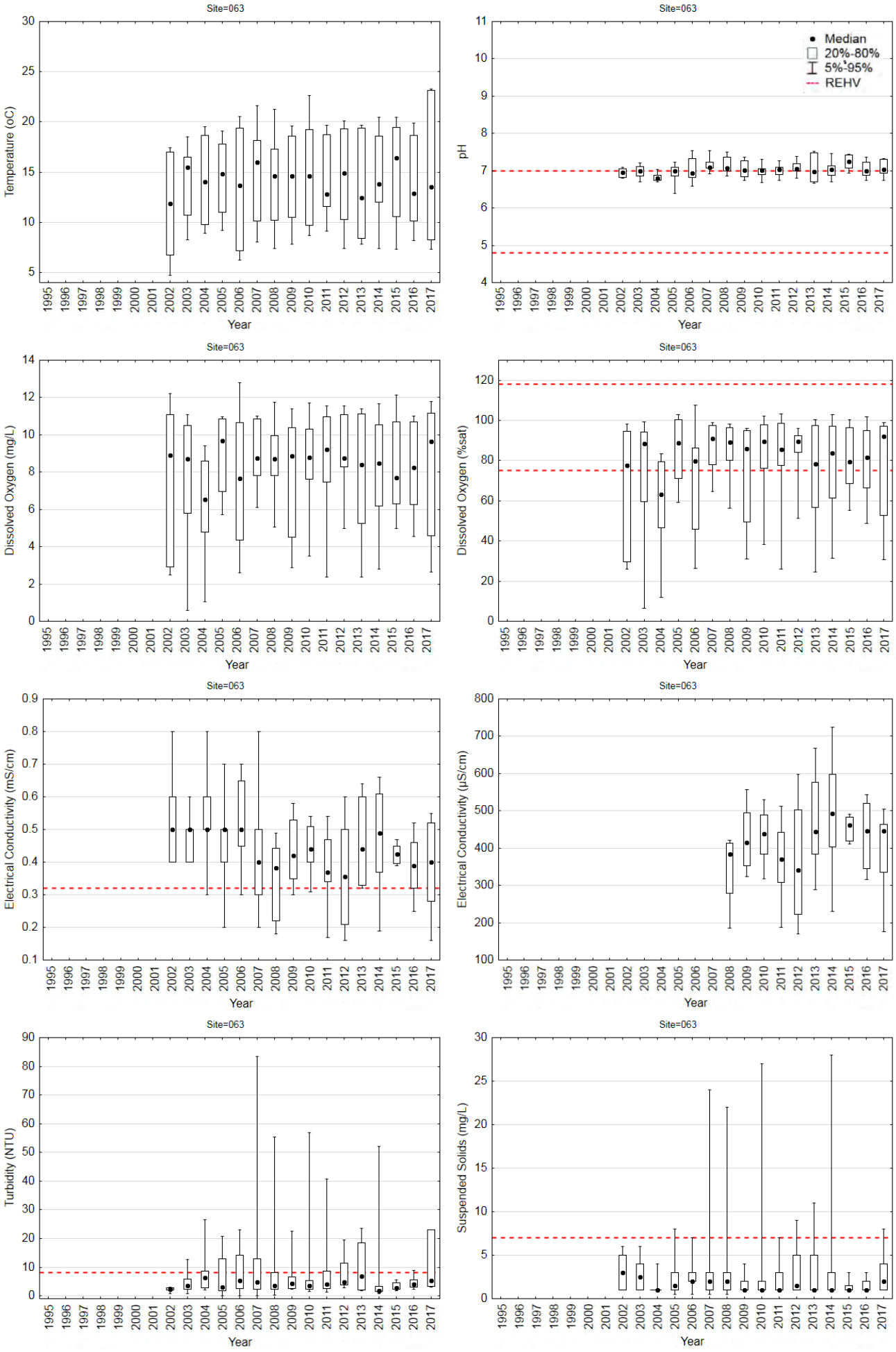
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

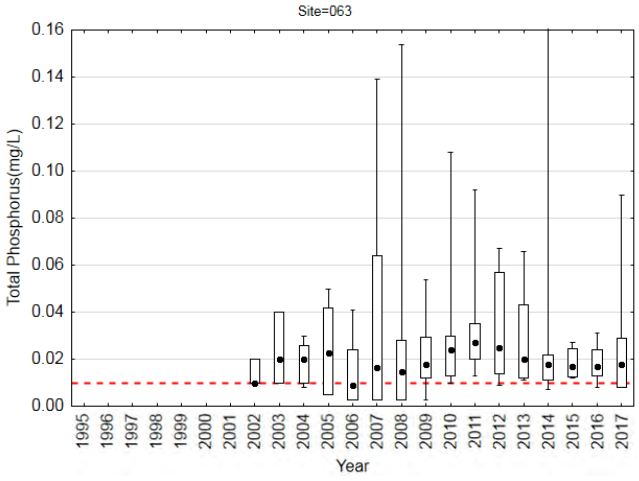
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 063 from July 2002 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	169	14.19	14.10	4.73	23.31	9.78	18.67	4.329
pH	167	7.04	7.02	6.40	7.54	6.87	7.21	0.209
DO (mg/L)	168	8.26	8.53	0.60	12.80	5.85	10.82	2.662
DO (%sat)	168	78.51	84.70	6.50	107.70	62.20	96.40	21.380
EC (mS/cm)	168	0.44	0.44	0.16	0.80	0.34	0.52	0.126
EC (µS/cm)	109	418.25	424.00	170.00	724.00	335.00	499.00	106.492
Turbidity (NTU)	168	7.4	3.8	0.0	83.5	2.3	8.6	11.02
TSS (mg/L)	176	3	1	1	28	1	3	4.0
TP (mg/L)	176	0.025	0.020	0.003	0.180	0.010	0.030	0.0250
TN (mg/L)	176	0.478	0.390	0.160	2.290	0.290	0.590	0.2940
NH_3-N (mg/L)	176	0.016	0.010	0.005	0.140	0.010	0.020	0.0180
NOx-N (mg/L)	176	0.142	0.070	0.005	1.400	0.020	0.190	0.2080
F.Cols (CFU/100ml)	176	581	52	4	48000	29	120	3846.8
E.Coli (CFU/100ml)	19	1153	41	13	15000	24	230	3555.1
Entero (CFU/100ml)	29	132	68	7	940	29	180	200.6

Boxplots showing annual variability for each variable measured

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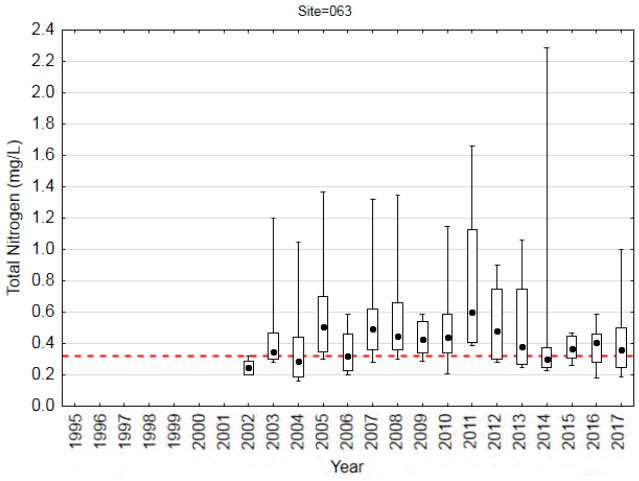
Total Phosphorus(mg/L)
Year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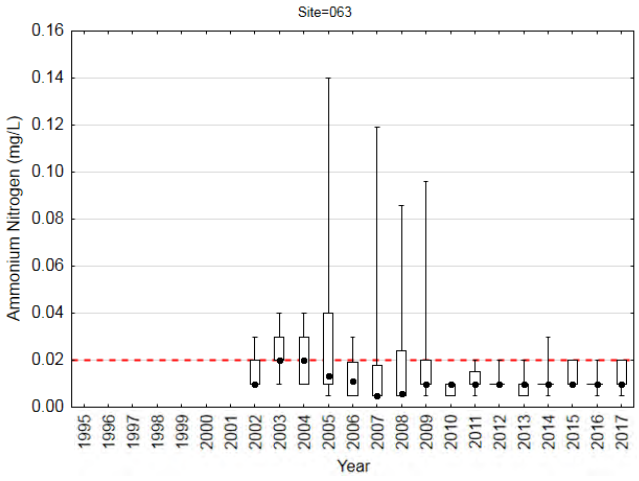
Total Nitrogen (mg/L)
Year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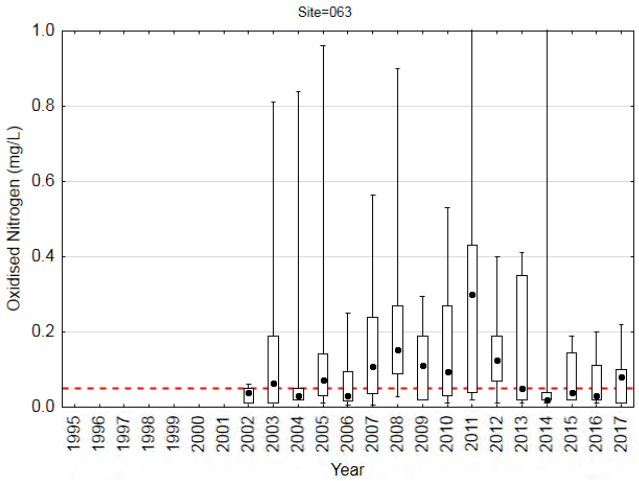
Ammonium Nitrogen (mg/L)
Year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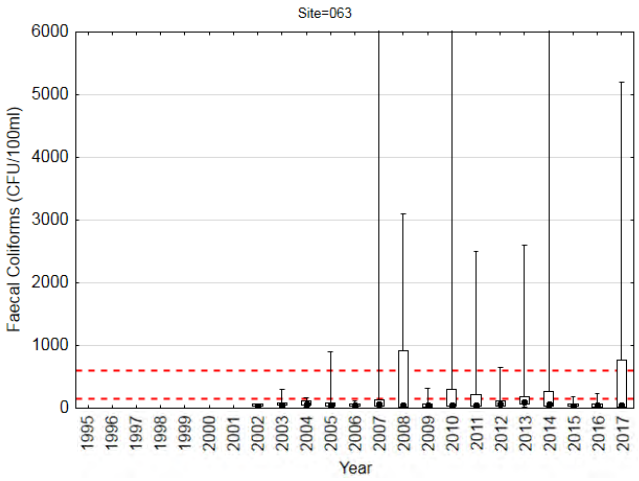
Oxidised Nitrogen (mg/L)
Year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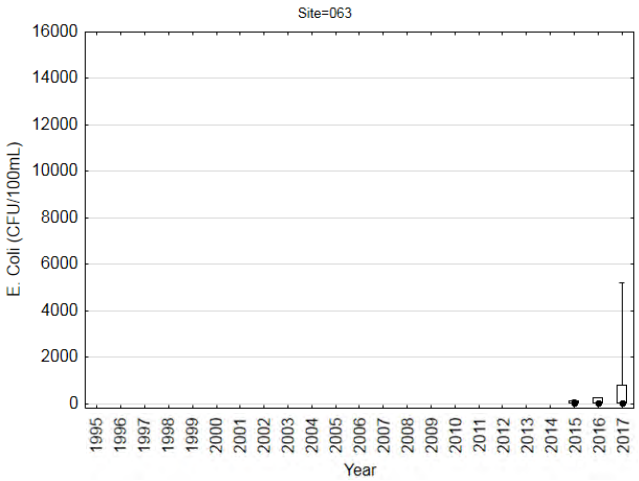
Faecal Coliforms (CFU/100ml)
Year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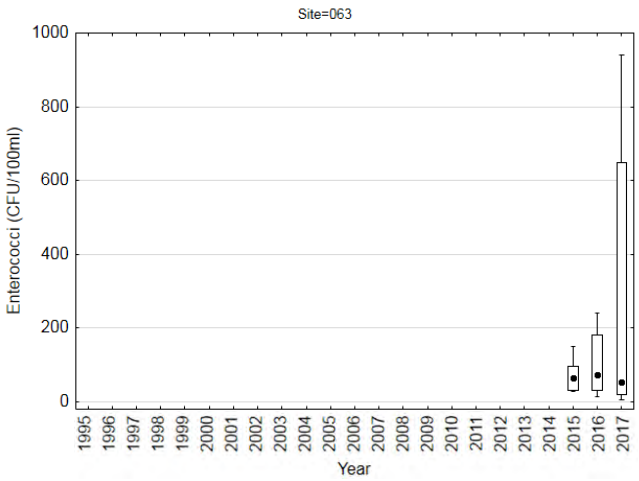
E. Coli (CFU/100mL)
Year


Site=063
Enterococci (CFU/100ml)
Year

Site 064 – Unnamed tributary of Colah Creek, Galston

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (064)	Jan 1995 – Sept 2017	Monthly
Targeted assessment (064)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and exceed REHVs approximately 70% of the time. A long-term decreasing trend in EC is evident. Clarity: Turbidity and TSS are generally low but variable, with turbidity exceeding REHVs approximately 45% of the time Nutrients: Nutrient levels are elevated with TN, TP and NOx-N consistently exceeding REHVs. Bacteria: Bacteria levels are slightly elevated and variable. A weak long-term increase in F.Cols is evident.
Issues	– Influenced by both rural and residential land-use – Impacts from onsite wastewater management systems (OWMS) in the catchment
Recommendations	– Targeted monitoring to assess changes since the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality) in 2015 – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with residents to minimise the impacts of OWMS – Education and collaboration with landholders to minimise impacts from rural activities

Site Photos

Unnamed creek looking downstream during high flow

Unnamed creek looking downstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 064

064	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	171	15.50	NA	↑	59	15.87	NA	NS
pH	4.8-7	170	7.15	71	NS	58	7.15	66	NS
DO (%sat)	75-118	170	88.90	27	NS	59	89.30	31	NS
EC (mS/cm)	0.32	170	0.47	81	↓	59	0.38	68	NS
Turbidity (NTU)	8	170	5.7	38	NS	58	7.8	47	NS
TSS (mg/L)	7	177	2	12	NS	60	2	8	NS
TP (mg/L)	0.01	178	0.063	96	NS	60	0.066	98	NS
TN (mg/L)	0.32	178	0.760	93	NS	60	0.600	92	NS
NH_3-N (mg/L)	0.02	178	0.030	62	NS	60	0.035	67	NS
NO_x-N (mg/L)	0.05	178	0.380	81	NS	60	0.180	80	NS
F.Cols (CFU/100ml)	150	178	280	61	↑	60	285	65	NS

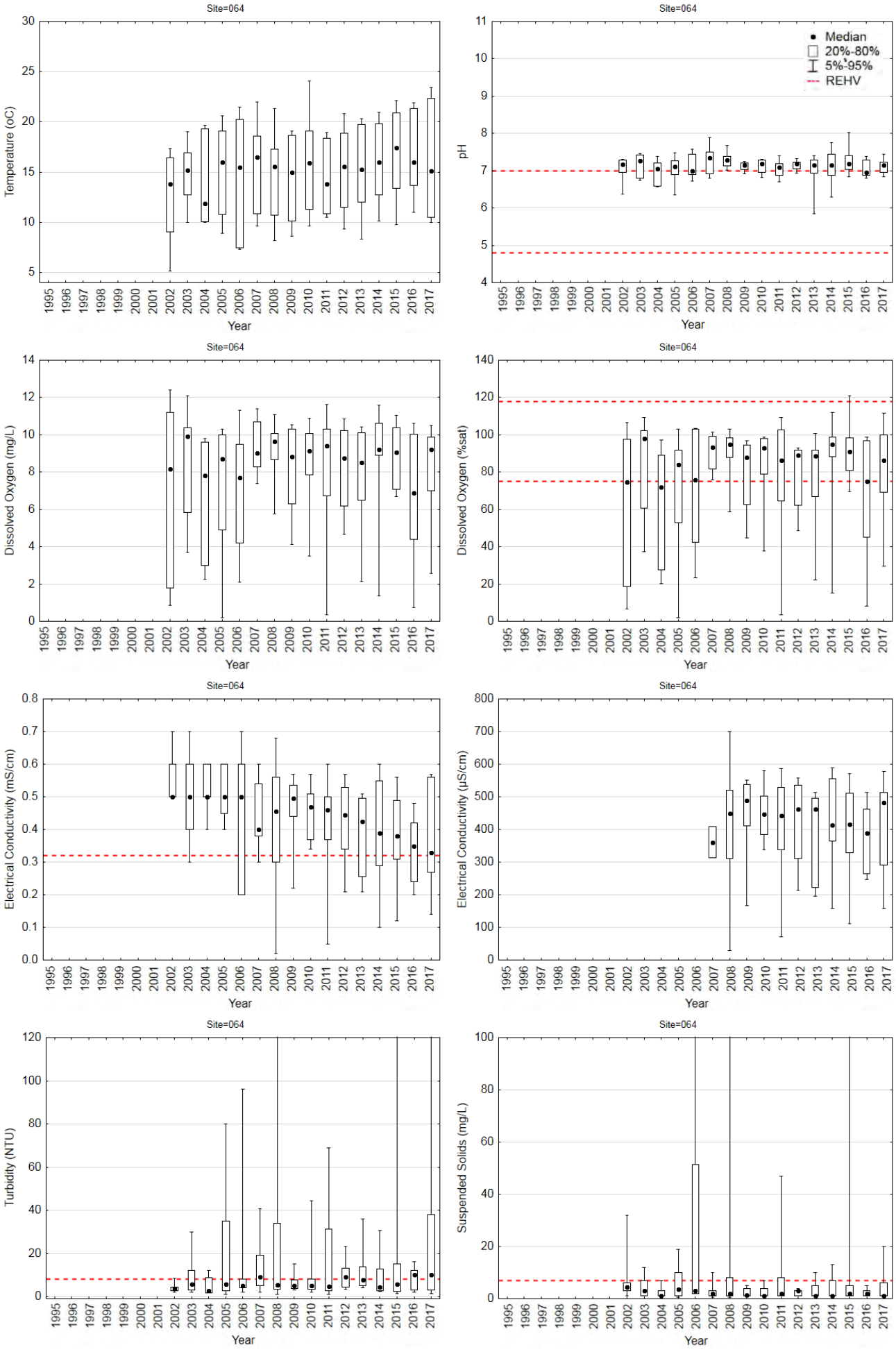
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

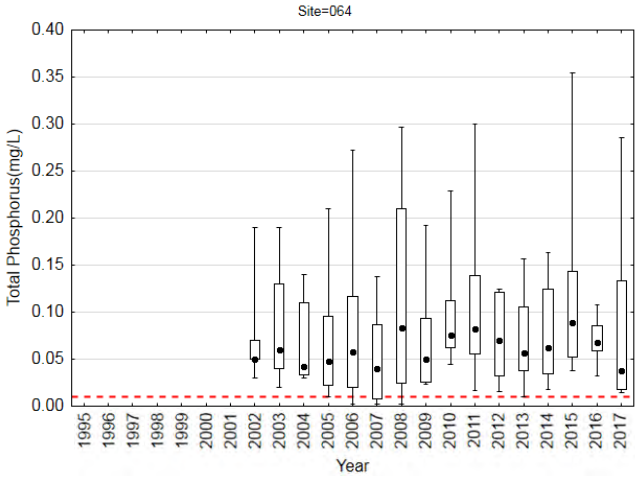
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 064 from July 2002 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	171	15.24	15.50	5.17	24.10	11.16	19.04	3.971
pH	170	7.13	7.15	5.85	8.03	6.92	7.30	0.273
DO (mg/L)	170	8.20	9.05	0.20	12.40	6.14	10.24	2.646
DO (%sat)	170	80.45	88.90	1.90	121.00	63.40	98.08	24.390
EC (mS/cm)	170	0.44	0.47	0.02	0.70	0.33	0.54	0.128
EC (µS/cm)	115	416.22	438.00	30.00	700.00	315.50	512.50	119.857
Turbidity (NTU)	170	17.8	5.7	1.0	550.0	3.1	14.4	56.94
TSS (mg/L)	177	9	2	1	496	1	5	40.6
TP (mg/L)	178	0.080	0.063	0.003	0.360	0.032	0.122	0.0620
TN (mg/L)	178	0.990	0.760	0.150	4.860	0.390	1.470	0.7840
NH_3-N (mg/L)	178	0.048	0.030	0.003	0.530	0.020	0.060	0.0610
NOx-N (mg/L)	178	0.612	0.380	0.005	5.010	0.056	1.130	0.7270
F.Cols (CFU/100ml)	178	1510	280	1	50000	74	1000	5255.5
E.Coli (CFU/100ml)	20	3767	385	6	41000	59	4300	9503.3
Entero (CFU/100ml)	32	2487	110	1	56000	18	650	9954.4

Boxplots showing annual variability for each variable measured

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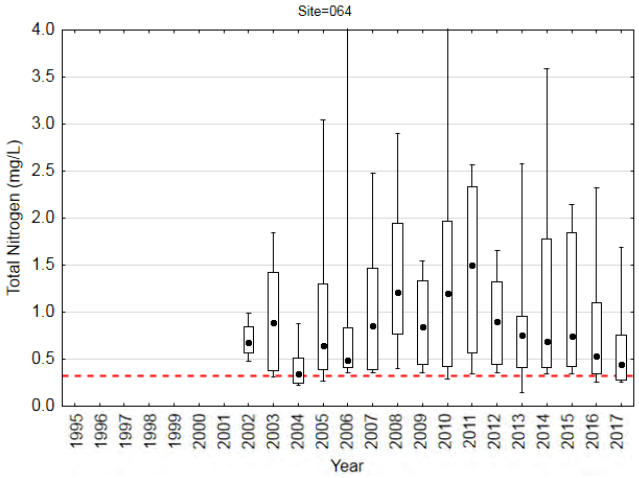
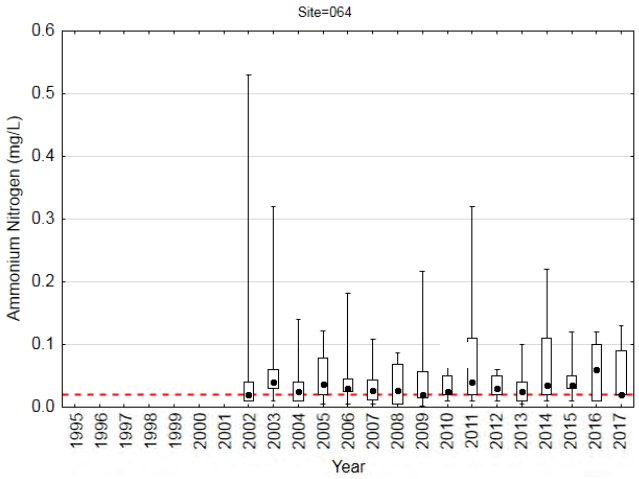
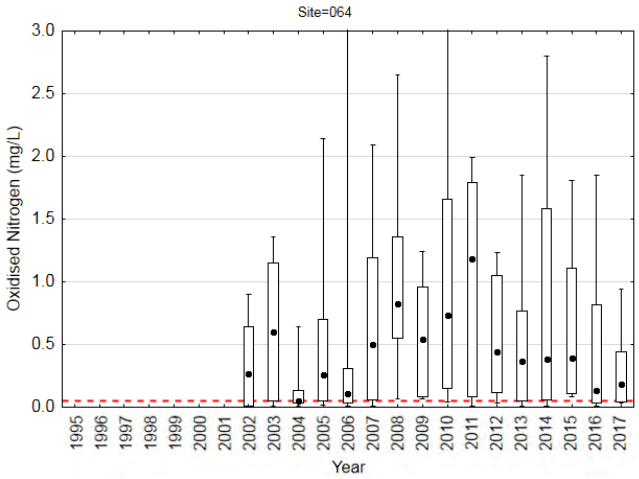
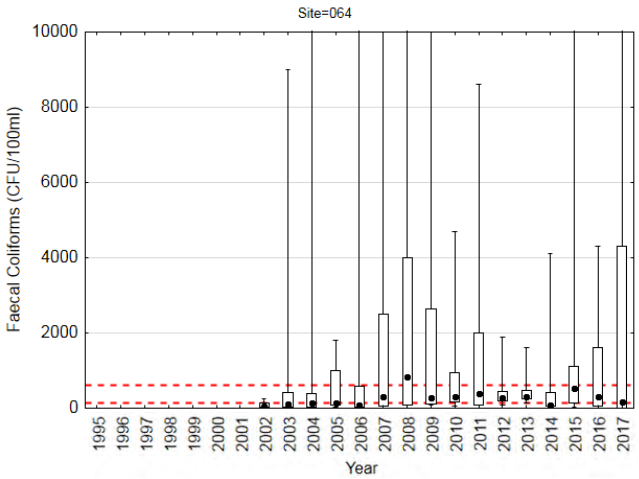
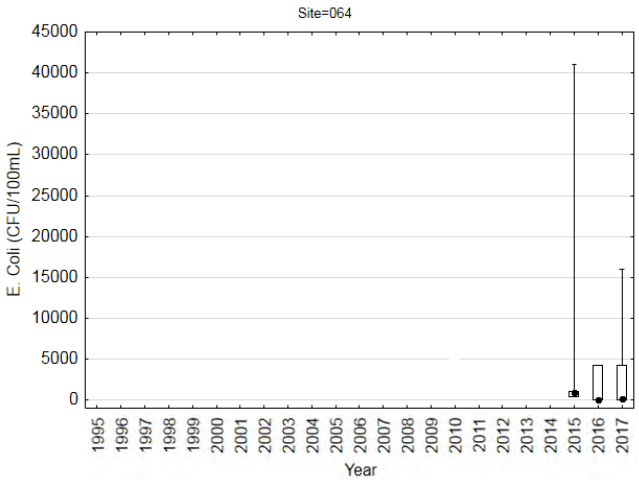
Total Phosphorus(mg/L)
Year


Site=064
Total Nitrogen (mg/L)
Year


Site=064
Ammonium Nitrogen (mg/L)
Year


Site=064
Oxidised Nitrogen (mg/L)
Year


Site=064
Faecal Coliforms (CFU/100ml)
Year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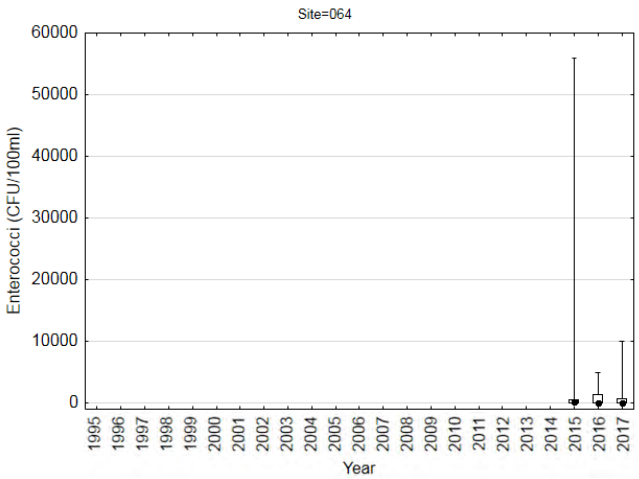
E. Coli (CFU/100mL)
Year


Site=064
Enterococci (CFU/100ml)
Year

Site 077 – Gleeson Creek, Mount Colah

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (077)	Jul 1999 – Sept 2017	Monthly
Targeted assessment (077)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH and EC are elevated and consistently exceed REHVs. DO is suppressed and complies with the REHV less than 20% of the time. Clarity: Turbidity and TSS are low and generally comply with REHVs, however turbidity results are variable and exceed the REHV approximately 30% of the time. Nutrients: TP is elevated and consistently exceed the REHV. N-based nutrients are extremely elevated and consistently exceed REHVs. Long-term trends of decrease are evident for N-based nutrients, however the short-term trend analysis indicates more recent increases (2012-17). Bacteria: Bacteria levels are elevated and exceed REHVs approximately 65% of the time.
Issues	– Potential impacts from the upstream disused landfill site at Foxglove Oval – Influenced by a relatively small urban catchment
Recommendations	– Targeted monitoring to assess the impacts of Foxglove Oval leachate on Gleeson Creek – Improved collaborative management of risks from Foxglove Oval legacy landfill – Investigate sources of nutrients and bacteria in the catchment (other than those from the legacy landfill site)

Site Photos

Gleeson Creek looking downstream during low flow

Gleeson Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 077

077	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	213	16.12	NA	NS	62	16.66	NA	NS
pH	4.8-7	212	7.41	95	↑	62	7.52	97	NS
DO (%sat)	75-118	211	56.00	86	↓	62	51.00	85	NS
EC (mS/cm)	0.32	212	0.90	89	↓	62	0.77	87	NS
Turbidity (NTU)	8	212	5.8	34	NS	62	5.5	29	NS
TSS (mg/L)	7	224	1	7	NS	61	1	5	NS
TP (mg/L)	0.01	224	0.020	85	NS	61	0.021	100	NS
TN (mg/L)	0.32	225	20.300	100	↓	62	17.500	100	↑
NH_3-N (mg/L)	0.02	225	11.000	100	NS	62	9.400	100	↑
NO_x-N (mg/L)	0.05	225	7.000	99	↓	62	6.170	100	↑
F.Cols (CFU/100ml)	150	224	240	62	NS	61	330	67	NS

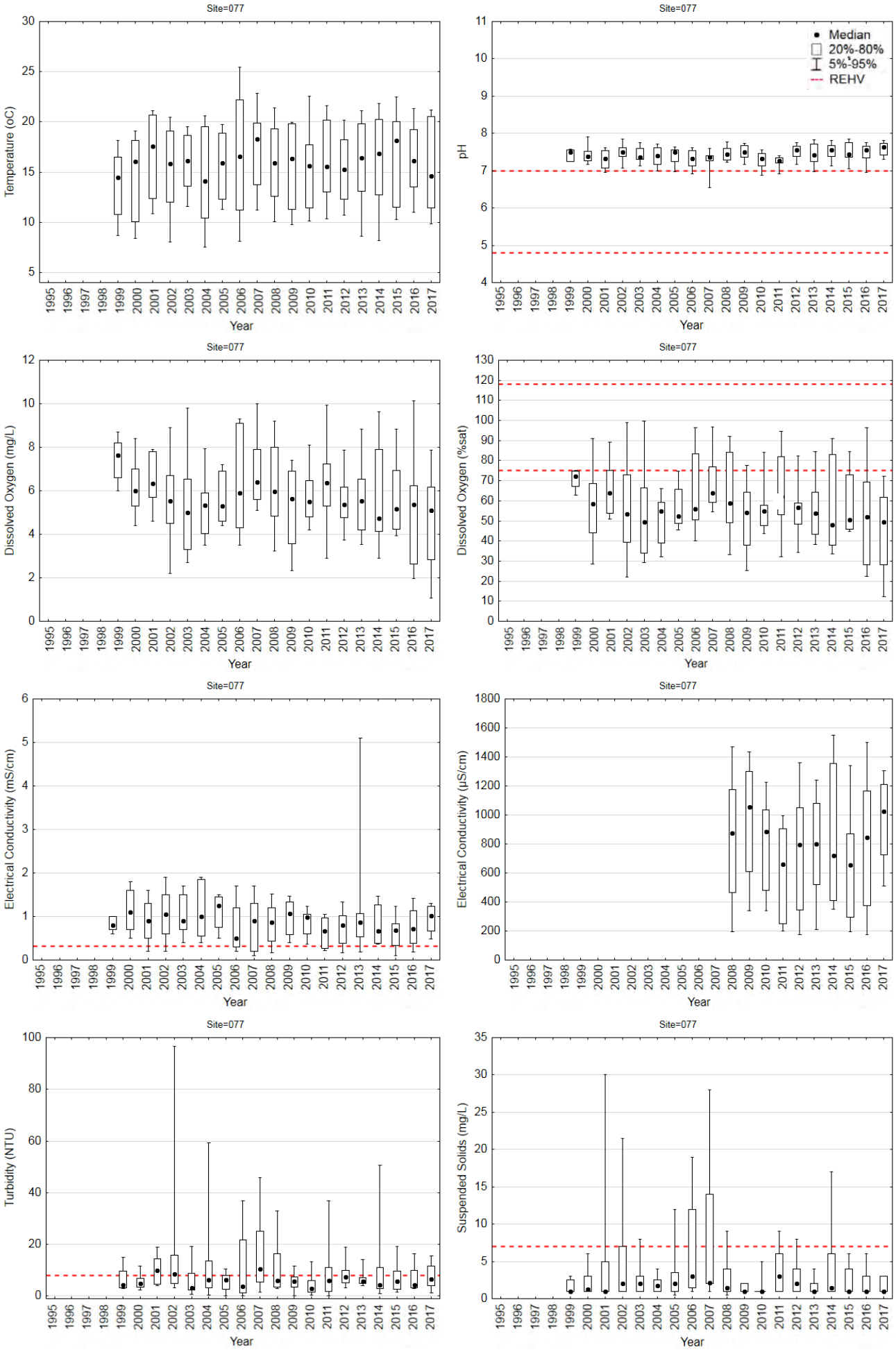
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

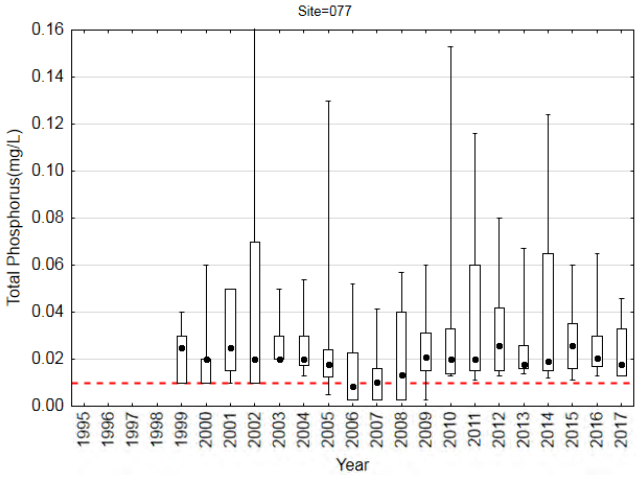
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 077 from July 1999 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	213	15.79	16.12	7.54	25.46	11.98	19.52	3.809
pH	212	7.43	7.41	6.54	7.90	7.26	7.61	0.221
DO (mg/L)	211	5.75	5.65	1.06	10.15	4.50	7.04	1.683
DO (%sat)	211	57.61	56.00	12.20	99.50	45.10	71.80	16.887
EC (mS/cm)	212	0.90	0.90	0.10	5.10	0.50	1.24	0.516
EC (µS/cm)	120	808.06	825.00	173.00	1551.00	450.50	1162.00	362.863
Turbidity (NTU)	212	8.7	5.8	0.0	96.7	3.1	11.1	10.61
TSS (mg/L)	224	3	1	1	30	1	4	4.2
TP (mg/L)	224	0.028	0.020	0.003	0.300	0.013	0.035	0.0310
TN (mg/L)	225	24.056	20.300	0.250	74.500	8.600	39.200	16.9940
NH_3-N (mg/L)	225	14.363	11.000	0.005	55.000	2.190	27.600	13.2330
NOx-N (mg/L)	225	7.699	7.000	0.020	31.500	4.005	10.350	4.9460
F.Cols (CFU/100ml)	224	1486	240	2	80000	79	850	5939.2
E.Coli (CFU/100ml)	18	2147	255	20	20000	84	2500	4821.2
Entero (CFU/100ml)	29	915	270	22	6800	75	1200	1607.9

Boxplots showing annual variability for each variable measured

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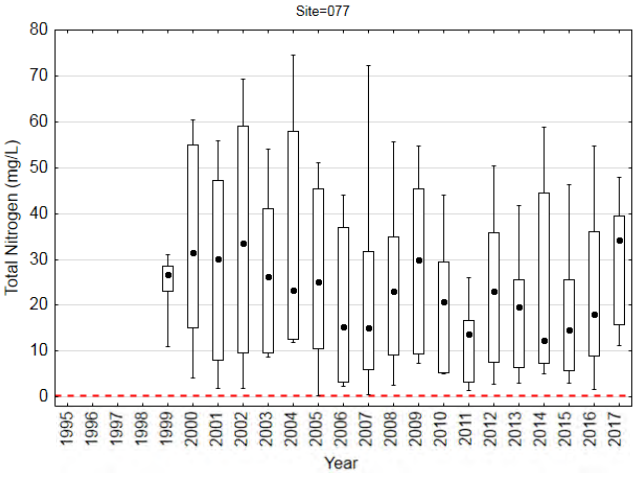
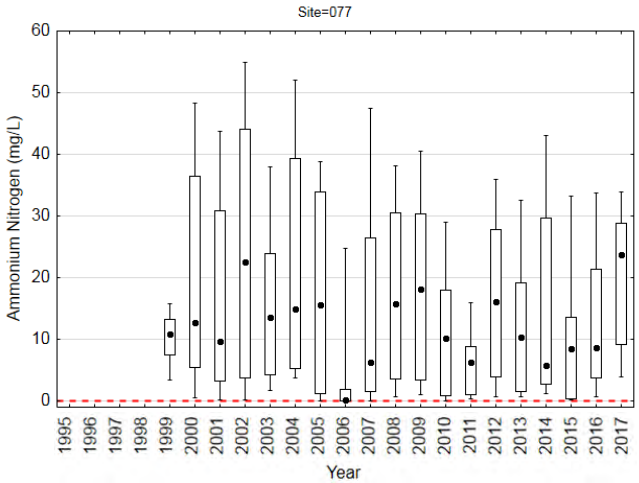
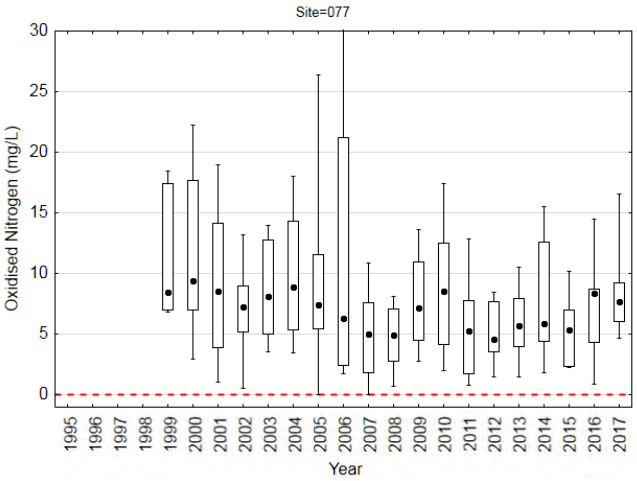
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=077
Total Nitrogen (mg/L)
80
70
60
50
40
30
20
10
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=077
Ammonium Nitrogen (mg/L)
60
50
40
30
20
10
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Oxidised Nitrogen (mg/L)
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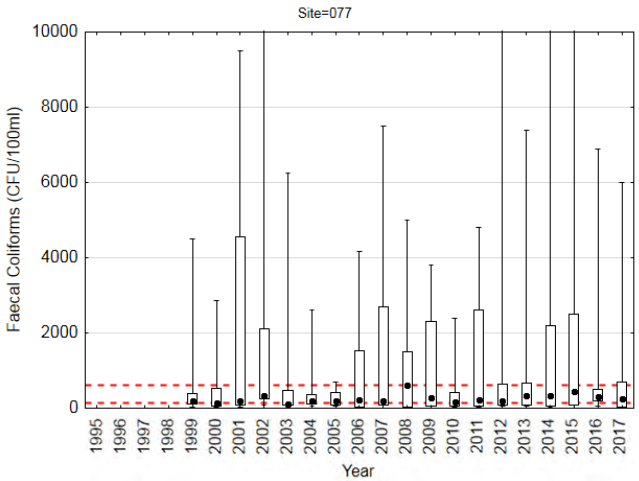
25
20
15
10
5
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Faecal Coliforms (CFU/100ml)
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8000
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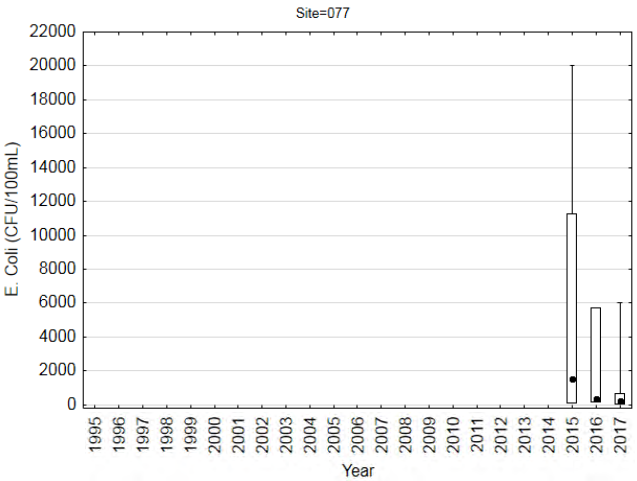
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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E. Coli (CFU/100mL)
22000
20000
18000
16000
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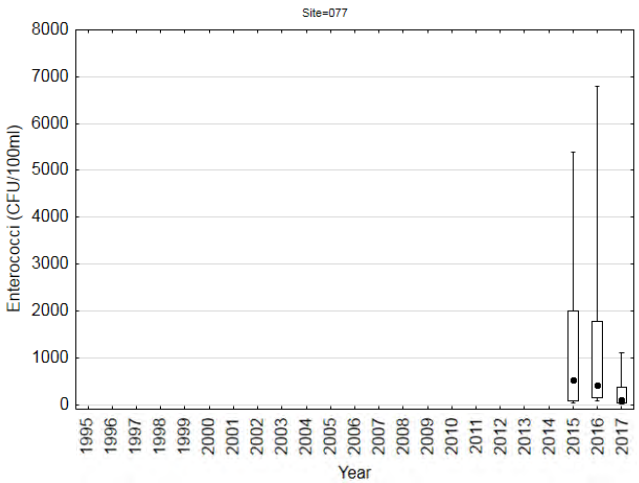
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year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Enterococci (CFU/100ml)
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6000
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4000
3000
2000
1000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 080 – Glenorie Creek, Glenorie

Freshwater site
Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (080)	Aug 1999 – Sept 2017	Monthly
Targeted assessment (080)	Commence 2019/20	To be determined

Key Findings and Recommendations

Condition	Phys-chem: pH is elevated, consistently exceeds REHVs and has a long-term increasing trend. EC is elevated and exceeds REHVs approximately 70% of the time despite a long-term decreasing trend. Variability of DO results significantly reduced post-2015. Clarity: Turbidity and TSS generally low but variable, with turbidity exceeding REHVs approximately 50% of the time. Nutrients: Nutrients are elevated and consistently exceed REHVs despite a long-term decreasing trend. Bacteria: Bacteria levels are elevated and consistently exceed REHVs despite a long-term decreasing trend.
Issues	– Influenced by rural land-use in the catchment – Impacts from onsite wastewater management systems (OWMS) in the catchment
Recommendations	– Targeted monitoring to assess the changes since the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality) in 2015 – Identify further opportunities for WSUD in the catchment – Ongoing collaboration with residents to minimise the impacts of OWMS – Education and collaboration with landholders to minimise impacts from rural activities

Site Photos

Glenorie Creek looking upstream during high flow

Glenorie Creek looking upstream during low flow

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 080

080	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	199	15.95	NA	NS	55	15.88	NA	NS
pH	4.8-7	198	7.20	84	↑	54	7.32	89	↑
DO (%sat)	75-118	199	91.30	10	NS	55	92.80	13	↑
EC (mS/cm)	0.32	198	0.50	85	↓	55	0.43	71	↓
Turbidity (NTU)	8	198	7.0	46	NS	54	8.4	54	NS
TSS (mg/L)	7	204	3	25	NS	56	3	21	NS
TP (mg/L)	0.01	205	0.159	100	↓	56	0.114	100	↓
TN (mg/L)	0.32	205	1.530	100	↓	56	1.285	100	↓
NH_3-N (mg/L)	0.02	205	0.170	100	↓	56	0.140	100	NS
NO_x-N (mg/L)	0.05	205	0.730	100	↓	56	0.565	100	↓
F.Cols (CFU/100ml)	150	205	1000	93	↓	56	830	84	NS

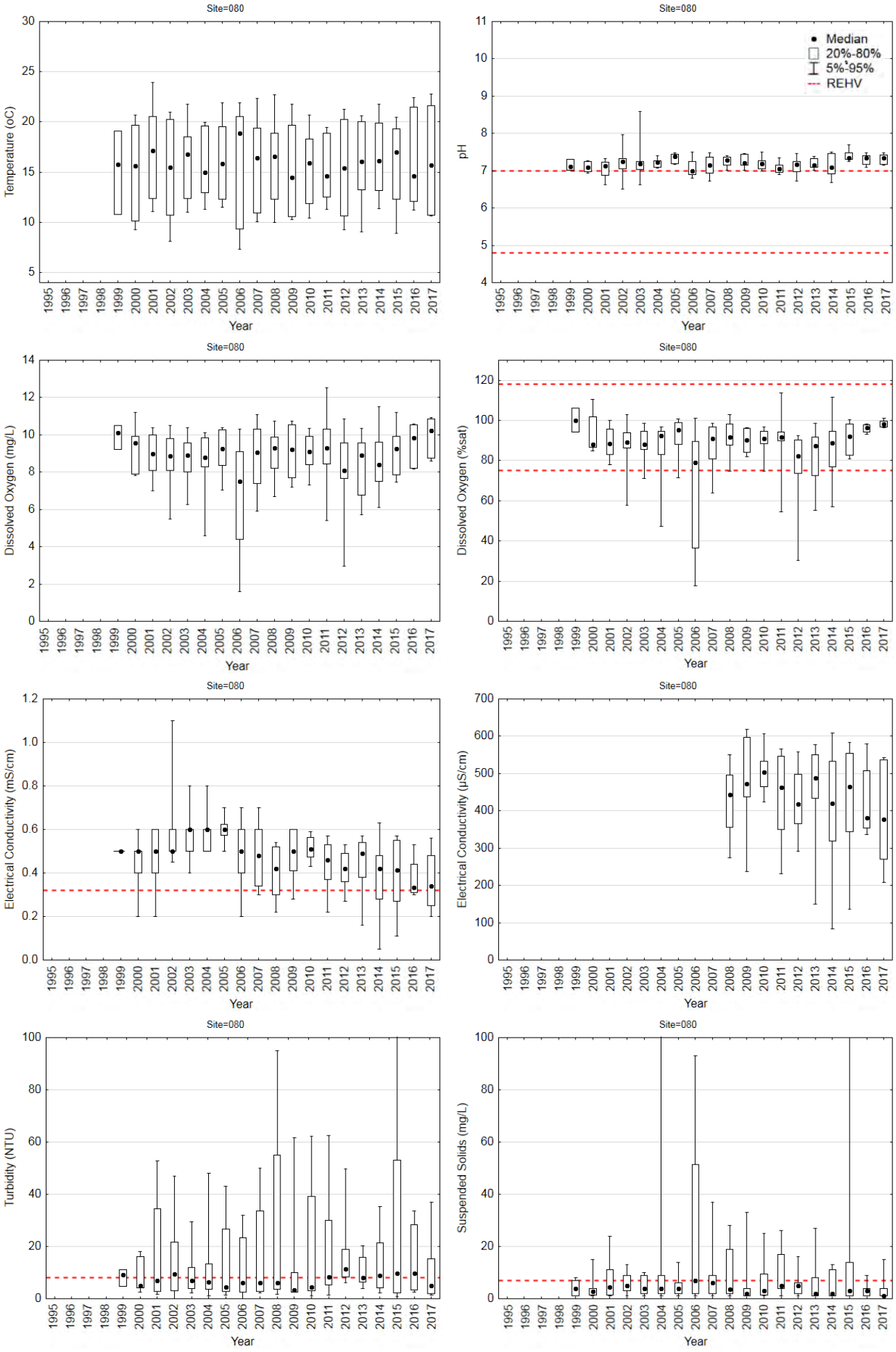
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

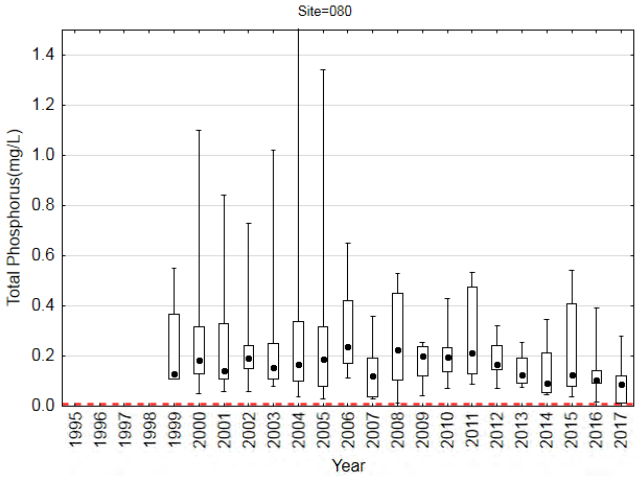
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 080 from August 1999 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	199	15.81	15.95	7.35	24.00	11.85	19.70	3.800
pH	198	7.20	7.20	6.51	9.00	7.04	7.36	0.200
DO (mg/L)	198	8.86	9.10	1.60	13.00	7.90	10.10	1.500
DO (%sat)	199	88.60	91.30	17.60	114.00	83.20	96.80	12.800
EC (mS/cm)	198	0.47	0.50	0.05	1.00	0.37	0.60	0.100
EC (µS/cm)	107	435.64	460.00	83.00	618.00	350.00	533.00	111.900
Turbidity (NTU)	198	14.5	7.0	0.0	170.0	3.3	21.5	19.70
TSS (mg/L)	204	8	3	1	169	1	9	16.7
TP (mg/L)	205	0.220	0.159	0.011	4.000	0.092	0.313	0.3000
TN (mg/L)	205	1.890	1.530	0.580	7.000	1.050	2.440	1.1000
NH_3-N (mg/L)	205	0.330	0.170	0.010	4.000	0.100	0.410	0.5000
NOx-N (mg/L)	205	1.020	0.730	0.040	4.000	0.407	1.470	0.9000
F.Cols (CFU/100ml)	205	25618	1000	20	2300000	375	4650	199837.6
E.Coli (CFU/100ml)	18	2606	525	20	14000	76	4700	4261.2
Entero (CFU/100ml)	28	2248	790	30	24000	440	2900	4716.2

Boxplots showing annual variability for each variable measured

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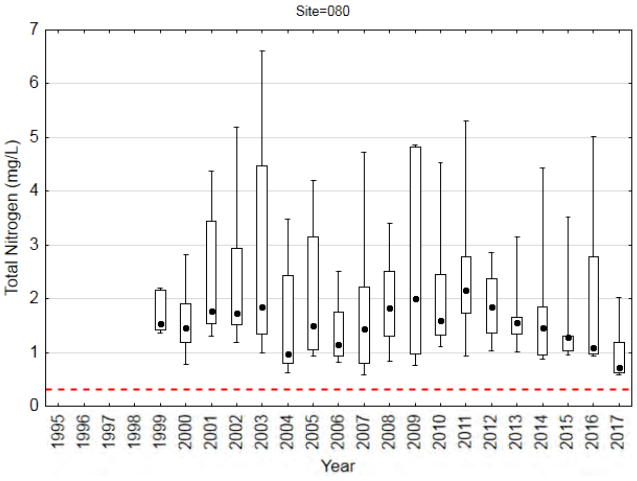
Total Phosphorus(mg/L)
Year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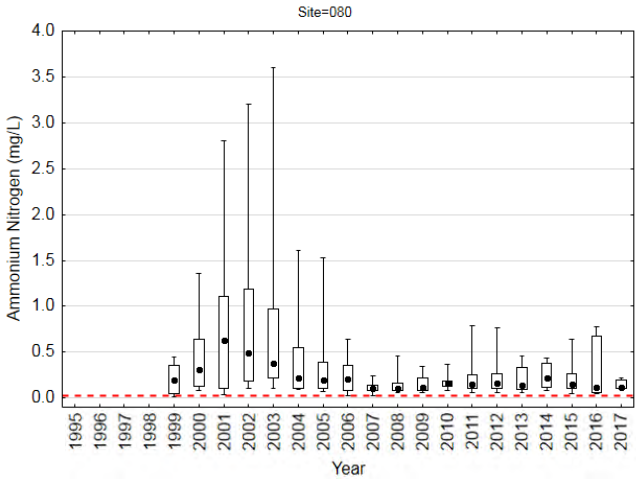
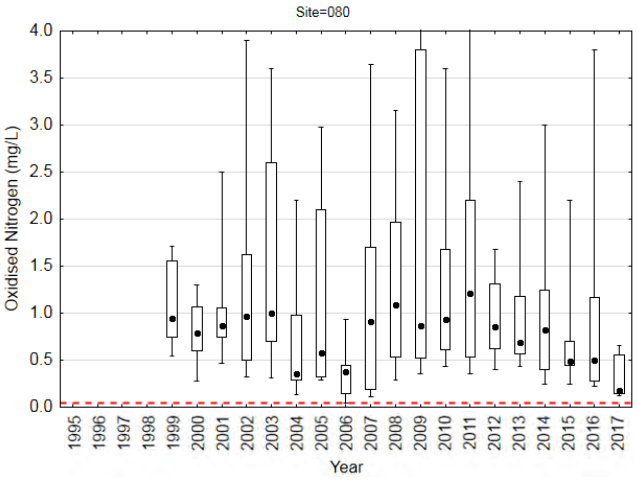
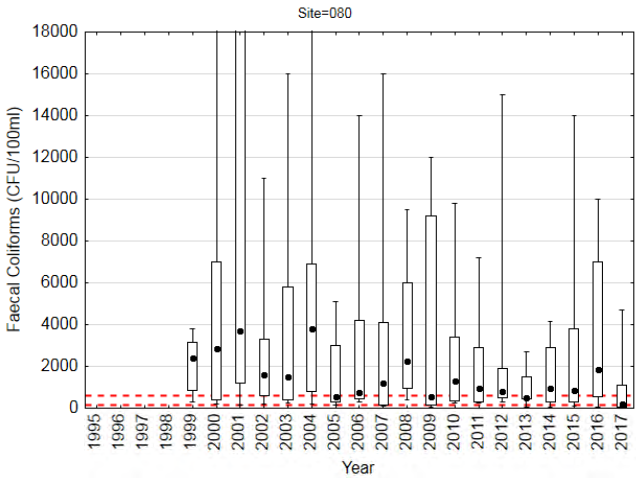
Total Nitrogen (mg/L)
Year


Site=080
Ammonium Nitrogen (mg/L)
Year


Site=080
Oxidised Nitrogen (mg/L)
Year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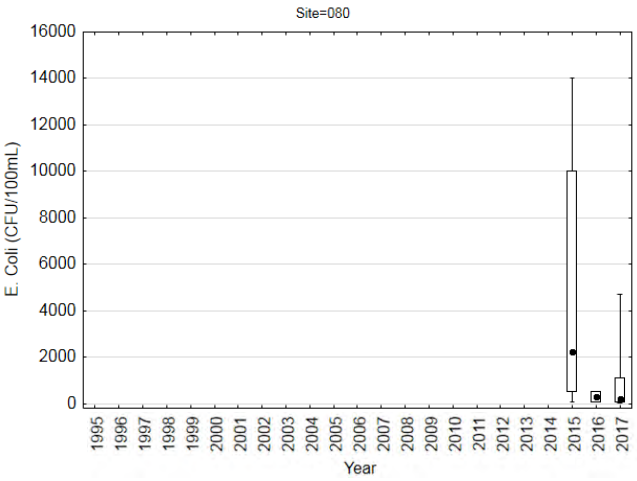
Faecal Coliforms (CFU/100ml)
Year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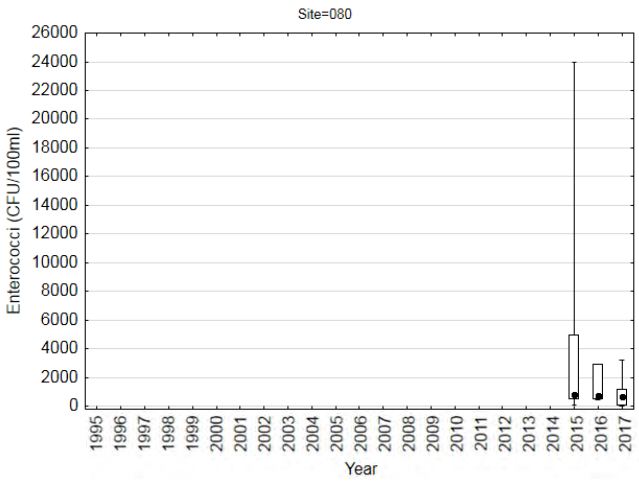
E. Coli (CFU/100mL)
Year


Site=080
Enterococci (CFU/100ml)
Year

Site 100 – Crosslands Reserve, Berowra Creek

Estuarine site, Berowra Creek Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Recreational (100)	Dec 2005 – Mar 2011 Nov 2016 – Mar 2017	Weekly
Long-term (100)	Jul 2009 – Sept 2017	Monthly
Algae (100)	Dec 2008 – Mar 2010 Jan 2015 – Sept 2017 Sept 2017 ongoing	Weekly (Dec-Mar) Monthly In response to elevated algae
Remote (BERO3)	Jan 2016 ongoing	Temperature (°C), salinity (ppt) recorded continuously at 15-minute intervals
Ecohealth (BERO3)	Oct 2017 ongoing	Quarterly
Event (BERO3)	Dec 2017 ongoing	Following rainfall events

Key Findings and Recommendations

Condition	Phys-chem: pH complies with the REHV consistently. DO is suppressed, complying with the REHV approximately 40% of the time. Clarity: Turbidity and TSS are low and generally comply with the REHVs. Biological: Chl-a levels are low and generally comply with the REHV. Nutrients: Nutrient levels are elevated and consistently exceed the REHVs. Bacteria: F.col levels are low and generally comply with REHVs. Entero levels are elevated and variable.
Issues	– Impacted by a large diverse catchment including urban, rural and industrial land-uses – Impacted by West Hornsby and Hornsby Heights WWTPs – Popular location for swimming and recreation
Recommendations	– Monitoring and assessment of bacteria levels to identify and manage risks in recreational waters – Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate the influence of wet-weather events on local conditions – Ongoing collaboration with Sydney Water to improve the management of wastewater – Ongoing (response) monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps

Site Photos

Berowra Creek looking upstream at low tide

Berowra Creek looking upstream at high tide

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 100

100	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	175	22.75	NA	↓	76	21.52	NA	NS
pH	7-8.5	173	7.16	20	↑	76	7.30	7	NS
DO (%sat)	80-110	174	70.30	70	NS	76	69.85	66	NS
Salinity (ppt)	NA	174	14.11	NA	NS	76	15.80	NA	NS
Turbidity (NTU)	10	173	3.5	13	↓	74	3.0	12	NS
TSS (mg/L)	6	158	4	23	↓	63	3	13	NS
Chl-a (ug/L)	4	171	2.4	23	NS	77	2.2	21	↑
TP (mg/L)	0.03	172	0.044	73	NS	77	0.044	69	NS
TN (mg/L)	0.3	172	0.681	99	↑	77	0.690	100	NS
NH_3-N (mg/L)	0.015	172	0.068	97	NS	77	0.070	97	NS
NOx-N (mg/L)	0.015	172	0.260	99	NS	77	0.260	99	NS
F.Cols (CFU/100ml)	150	175	37	22	NS	77	30	17	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	180	610	26	↓	73	300	15	NS

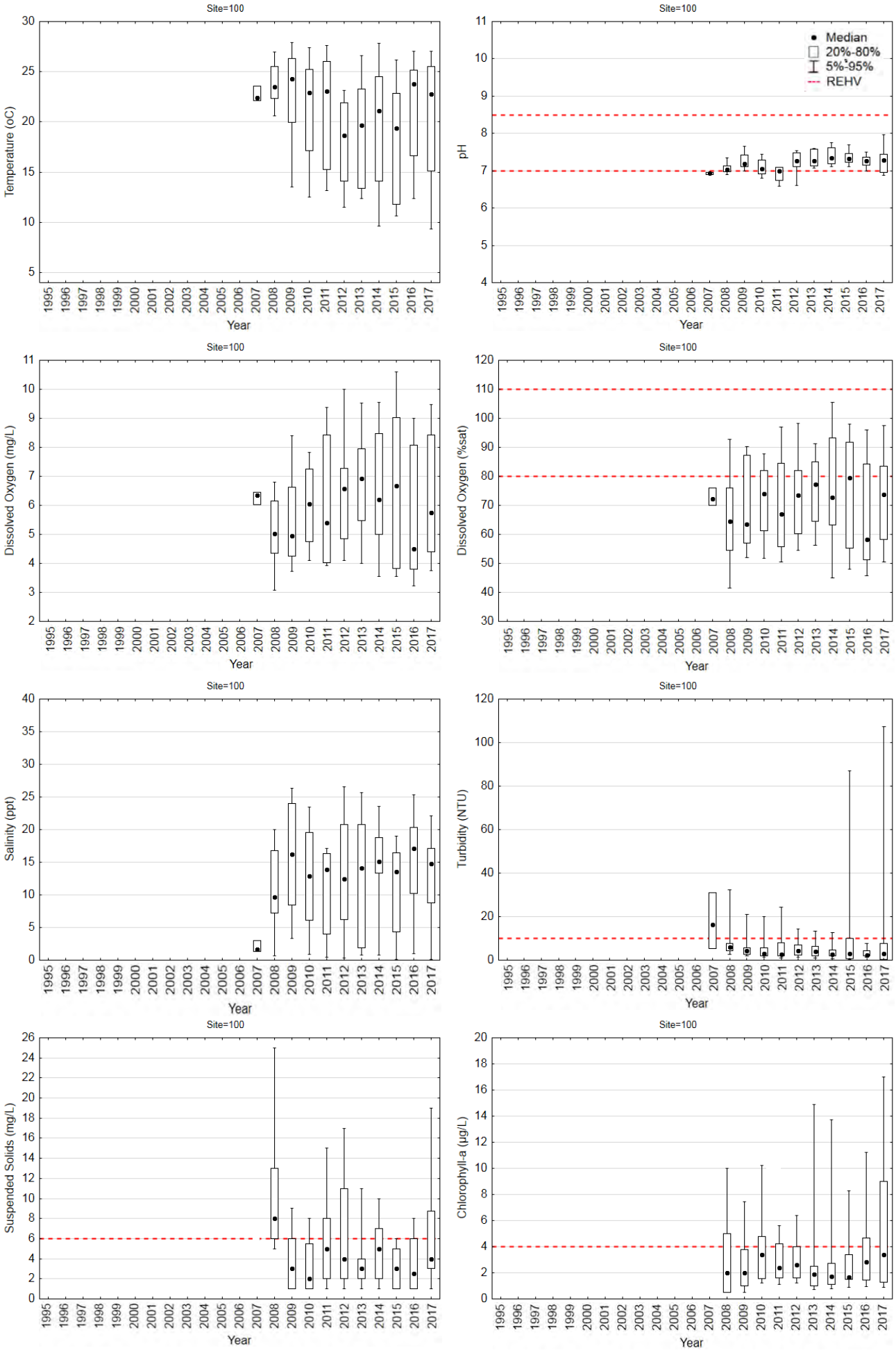
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

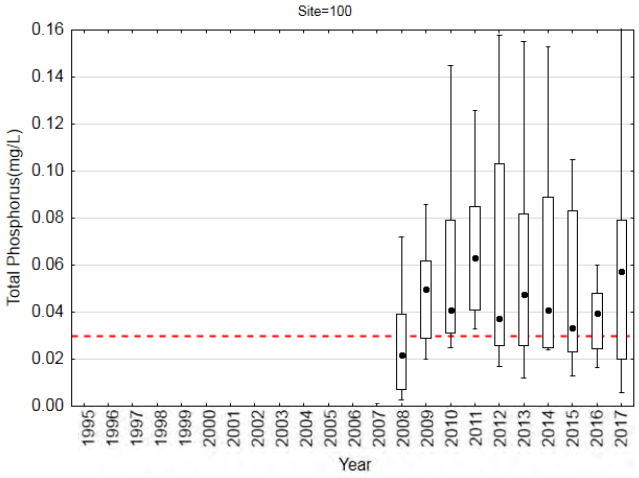
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 100 from December 2005 to September 2017.

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	175	21.11	22.75	9.37	30.10	15.92	25.21	4.920
pH	173	7.18	7.16	6.50	8.00	6.99	7.38	0.250
DO (mg/L)	174	5.98	5.67	2.98	10.60	4.32	7.62	1.770
DO (%sat)	174	70.79	70.30	41.40	105.40	55.80	85.00	14.740
Salinity (ppt)	174	13.05	14.11	0.15	29.00	6.14	18.75	7.010
Turbidity (NTU)	175	6.4	3.5	0.0	107.4	2.0	6.4	11.49
TSS (mg/L)	158	5	4	1	25	2	8	4.3
Chlorophyll-a (µg/L)	171	3.3	2.4	0.2	17.0	1.3	4.5	3.01
TP (mg/L)	172	0.052	0.044	0.003	0.200	0.026	0.072	0.0400
TN (mg/L)	172	0.744	0.681	0.290	2.600	0.480	0.910	0.3600
NH_3-N (mg/L)	172	0.081	0.068	0.003	0.500	0.040	0.110	0.0700
NOx-N (mg/L)	172	0.322	0.260	0.005	2.200	0.120	0.470	0.2900
SRP (mg/L)	39	0.020	0.018	0.001	0.100	0.006	0.032	0.0100
F.Cols (CFU/100ml)	175	2174	37	1	270000	15	205	20631.4
E.Coli (CFU/100ml)	35	996	30	4	28000	9	205	4719.3
Entero (CFU/100ml)	180	161	18	1	5500	6	59	644.2

Boxplots showing annual variability for each variable measured

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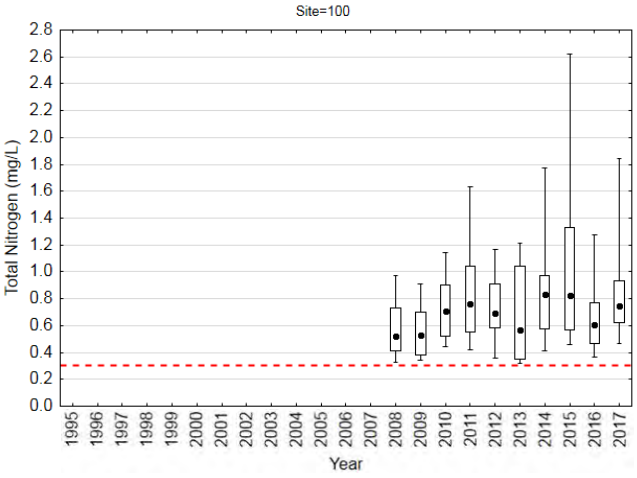
Total Phosphorus(mg/L)
Year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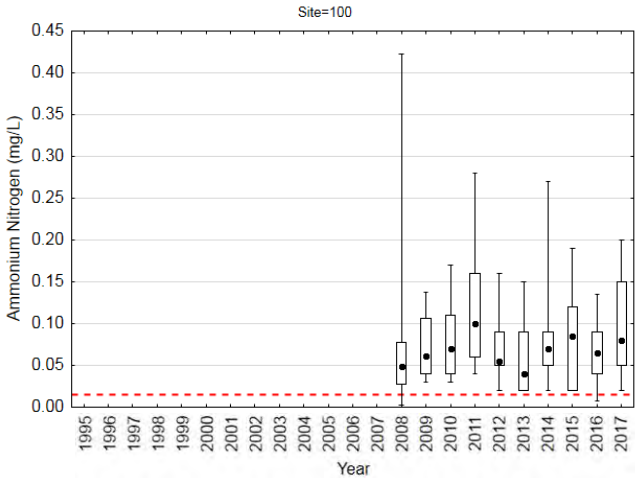
Total Nitrogen (mg/L)
Year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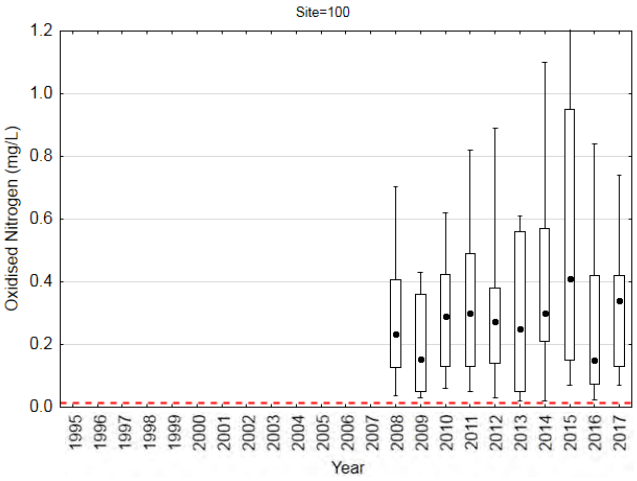
Ammonium Nitrogen (mg/L)
Year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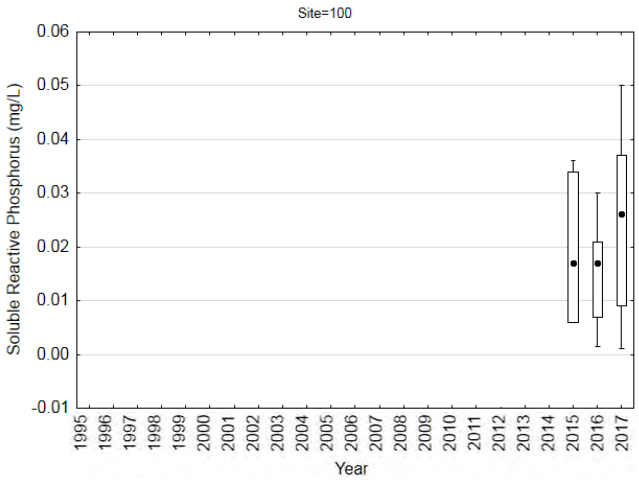
Oxidised Nitrogen (mg/L)
Year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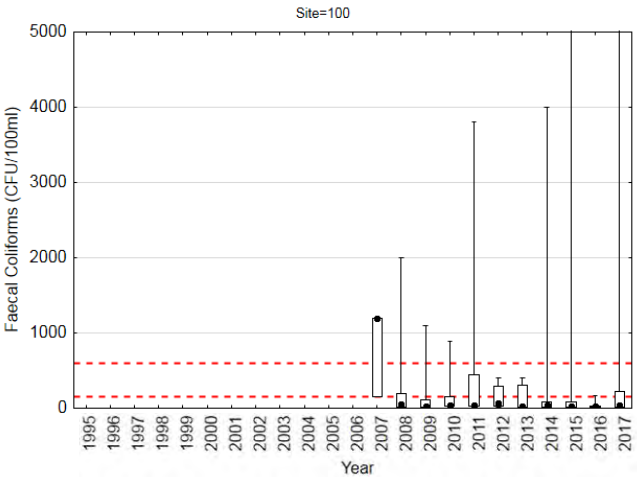
Soluble Reactive Phosphorus (mg/L)
Year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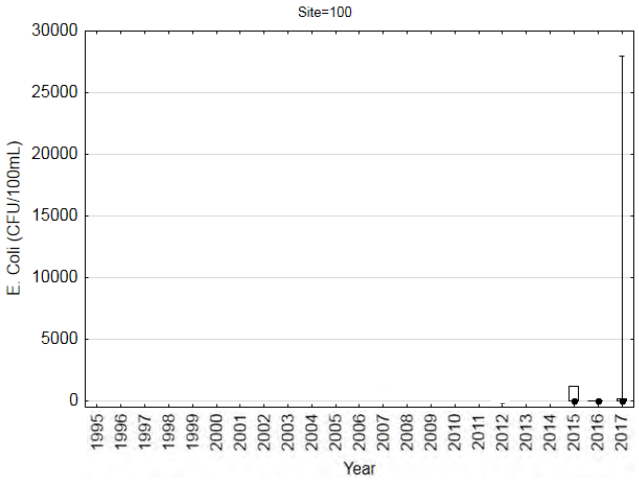
Faecal Coliforms (CFU/100ml)
Year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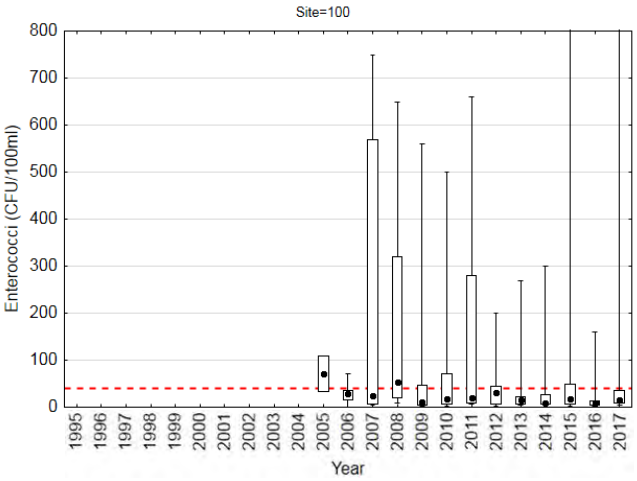
E. Coli (CFU/100mL)
Year


Site=100
Enterococci (CFU/100ml)
Year

Site 103 – Milsons Passage, Hawkesbury River

Estuarine site
Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (103)	Jun 2006 – Sept 2017	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO consistently comply with REHVs. Clarity: Turbidity and TSS are elevated and consistently exceed REHVs. Biological: Chl-a is low and generally complies with the REHV. Nutrients: TP and TN are low and generally comply with REHVs, although an increasing trend is evident. NH_3-N and NOx-N are elevated and exceed the REHVs approximately 50% and 75% of the time, respectively. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Possible influence from local riverside settlements – Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Education and collaboration with riverside residents to minimise impacts from these settlements – Further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Suitability for recreational use to be advised on Council's web-based swimming maps

Site Photos

Milsons Passage looking east

Milsons Passage looking west

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 103

103	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	136	20.37	NA	NS	61	20.70	NA	NS
pH	7-8.5	136	7.81	1	↑	61	7.90	0	NS
DO (%sat)	80-110	134	88.75	8	NS	61	89.30	5	NS
Salinity (ppt)	NA	134	28.93	NA	↓	60	29.15	NA	NS
Turbidity (NTU)	10	136	15.7	77	↑	61	20.1	80	NS
TSS (mg/L)	6	134	18	92	NS	60	19	92	NS
Chl-a (ug/L)	4	134	2.4	9	NS	61	2.4	11	↓
TP (mg/L)	0.03	136	0.021	18	↑	61	0.023	23	NS
TN (mg/L)	0.3	120	0.270	31	↑	61	0.280	38	↑
NH_3-N (mg/L)	0.015	120	0.010	43	↑	61	0.020	57	NS
NOx-N (mg/L)	0.015	136	0.030	74	↑	61	0.030	74	↑
F.Cols (CFU/100ml)	150	136	1	1	NS	61	1	2	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	124	22	3	NS	59	10	2	NS

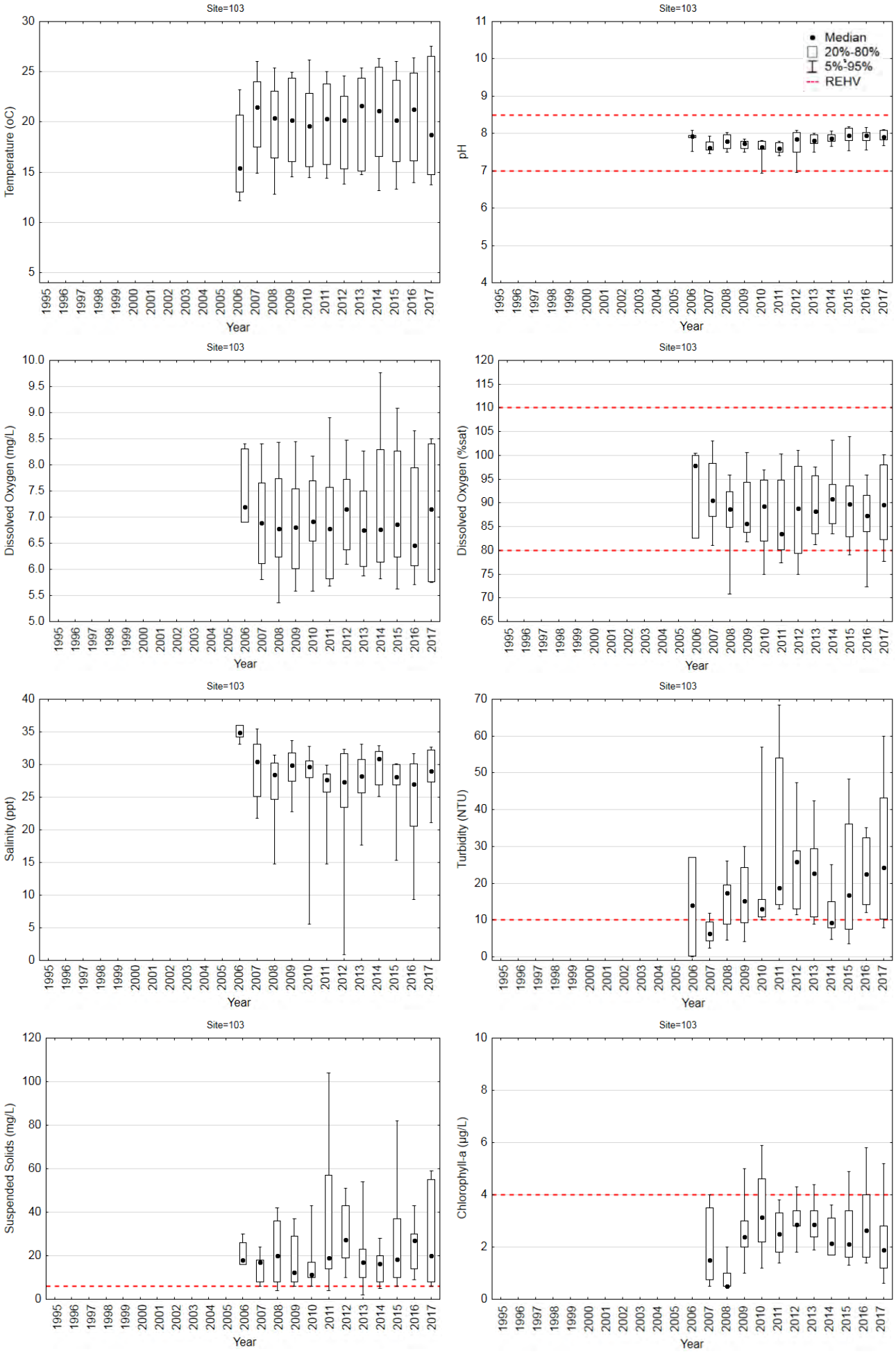
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

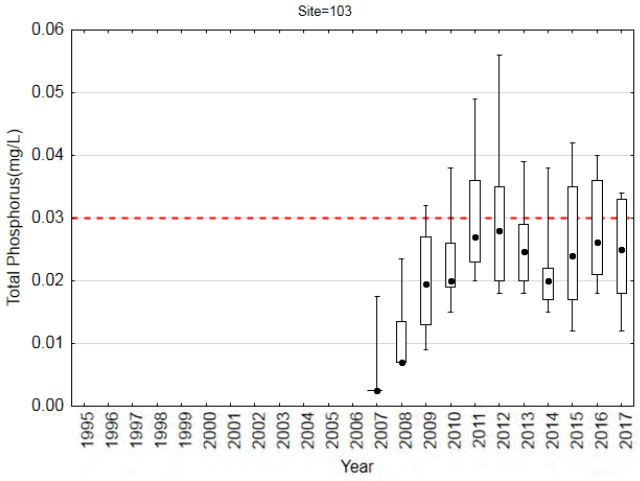
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

Table 2 Descriptive statistics for variables measured at Site 103 from June 2006 to September 2017

Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	136	19.90	20.37	12.13	27.54	15.74	24.06	4.071
pH	136	7.79	7.81	6.93	8.18	7.60	7.96	0.213
DO (mg/L)	134	6.98	6.85	5.36	9.76	6.10	7.73	0.913
DO (%sat)	134	89.01	88.75	70.80	104.00	82.90	95.90	6.811
Salinity (ppt)	134	28.02	28.93	0.91	36.00	25.79	31.69	5.455
Turbidity (NTU)	136	19.2	15.7	0.0	68.5	9.3	27.1	12.99
TSS (mg/L)	134	21	18	2	104	10	30	15.5
Chlorophyll-a (µg/L)	134	2.5	2.4	0.5	5.9	1.6	3.3	1.14
TP (mg/L)	136	0.021	0.021	0.003	0.056	0.012	0.029	0.0110
TN (mg/L)	120	0.282	0.270	0.070	0.670	0.210	0.350	0.1047
NH_3-N (mg/L)	120	0.018	0.010	0.003	0.114	0.010	0.020	0.0163
NOx-N (mg/L)	136	0.046	0.030	0.005	0.240	0.010	0.077	0.0418
SRP (mg/L)	27	0.007	0.006	0.002	0.013	0.005	0.009	0.0029
F.Cols (CFU/100ml)	136	6	1	1	280	1	4	26.0
E.Coli (CFU/100ml)	16	2	1	1	5	1	2	1.6
Entero (CFU/100ml)	124	7	2	0	350	1	5	32.1

Boxplots showing annual variability for each variable measured

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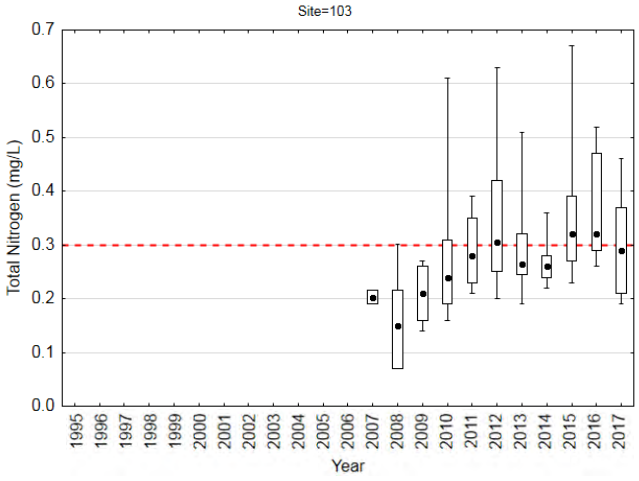
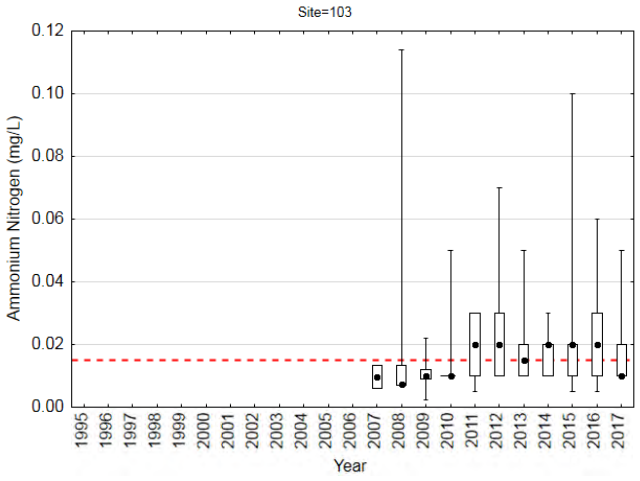
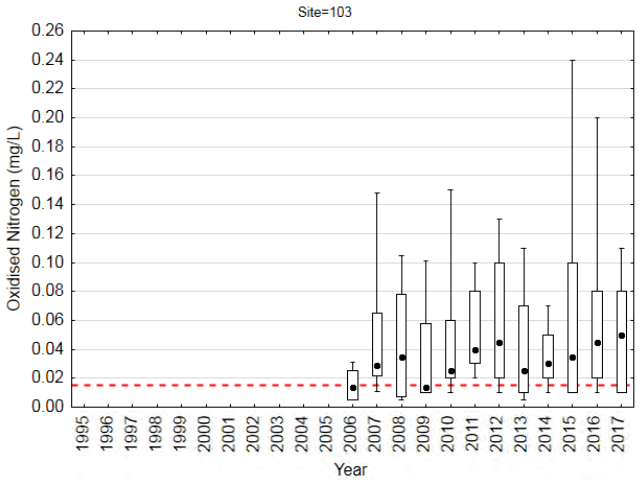
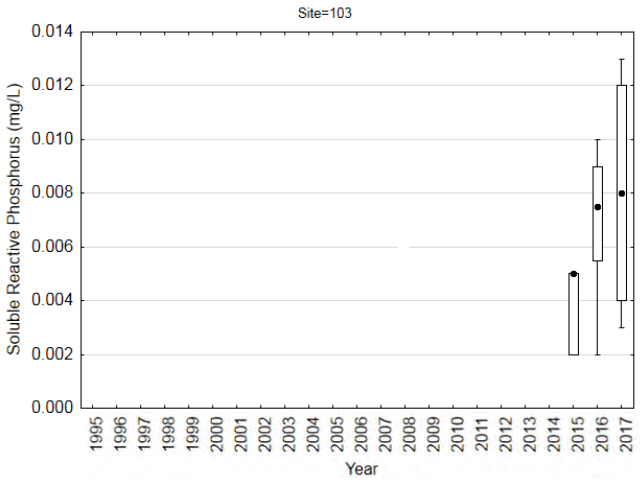
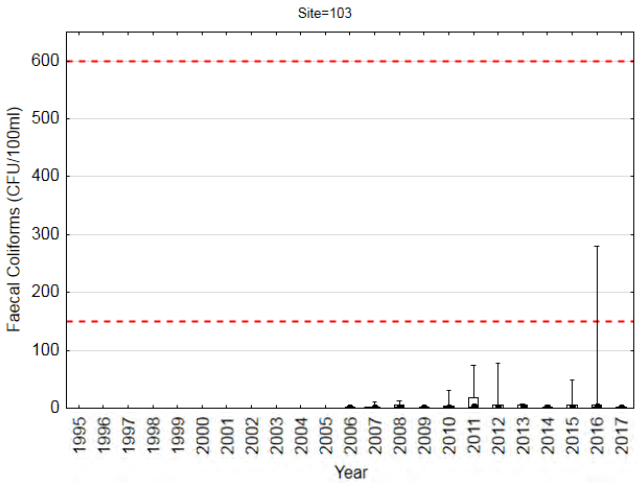
Total Phosphorus(mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

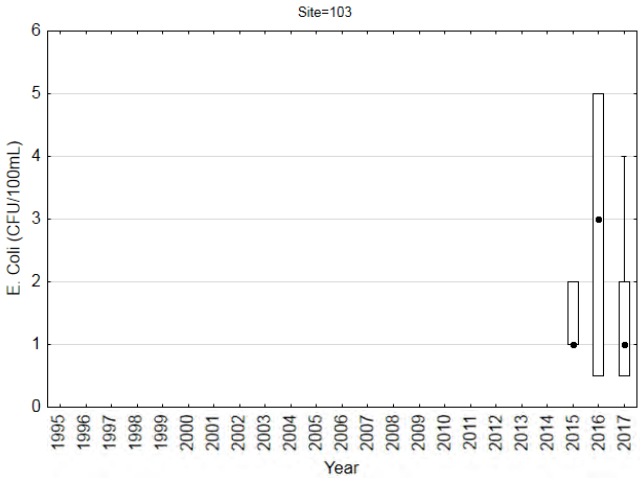

Site=103
Total Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

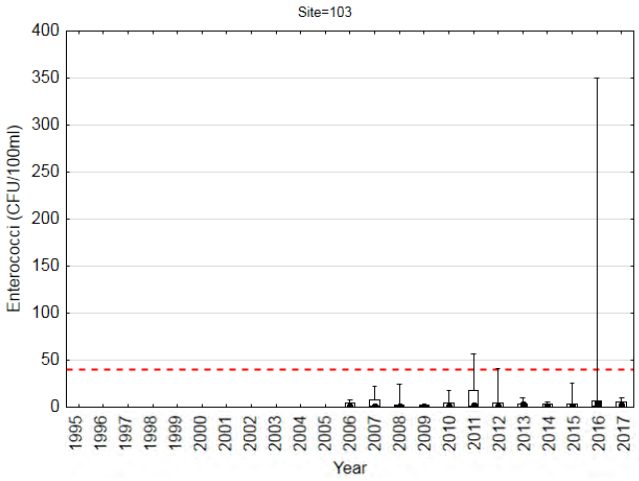

Site=103
Ammonium Nitrogen (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=103
Oxidised Nitrogen (mg/L)
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=103
Soluble Reactive Phosphorus (mg/L)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=103
Faecal Coliforms (CFU/100ml)
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=103
E. Coli (CFU/100mL)
6
5
4
3
2
1
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=103
Enterococci (CFU/100ml)
400
350
300
250
200
150
100
50
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 108 – Bradleys Beach, Dangar Island

Estuarine site
Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Long-term (108)	Jun 2006 – Sept 2017	Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO consistently comply with REHVs. A weak long-term decreasing trend in DO evident. Clarity: Turbidity is generally low but exceeds the REHV approximately 40% of the time. TSS is slightly elevated and exceeds the REHV approximately 40% of the time. Biological: Chl-a is low and consistently complies with the REHV. Nutrients: Nutrients are low and generally comply with REHVs with the exception of NOx-N which is slightly elevated and exceeds the REHV approximately 60% of the time. Long-term increasing trend evident for all nutrients. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Recreational swimming location – Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Suitability for recreational use to be advised on Council's web-based swimming maps

Site Photos

Bradleys Beach, Dangar Island looking south west

Bradleys Beach, Dangar Island looking south

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 108

108	REHV	Long-term				2012-2017			
		n	Median	%NCs	Trend	n	Median	%NCs	Trend
Temp (°C)	NA	132	19.77	NA	NS	59	19.81	NA	NS
pH	7-8.5	132	7.93	0	↑	59	8.02	0	↑
DO (%sat)	80-110	131	92.30	5	↓	59	90.90	5	NS
Salinity (ppt)	NA	129	33.15	NA	NS	58	33.31	NA	NS
Turbidity (NTU)	10	132	8.0	36	↑	59	9.6	44	NS
TSS (mg/L)	6	132	11	79	NS	58	11	81	NS
Chl-a (ug/L)	4	132	2.2	5	↑	59	2.2	5	NS
TP (mg/L)	0.03	133	0.018	2	↑	59	0.019	2	NS
TN (mg/L)	0.3	117	0.220	9	↑	59	0.240	12	↑
NH_3-N (mg/L)	0.015	117	0.010	33	↑	59	0.010	37	NS
NOx-N (mg/L)	0.015	133	0.020	59	↑	59	0.020	56	NS
F.Cols (CFU/100ml)	150	133	1	1	↓	59	1	2	NS
		n	95th%ile	%NCs	Trend	n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	121	21	1	↓	59	8	2	NS

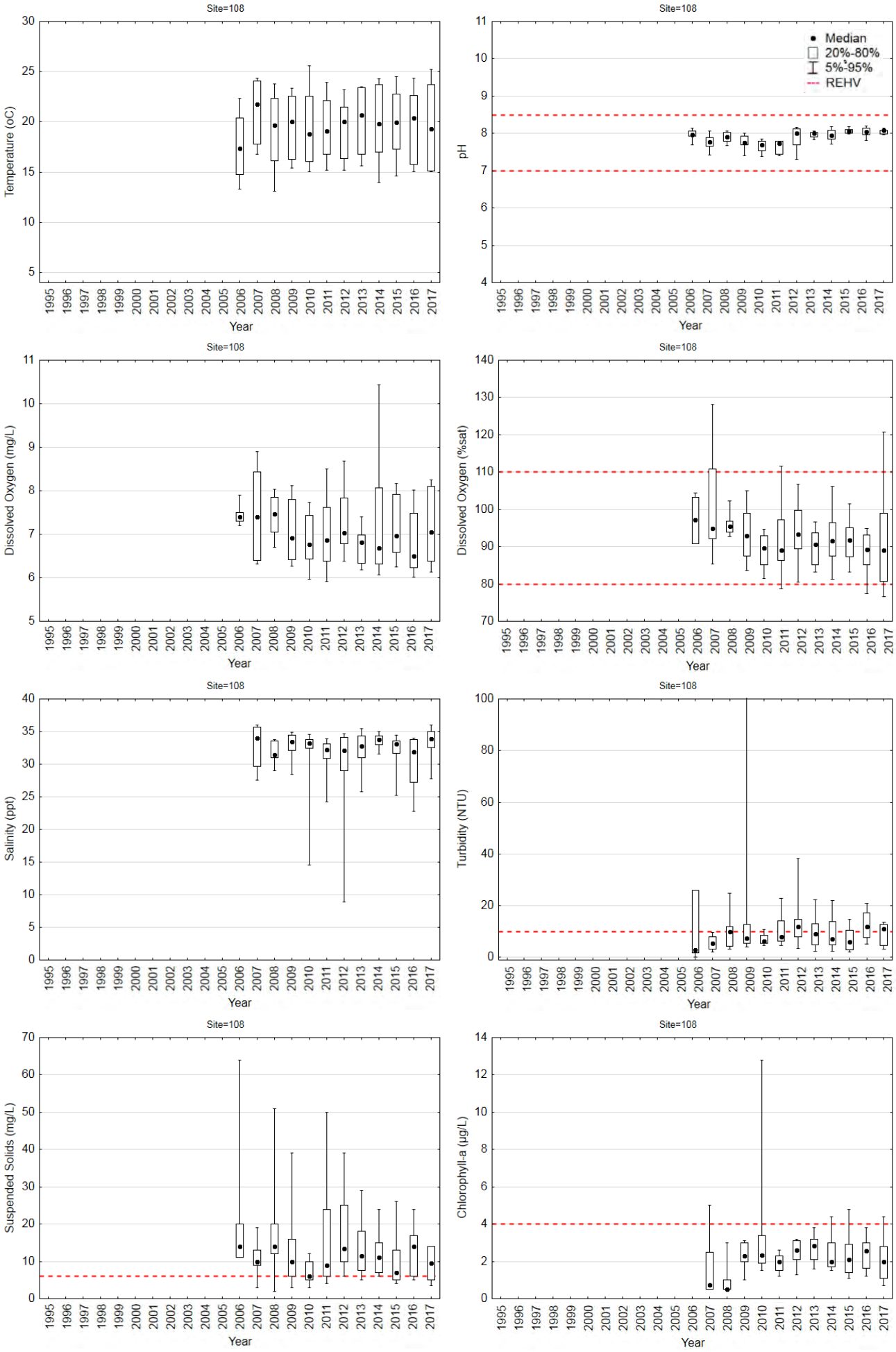
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

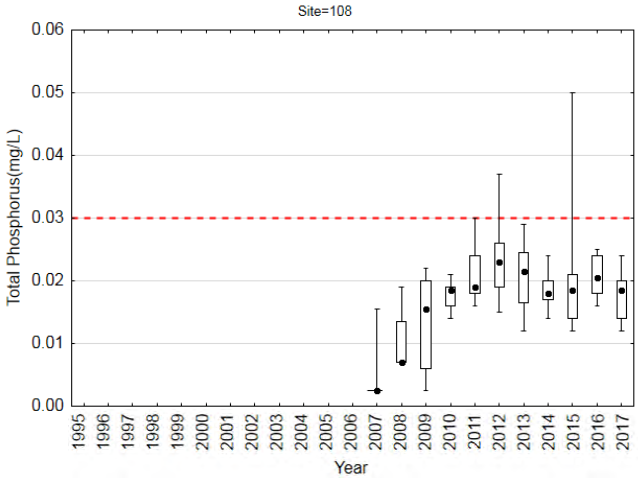
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

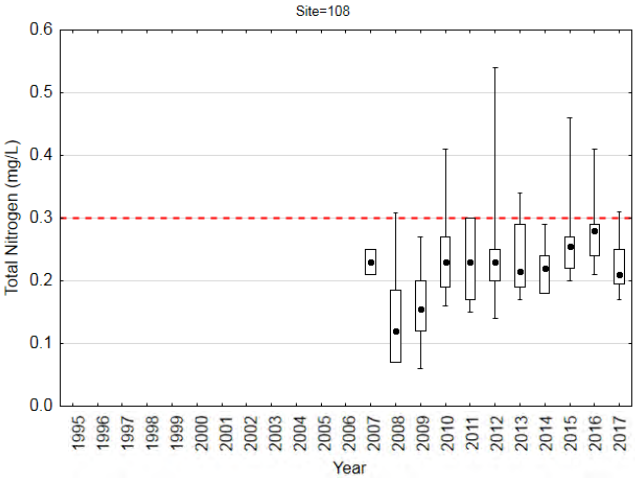
Table 2 Descriptive statistics for variables measured at Site 108 from June 2006 to September 2017

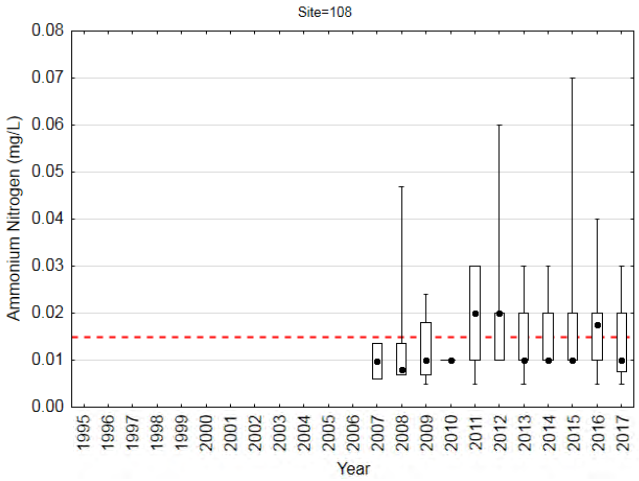
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	132	19.63	19.77	13.12	25.60	16.37	22.78	3.134
pH	132	7.88	7.93	7.30	8.20	7.70	8.06	0.203
DO (mg/L)	131	7.11	6.95	5.92	10.43	6.46	7.77	0.738
DO (%sat)	131	92.87	92.30	76.60	128.10	87.27	97.30	7.784
Salinity (ppt)	129	32.14	33.15	8.85	36.00	30.97	34.31	3.878
Turbidity (NTU)	132	10.7	8.0	0.0	190.0	5.0	12.7	16.84
TSS (mg/L)	132	13	11	2	64	6	17	9.9
Chlorophyll-a (µg/L)	132	2.2	2.2	0.5	12.8	1.4	3.0	1.34
TP (mg/L)	133	0.016	0.018	0.003	0.050	0.008	0.021	0.0078
TN (mg/L)	117	0.224	0.220	0.060	0.540	0.170	0.270	0.0767
NH_3-N (mg/L)	117	0.015	0.010	0.005	0.070	0.010	0.020	0.0100
NOx-N (mg/L)	133	0.028	0.020	0.005	0.130	0.010	0.047	0.0249
SRP (mg/L)	27	0.006	0.006	0.001	0.012	0.004	0.007	0.0028
F.Cols (CFU/100ml)	133	6	1	0	390	1	3	34.5
E.Coli (CFU/100ml)	16	1	1	1	3	1	1	0.7
Entero (CFU/100ml)	121	5	1	1	260	1	4	24.3

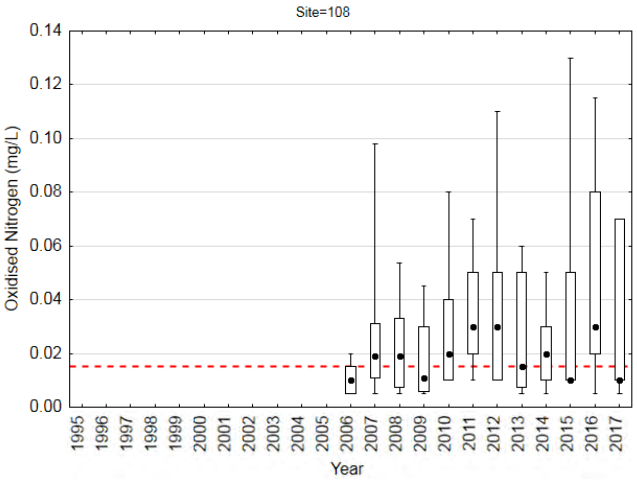
Boxplots showing annual variability for measured variables

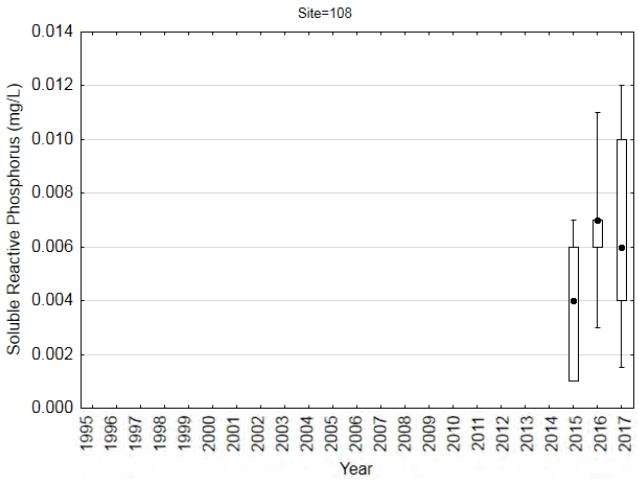


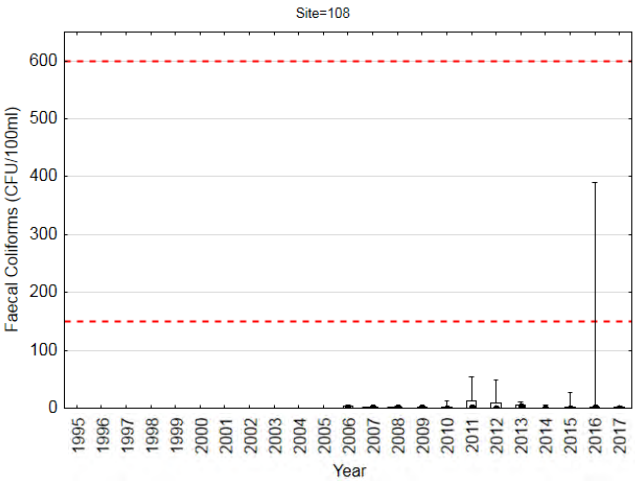

Site=108
Total Phosphorus(mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

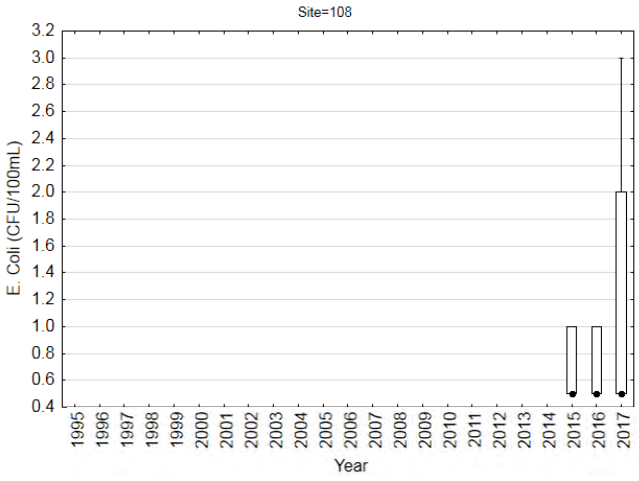

Site=108
Total Nitrogen (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

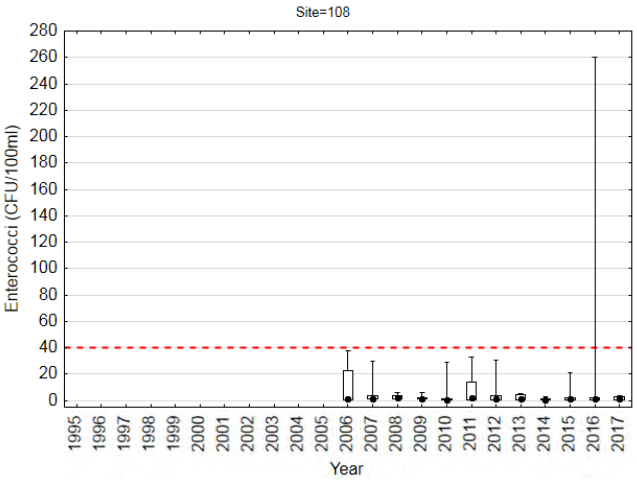

Site=108
Ammonium Nitrogen (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=108
Oxidised Nitrogen (mg/L)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=108
Soluble Reactive Phosphorus (mg/L)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=108
Faecal Coliforms (CFU/100ml)
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=108
E. Coli (CFU/100mL)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=108
Enterococci (CFU/100ml)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 150 – Gunyah Point, Hawkesbury River

Estuarine site, Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Remote (HAWK1)	Aug 2008 ongoing	Temperature (°C), salinity (ppt), turbidity (NTU) and chlorophyll-a (µg/L) recorded continuously at 15-minute intervals (data not analysed in this report)
Long-term (150)	Dec 2010 – Sept 2017	Monthly from July to September, every 3 weeks for the remainder of the year
Ecohealth (HAWK1)	Oct 2017 ongoing	Quarterly
Algae (HAWK1)	Oct 2017 ongoing	~ Monthly

Key Findings and Recommendations

Condition	Phy-chem: pH and DO consistently comply with REHVs. Clarity: Turbidity is low and consistently complies with the REHV. TSS is slightly elevated and exceeds the REHV approximately 55% of the time. Biological: Chl-a is low and consistently complies with the REHV. Nutrients: Nutrients are low and generally comply with REHVs, with the exception of NOx-N, which is slightly elevated and exceeds the REHV approximately 60% of the time. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Significant location for commercial oyster farming – Significant location for commercial fishing operations – Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Ongoing collaboration with stakeholders for a coordinated approach to the management of risks to local aquaculture and commercial fishing operations – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data

Site Photos

Gunyah Point looking south

Gunyah Point looking north

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 150

150	REHV	Long-term 2010-2017			
		n	Median	%NCs	Trend
Temp (°C)	NA	98	20.47	NA	NS
pH	7-8.5	96	7.97	1	↑
DO (%sat)	80-110	96	91.95	5	NS
Salinity (ppt)	NA	98	32.82	NA	NS
Turbidity (NTU)	10	96	5.0	15	↑
TSS (mg/L)	6	60	8	55	NS
Chl-a (ug/L)	4	60	2.1	5	NS
TP (mg/L)	0.03	65	0.019	8	NS
TN (mg/L)	0.3	65	0.230	14	↑
NH_3-N (mg/L)	0.015	65	0.010	31	↑
NOx-N (mg/L)	0.015	65	0.020	60	↑
F.Cols (CFU/100ml)	150	60	1	0	↑
		n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	60	9	0	NS

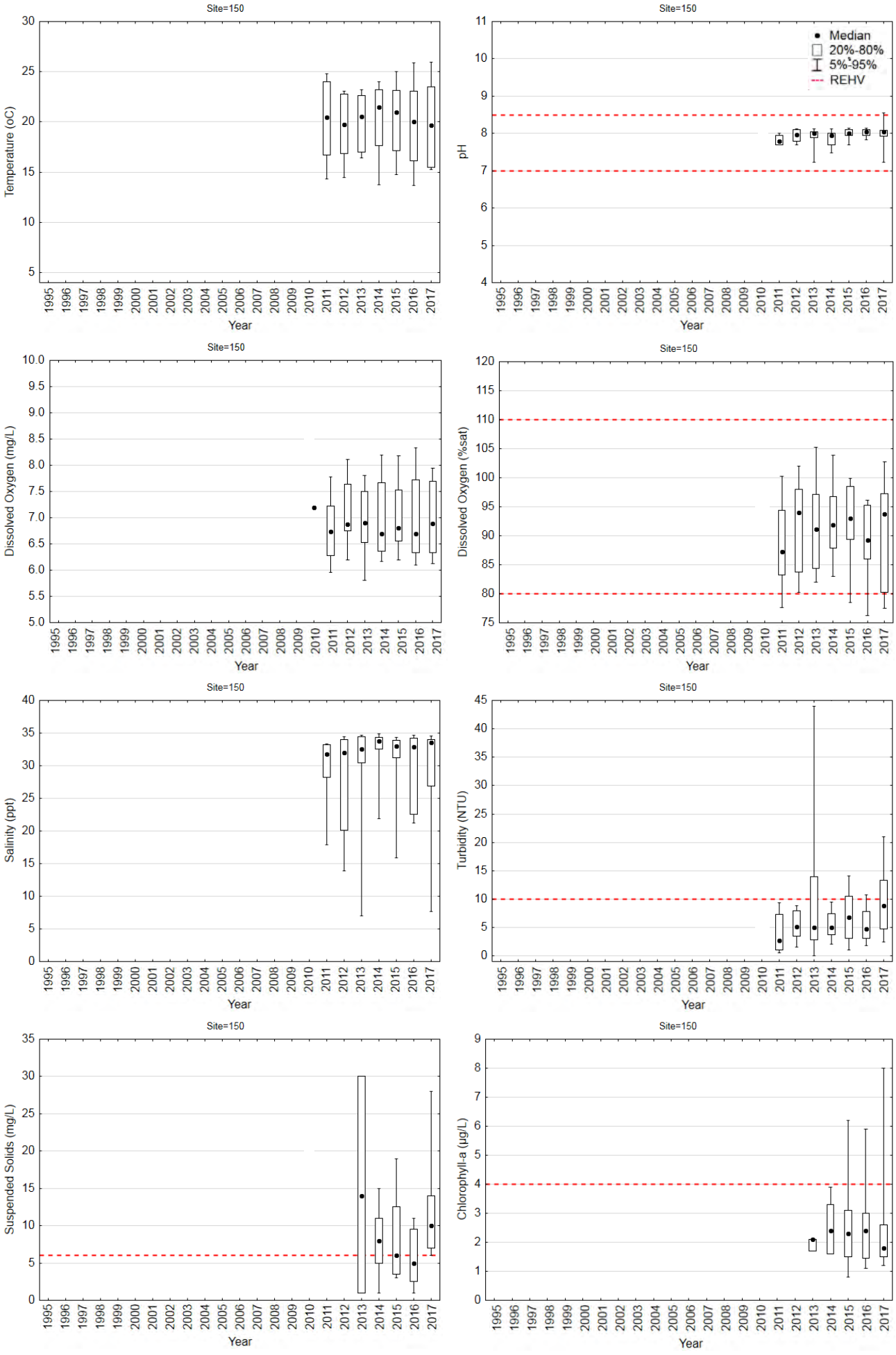
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs – percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

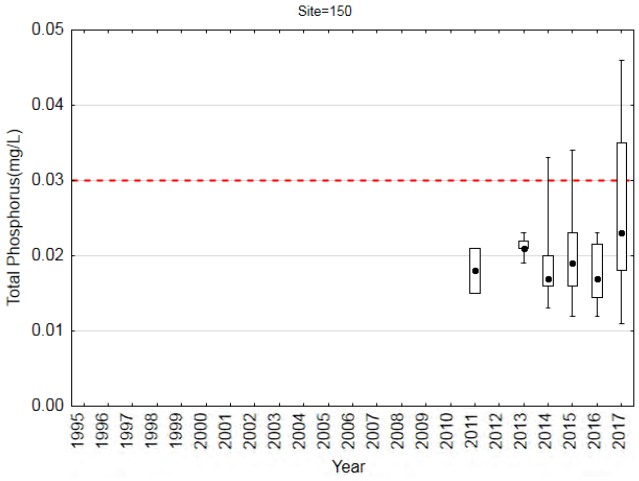
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

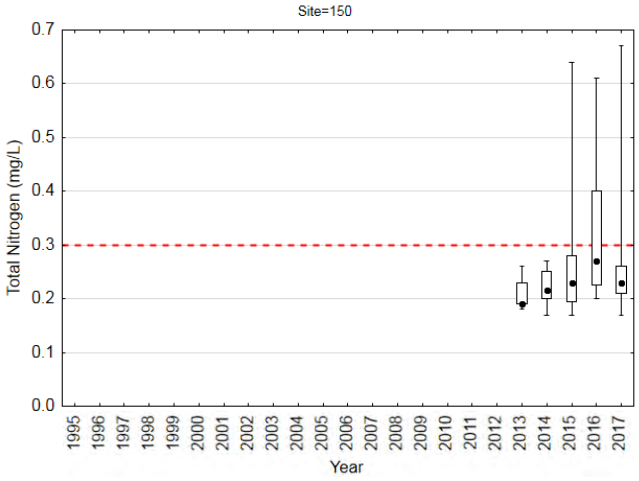
Table 2 Descriptive statistics for variables measured at Site 150 from December 2010 to September 2017

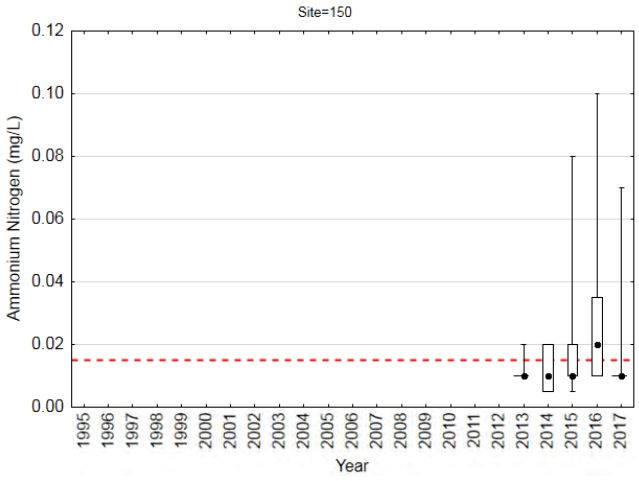
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	98	19.98	20.47	13.68	25.93	16.74	23.07	3.235
pH	96	7.94	7.97	7.22	8.56	7.81	8.06	0.185
DO (mg/L)	96	6.96	6.81	5.81	8.34	6.38	7.50	0.598
DO (%sat)	96	91.33	91.95	76.30	105.30	86.00	96.80	6.361
Salinity (ppt)	98	30.58	32.82	7.00	34.91	28.65	34.02	5.691
Turbidity (NTU)	96	6.7	5.0	0.0	44.0	3.0	8.9	6.25
TSS (mg/L)	60	8	8	1	30	3	12	5.8
Chlorophyll-a (µg/L)	60	2.5	2.1	0.8	8.0	1.6	3.1	1.26
TP (mg/L)	65	0.020	0.019	0.011	0.046	0.016	0.022	0.0061
TN (mg/L)	65	0.260	0.230	0.170	0.670	0.200	0.270	0.1033
NH_3-N (mg/L)	65	0.017	0.010	0.005	0.100	0.010	0.020	0.0178
NOx-N (mg/L)	65	0.043	0.020	0.005	0.290	0.010	0.070	0.0590
SRP (mg/L)	38	0.007	0.006	0.001	0.021	0.005	0.009	0.0035
F.Cols (CFU/100ml)	60	3	1	1	42	1	2	7.3
E.Coli (CFU/100ml)	17	3	1	1	17	1	2	4.1
Entero (CFU/100ml)	60	2	1	1	16	1	3	3.1

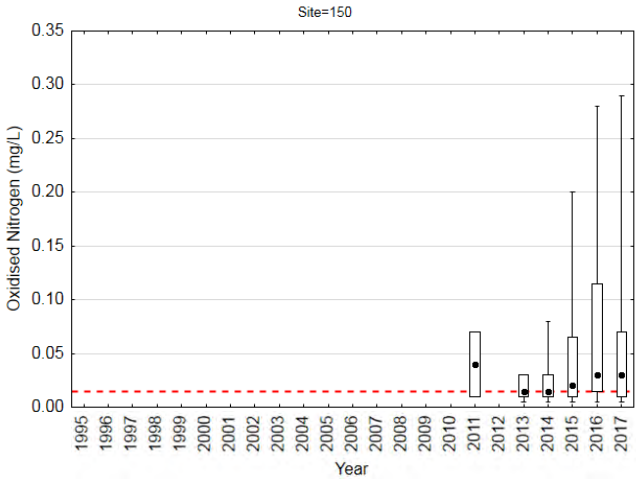
Boxplots showing annual variability for each variable measured

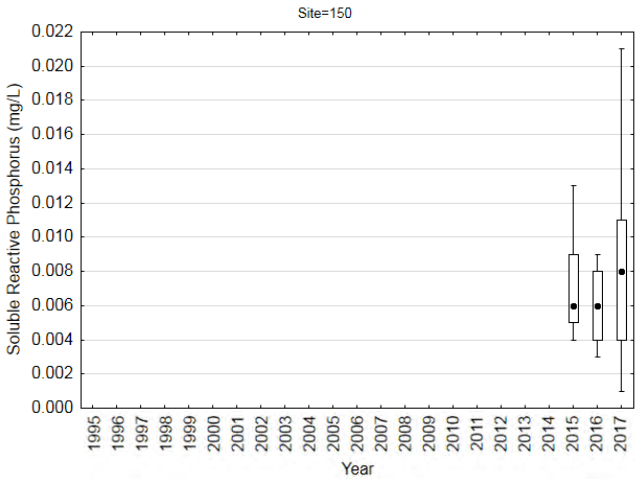


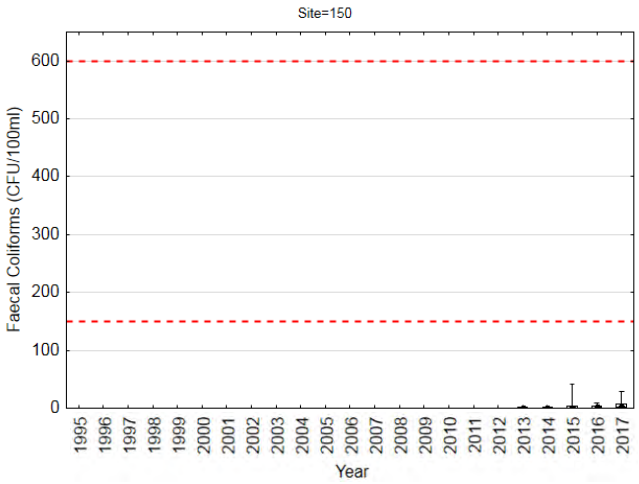

Site=150
Total Phosphorus(mg/L)
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

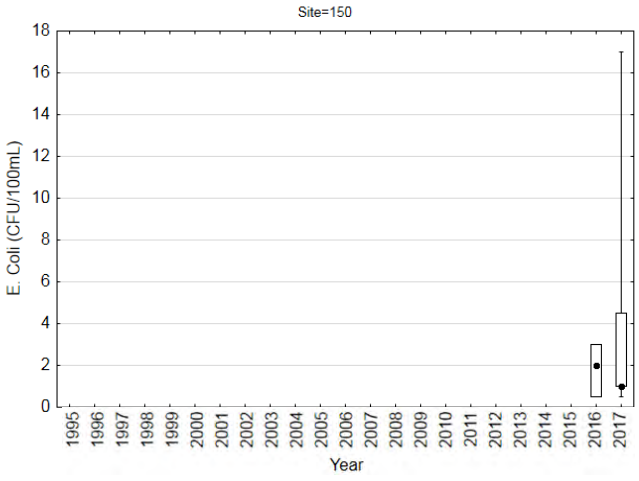

Site=150
Total Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

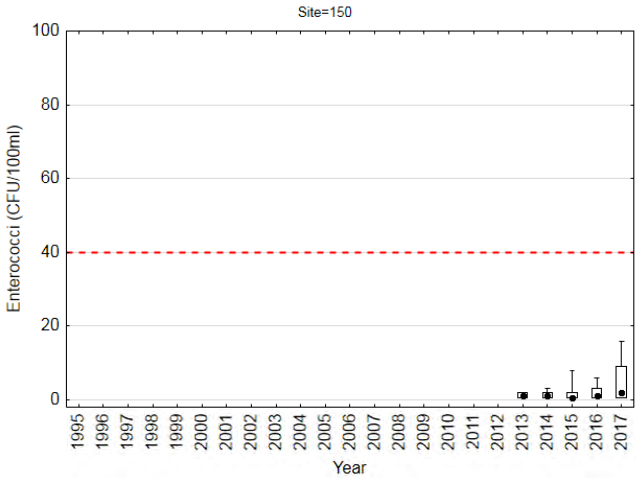

Site=150
Ammonium Nitrogen (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=150
Oxidised Nitrogen (mg/L)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=150
Soluble Reactive Phosphorus (mg/L)
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=150
Faecal Coliforms (CFU/100ml)
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=150
E. Coli (CFU/100mL)
18
16
14
12
10
8
6
4
2
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=150
Enterococci (CFU/100ml)
100
80
60
40
20
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 151 – Bar Island, Hawkesbury River

Estuarine site, Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Remote (151)	Jun 2010 ongoing	Temperature (°C), salinity (ppt), turbidity (NTU) and chlorophyll-a (µg/L) recorded continuously at 15-minute intervals (data not anlaysed in this report)
Long-term (151)	Nov 2010 – Sept 2017	Monthly from July to September, every 3 weeks for the remainder of the year
Algae (151)	Oct 2017 ongoing	~ Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO consistently comply with REHVs. Clarity: Turbidity and TSS are slightly elevated, exceeding the REHVs approximately 50% and 75% of the time, respectively. Biological: Chl-a results are generally close to the REHV, exceeding it approximately 60% of the time. Nutrients: TN and NOx-N are elevated and exceed REHVs 55% and 75% of the time, respectively. An increasing trend is evident for both TN and NOx-N. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Significant location for commercial oyster farming – Significant location for commercial fishing operations – Possible influence from local riverside settlements – Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Ongoing collaboration with stakeholders for a coordinated approach to the management of risks to local aquaculture and commercial fishing operations – Education and collaboration with riverside residents to minimise impacts from these settlements – Investigate sources of increasing nutrients in the Hawkesbury River – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data

Site Photos

Mouth of Marramarra Creek looking south

Mouth of Marramarra Creek looking north

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 151

151	REHV	Long-term 2010-2017			
		n	Median	%NCs	Trend
Temp (°C)	NA	98	21.48	NA	NS
pH	7-8.5	96	7.76	3	↑
DO (%sat)	80-110	96	88.05	17	NS
Salinity (ppt)	NA	98	24.85	NA	NS
Turbidity (NTU)	10	95	10.1	52	NS
TSS (mg/L)	6	61	9	74	NS
Chl-a (ug/L)	4	61	4.7	57	NS
TP (mg/L)	0.03	66	0.021	12	NS
TN (mg/L)	0.3	66	0.315	55	↑
NH_3-N (mg/L)	0.015	66	0.010	33	NS
NOx-N (mg/L)	0.015	66	0.040	76	↑
F.Cols (CFU/100ml)	150	61	1	2	NS
		n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	61	13	2	NS

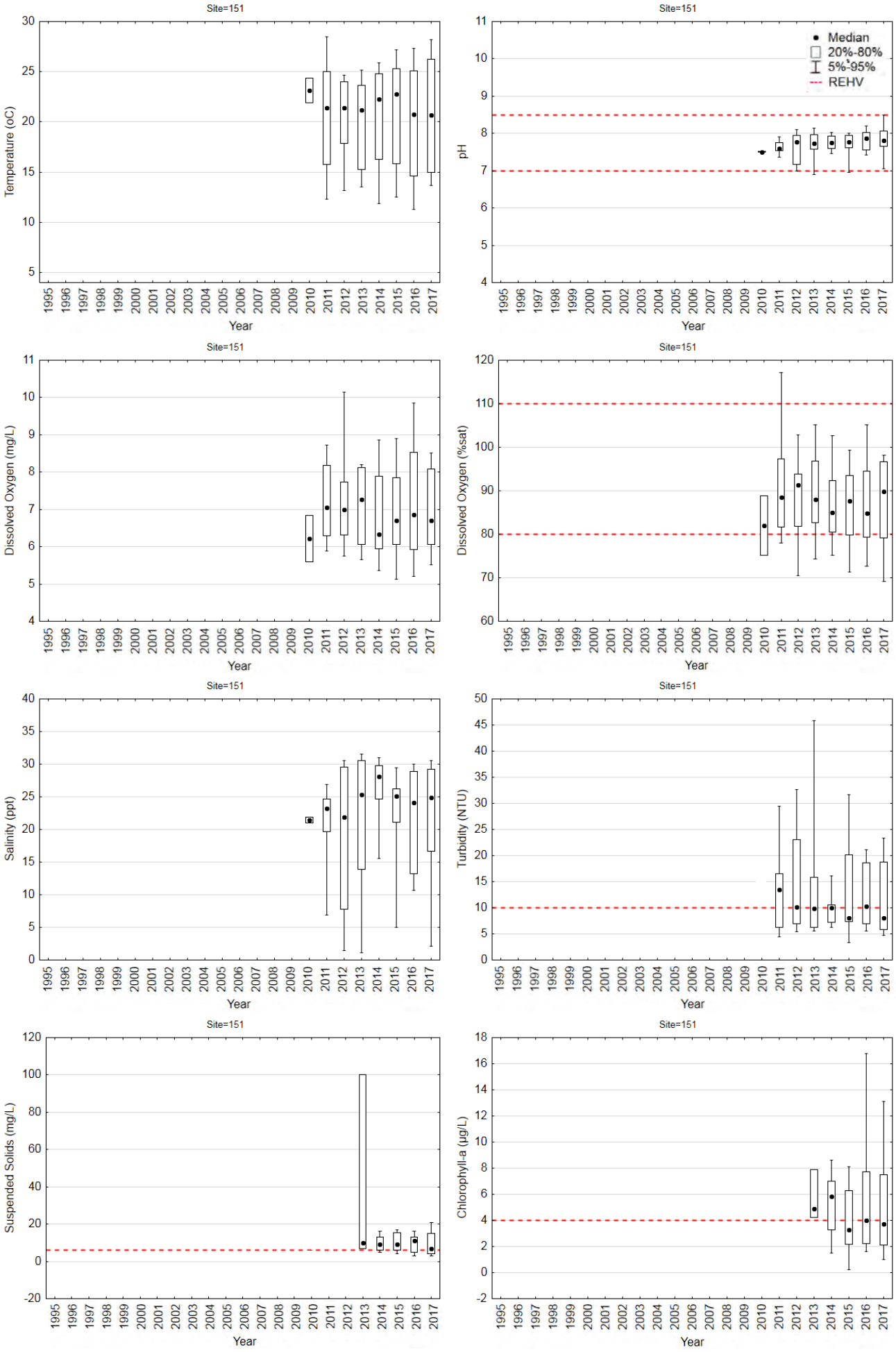
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

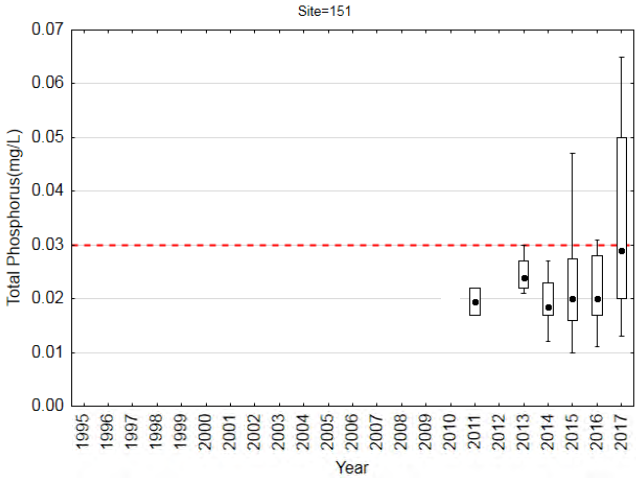
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

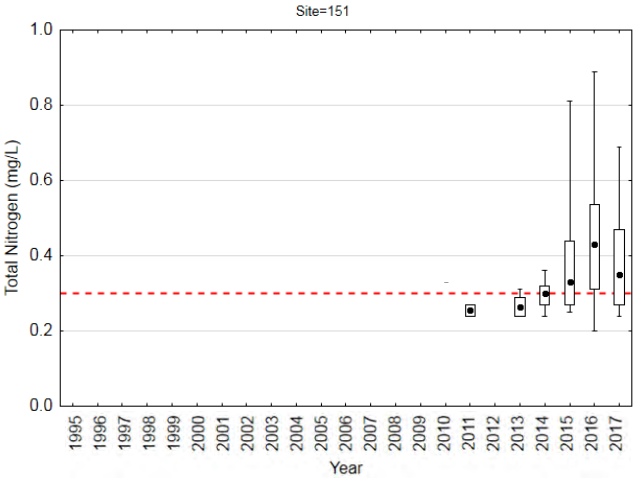
Table 2 Descriptive statistics for variables measured at Site 151 from November 2010 to September 2017

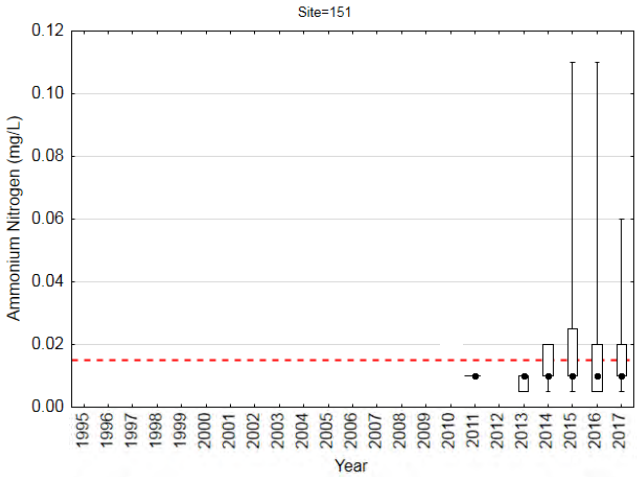
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	98	20.47	21.48	11.30	28.48	15.72	24.65	4.488
pH	96	7.73	7.76	6.90	8.50	7.58	7.94	0.269
DO (mg/L)	96	7.01	6.82	5.13	10.14	6.07	8.12	1.065
DO (%sat)	96	87.98	88.05	69.10	117.10	80.67	95.50	8.624
Salinity (ppt)	98	22.84	24.85	1.14	31.57	19.20	28.89	7.242
Turbidity (NTU)	95	12.1	10.1	3.3	45.9	7.1	16.0	7.04
TSS (mg/L)	61	11	9	3	100	6	14	12.3
Chlorophyll-a (µg/L)	61	5.1	4.7	0.2	16.8	2.3	7.2	2.95
TP (mg/L)	66	0.023	0.021	0.010	0.065	0.017	0.027	0.0097
TN (mg/L)	66	0.356	0.315	0.200	0.890	0.270	0.430	0.1350
NH_3-N (mg/L)	66	0.017	0.010	0.005	0.110	0.010	0.020	0.0204
NOx-N (mg/L)	66	0.069	0.040	0.005	0.410	0.010	0.120	0.0767
SRP (mg/L)	38	0.006	0.005	0.001	0.014	0.003	0.009	0.0032
F.Cols (CFU/100ml)	61	7	1	1	180	1	4	23.9
E.Coli (CFU/100ml)	17	14	1	1	180	1	10	43.2
Entero (CFU/100ml)	61	5	2	1	59	1	6	8.8

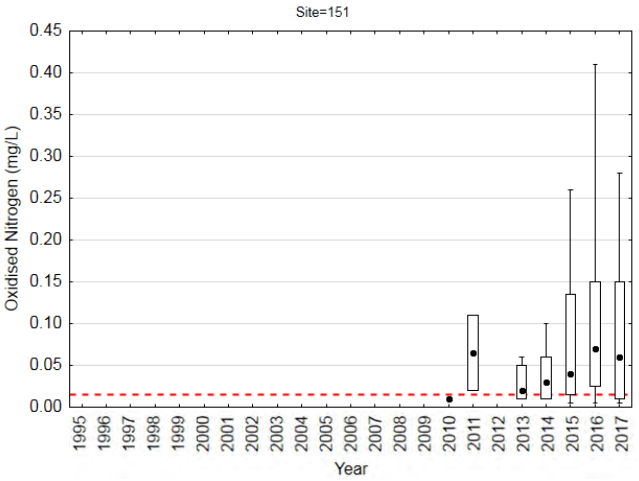
Boxplots showing annual variability for each variable measured

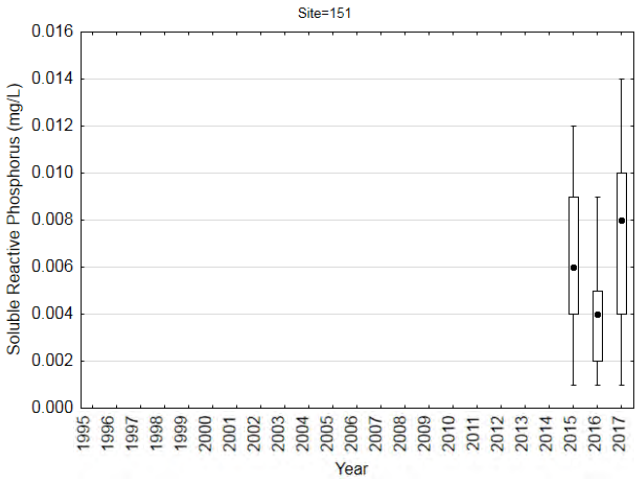


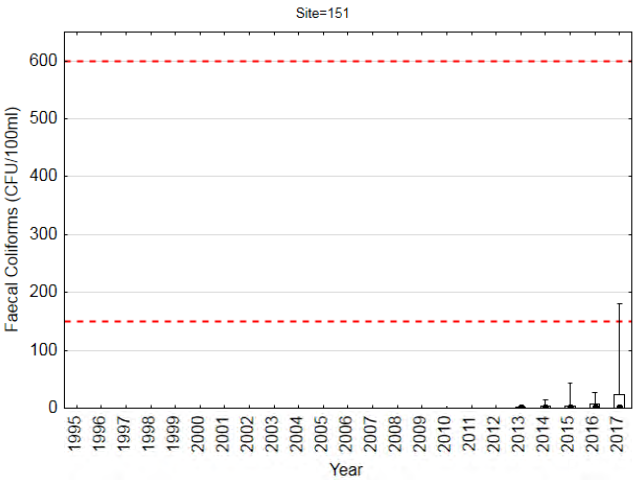

Site=151
Total Phosphorus(mg/L)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

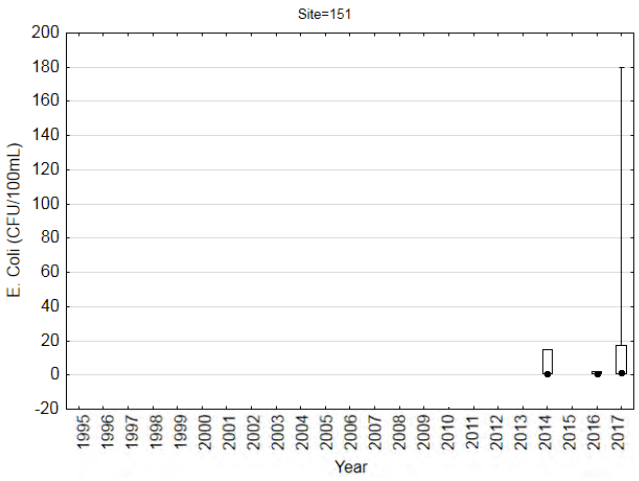

Site=151
Total Nitrogen (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

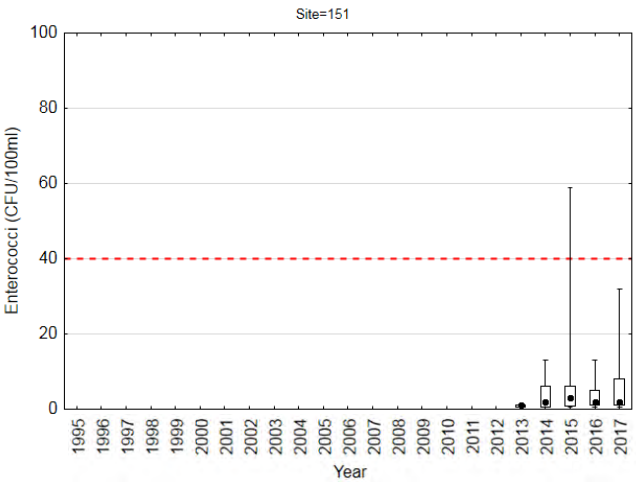

Site=151
Ammonium Nitrogen (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=151
Oxidised Nitrogen (mg/L)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=151
Soluble Reactive Phosphorus (mg/L)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=151
Faecal Coliforms (CFU/100ml)
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=151
E. Coli (CFU/100mL)
200
180
160
140
120
100
80
60
40
20
0
-20
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=151
Enterococci (CFU/100ml)
100
80
60
40
20
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

Site 152 – Courangra Point, Hawkesbury River

Estuarine site, Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Remote (HAWK2)	Aug 2008 ongoing	Temperature (°C), salinity (ppt), turbidity (NTU) and chlorophyll-a (µg/L) recorded continuously at 15-minute intervals (data not analysed in this report)
Long-term (152)	Nov 2010 – Sept 2017	Monthly from July to September, every 3 weeks for the remainder of the year
Ecohealth (HAWK2)	Oct 2017 ongoing	Quarterly
Algae (HAWK2)	Oct 2017 ongoing	~ Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO consistently comply with REHVs Clarity: Turbidity is generally low but variable exceeding the REHV approximately 50% of the time. TSS is slightly elevated and exceeds the REHV approximately 75% of the time. Biological: Chl-a is low and generally complies with the REHV. Nutrients: TN and NOx-N are elevated and consistently exceed REHVs. An increasing trend is evident for all nutrients. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment – Significant area for commercial fishing operations – Possible influence from local riverside settlements and holiday parks
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Ongoing collaboration with stakeholders for a coordinated approach to the management of risks to local commercial fishing operations – Education and collaboration with riverside residents and holiday park operators to minimise impacts from these settlements – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data

Site Photos

Courangra Point probe looking downstream

Courangra Point probe looking upstream

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 152

152	REHV	Long-term 2010-2017			
		n	Median	%NCs	Trend
Temp (°C)	NA	89	20.68	NA	NS
pH	7-8.5	87	7.60	5	NS
DO (%sat)	80-110	87	86.10	23	NS
Salinity (ppt)	NA	89	19.86	NA	NS
Turbidity (NTU)	10	87	9.6	46	NS
TSS (mg/L)	6	58	9	74	NS
Chl-a (ug/L)	4	58	3.1	34	NS
TP (mg/L)	0.03	63	0.022	19	↑
TN (mg/L)	0.3	63	0.380	83	↑
NH_3-N (mg/L)	0.015	63	0.010	44	↑
NOx-N (mg/L)	0.015	63	0.110	94	↑
F.Cols (CFU/100ml)	150	58	4	0	NS
		n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	58	28	0	NS

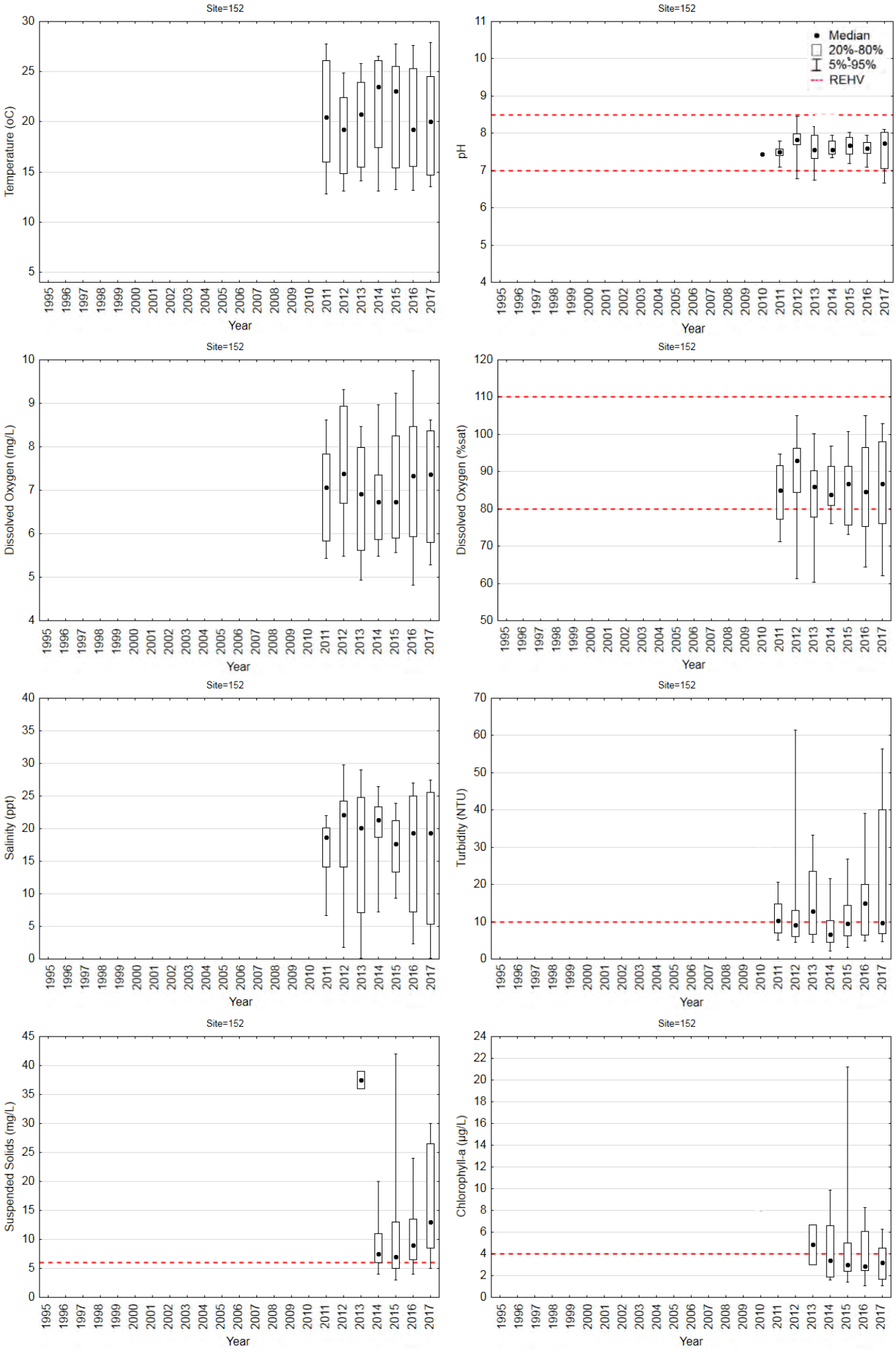
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

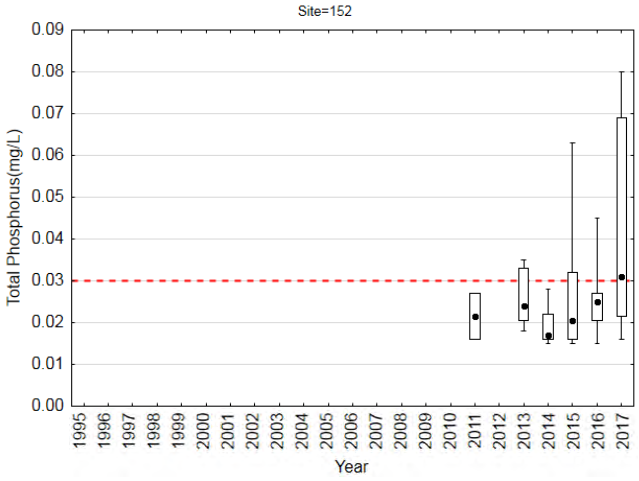
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

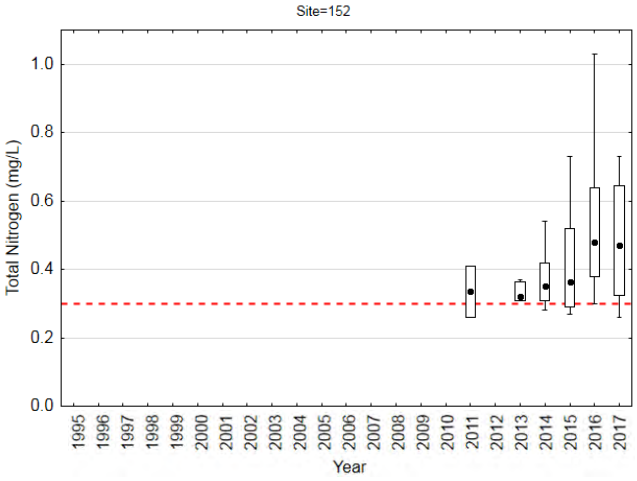
Table 2 Descriptive statistics for variables measured at Site 152 from December 2010 to September 2017

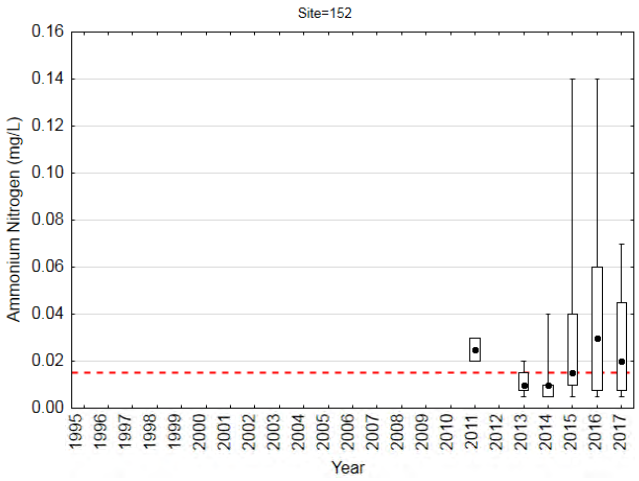
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	89	20.39	20.68	12.82	27.94	15.46	25.26	4.588
pH	87	7.61	7.60	6.66	8.45	7.44	7.85	0.319
DO (mg/L)	87	7.03	6.94	4.81	9.75	5.86	8.19	1.208
DO (%sat)	87	85.59	86.10	60.40	105.10	77.80	93.70	9.640
Salinity (ppt)	89	18.04	19.86	0.07	29.75	11.09	23.40	7.032
Turbidity (NTU)	87	13.4	9.6	2.2	61.5	6.1	18.1	11.04
TSS (mg/L)	58	12	9	1	42	5	14	8.8
Chlorophyll-a (µg/L)	58	4.1	3.1	1.1	21.2	2.2	5.9	3.11
TP (mg/L)	63	0.026	0.022	0.015	0.080	0.016	0.029	0.0138
TN (mg/L)	63	0.428	0.380	0.260	1.030	0.310	0.530	0.1521
NH_3-N (mg/L)	63	0.023	0.010	0.005	0.140	0.005	0.030	0.0280
NOx-N (mg/L)	63	0.129	0.110	0.005	0.550	0.050	0.210	0.1001
SRP (mg/L)	36	0.008	0.007	0.001	0.014	0.006	0.010	0.0033
F.Cols (CFU/100ml)	58	11	4	1	150	2	12	22.8
E.Coli (CFU/100ml)	16	5	3	1	14	1	9	4.4
Entero (CFU/100ml)	58	7	4	1	38	1	11	8.4

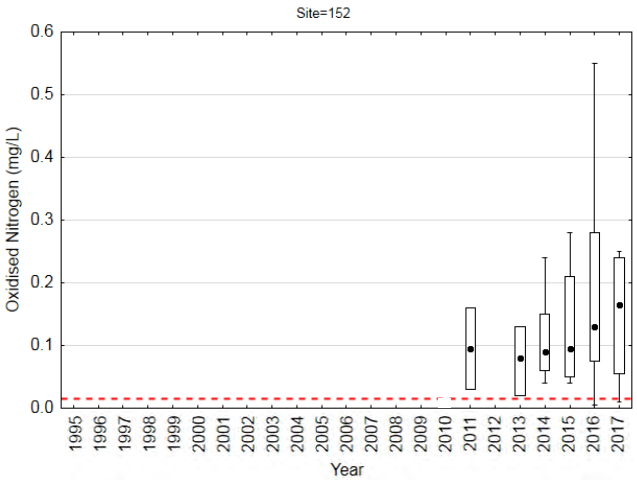
Boxplots showing annual variability for each variable measured

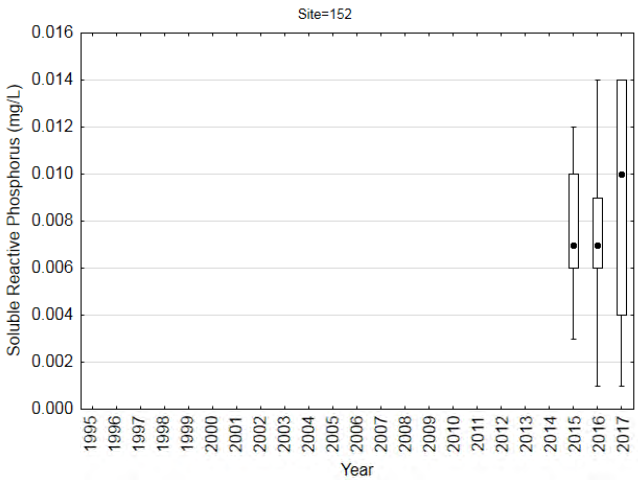


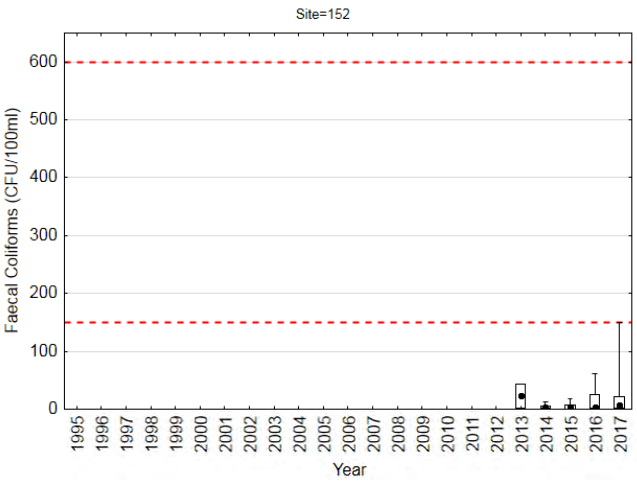

Site=152
Total Phosphorus(mg/L)
Year

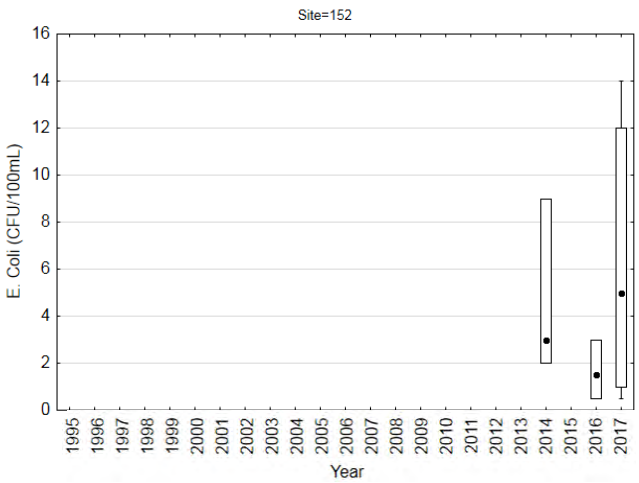

Site=152
Total Nitrogen (mg/L)
Year

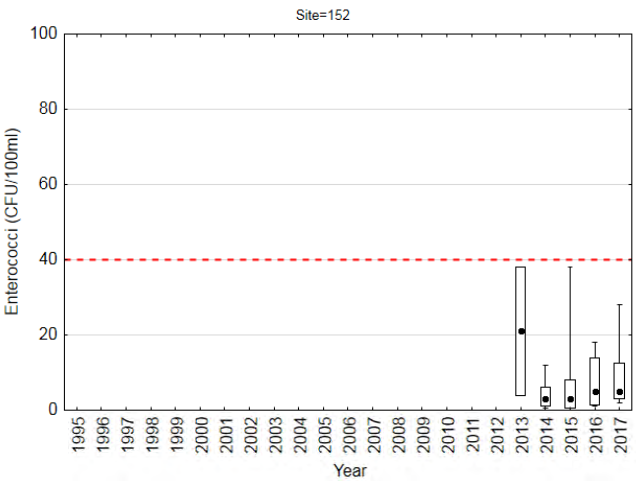

Site=152
Ammonium Nitrogen (mg/L)
Year


Site=152
Oxidised Nitrogen (mg/L)
Year


Site=152
Soluble Reactive Phosphorus (mg/L)
Year


Site=152
Faecal Coliforms (CFU/100ml)
Year


Site=152
E. Coli (CFU/100mL)
Year


Site=152
Enterococci (CFU/100ml)
Year

Site 153 – Laughtondale, Hawkesbury River

Estuarine site, Hawkesbury River Catchment

Monitoring Program Timelines

Program Name (site reference)	Sampling Period	Sampling Frequency
Remote (HAWK3)	Aug 2008 ongoing	Temperature (°C), salinity (ppt), turbidity (NTU) and chlorophyll-a (µg/L) recorded continuously at 15-minute intervals (data not analysed in this report)
Long-term (153)	Dec 2010 – Sept 2017	Monthly from July to September, every 3 weeks for the remainder of the year
Ecohealth (HAWK3)	Oct 2017 ongoing	Quarterly
Algae (HAWK3)	Oct 2017 ongoing	~ Monthly

Key Findings and Recommendations

Condition	Phys-chem: pH and DO generally comply with REHVs. Clarity: Turbidity and TSS are elevated and exceed REHVs most of the time. Biological: Chl-a levels are elevated and exceed the REHV approximately 80% of the time. Nutrients: TN and NOx-N are elevated, consistently exceed REHVs with an increasing trend evident. TP is low but variable exceeding the REHV approximately 50% of the time. An increasing trend in TP is evident. Bacteria: Bacteria levels are low and consistently comply with REHVs.
Issues	– Pressure from increasing urbanisation in the wider Hawkesbury-Nepean Catchment – Significant area for commercial fishing operations – Possible influence from local riverside settlements and holiday parks
Recommendations	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Ongoing collaboration with stakeholders for a coordinated approach to the management of risks to local commercial fishing operations – Education and collaboration with riverside residents and holiday park operators to minimise impacts from these settlements – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data

Site Photos

Laughtondale probe looking upstream

Laughtondale probe looking downstream

Results of Data Analysis

Table 1 Results of non-conformance calculations and *Kendall Tau* (p<0.05) trend analysis for Site 153

153	REHV	Long-term			
		n	Median	%NCs	Trend
Temp (°C)	NA	92	21.24	NA	NS
pH	7-8.5	90	7.43	13	NS
DO (%sat)	80-110	90	91.40	24	NS
Salinity (ppt)	NA	91	5.46	NA	NS
Turbidity (NTU)	10	90	16.5	79	NS
TSS (mg/L)	6	57	14	93	NS
Chl-a (ug/L)	4	57	11.1	82	↓
TP (mg/L)	0.03	62	0.029	48	↑
TN (mg/L)	0.3	62	0.490	95	↑
NH_3-N (mg/L)	0.015	62	0.010	24	NS
NOx-N (mg/L)	0.015	62	0.150	84	↑
F.Cols (CFU/100ml)	150	57	6	4	NS
		n	95th%ile	%NCs	Trend
Entero (CFU/100ml)	40	57	35	2	NS

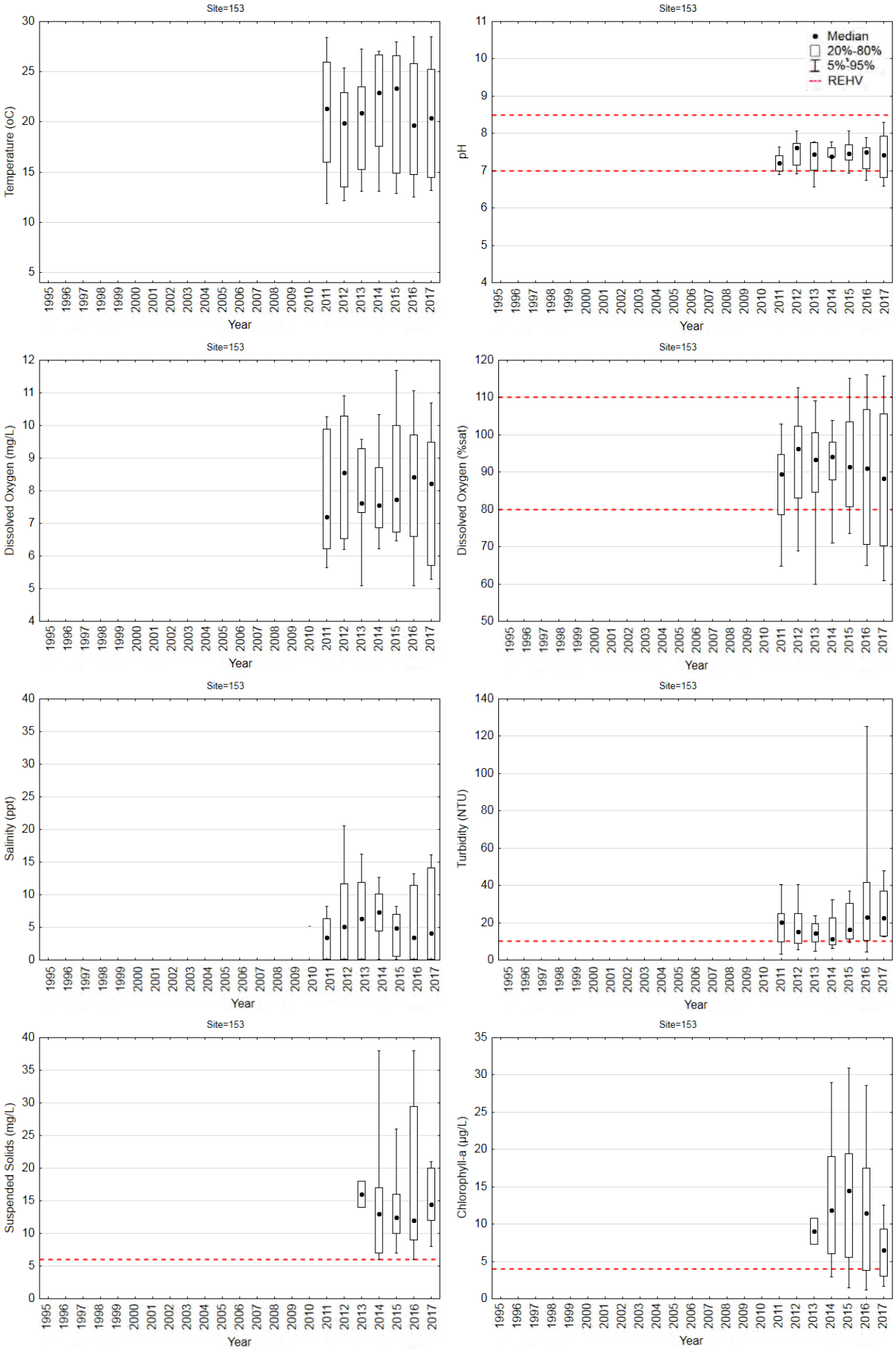
REHV – Regional Environmental Health Value
n - Number of sampling events
%NCs - percent non-conformance based on REHVs
NA - No associated REHV or benchmark value
NS - trend not significant based on Kendall Tau analysis at p<0.05
↑ - significant increasing trend based on Kendall Tau at p<0.05
↓ - significant decreasing trend based on Kendall Tau at p<0.05

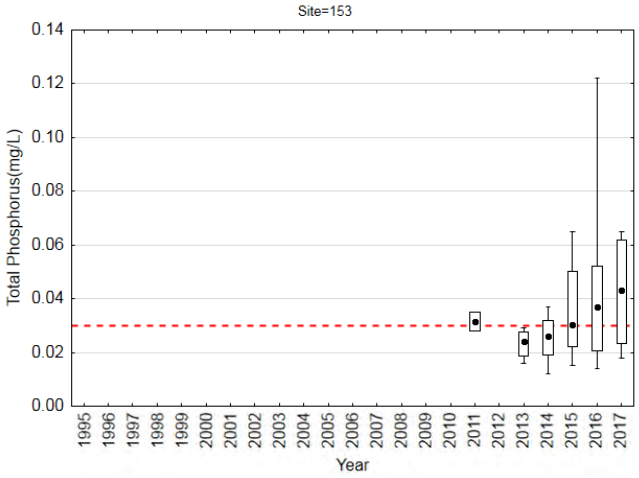
Median	*%NCs*
Within or below REHV	*<25%*
Equal to REHV	*25% to 75%*
Outside or above REHV	*>75%*
No associated REHV	*Not Applicable*

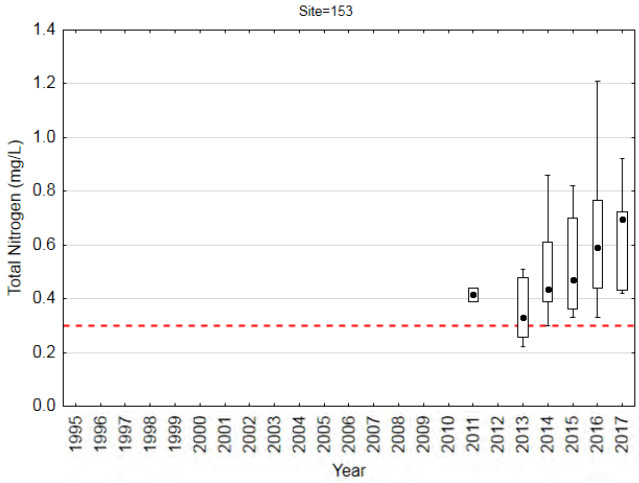
Table 2 Descriptive statistics for variables measured at Site 153 from December 2010 to September 2017

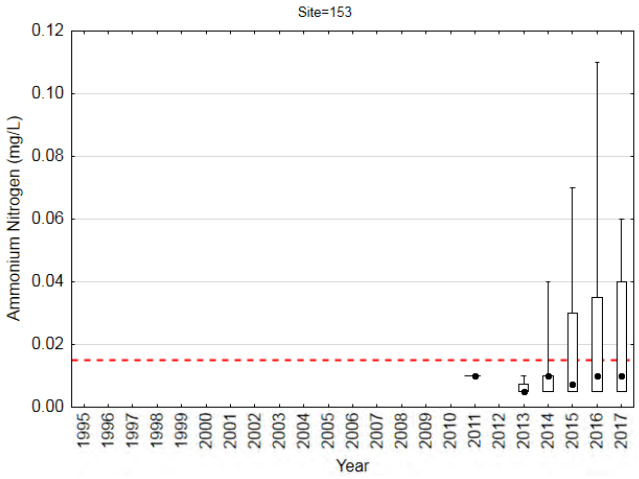
Variable	Valid n	Mean	Median	Minimum	Maximum	20th Percentile	80th Percentile	Std Dev
Temp (°C)	92	20.56	21.24	11.91	28.52	15.12	25.69	5.015
pH	90	7.40	7.43	6.56	8.29	7.09	7.66	0.351
DO (mg/L)	90	7.98	7.71	5.09	11.68	6.68	9.40	1.565
DO (%sat)	90	90.25	91.40	60.00	116.20	81.20	99.75	12.709
Salinity (ppt)	91	5.63	5.46	0.05	20.59	0.30	9.65	4.791
Turbidity (NTU)	90	19.9	16.5	3.3	125.1	9.7	27.2	15.16
TSS (mg/L)	57	15	14	6	38	9	20	7.7
Chlorophyll-a (µg/L)	57	11.5	11.1	1.2	30.9	4.9	17.0	7.37
TP (mg/L)	62	0.034	0.029	0.012	0.122	0.021	0.045	0.0181
TN (mg/L)	62	0.540	0.490	0.220	1.210	0.380	0.720	0.1962
NH_3-N (mg/L)	62	0.017	0.010	0.005	0.110	0.005	0.020	0.0207
NOx-N (mg/L)	62	0.187	0.150	0.005	0.660	0.030	0.340	0.1658
SRP (mg/L)	36	0.006	0.004	0.001	0.033	0.001	0.009	0.0067
F.Cols (CFU/100ml)	57	16	6	1	270	3	15	40.6
E.Coli (CFU/100ml)	16	10	7	1	23	4	20	8.1
Entero (CFU/100ml)	57	9	6	1	50	2	13	9.8

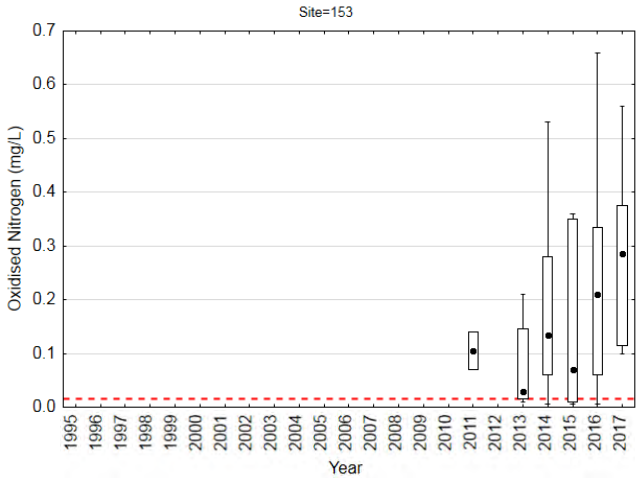
Boxplots showing annual variability for each variable measured

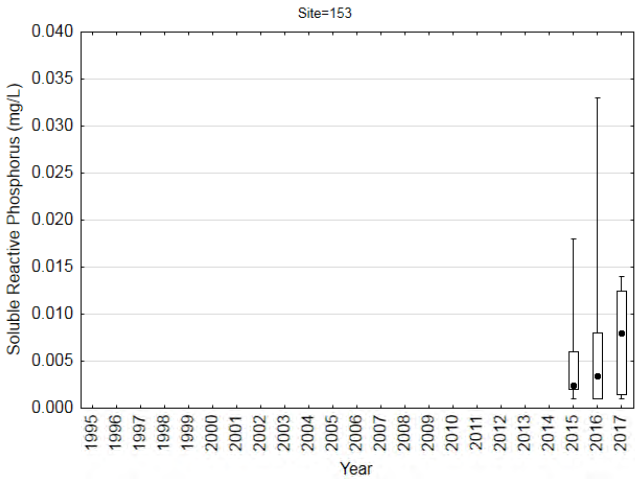


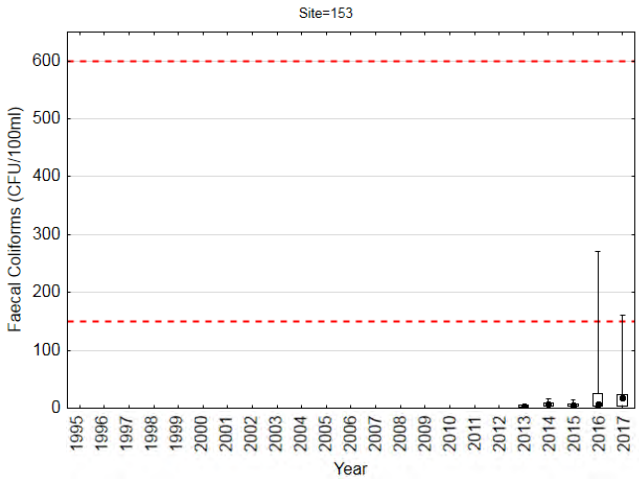

Site=153
Total Phosphorus(mg/L)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

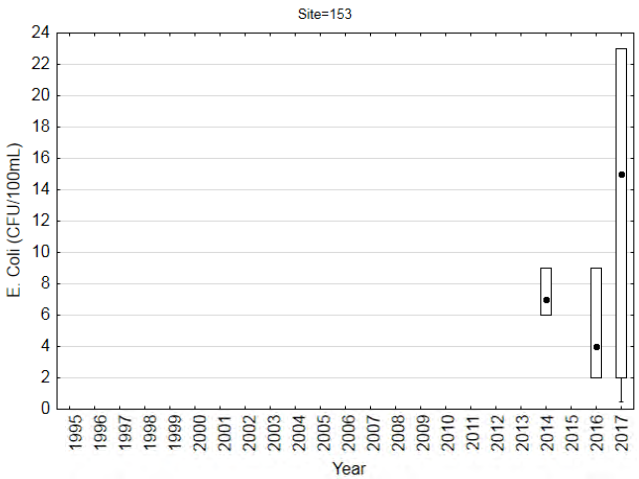

Site=153
Total Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

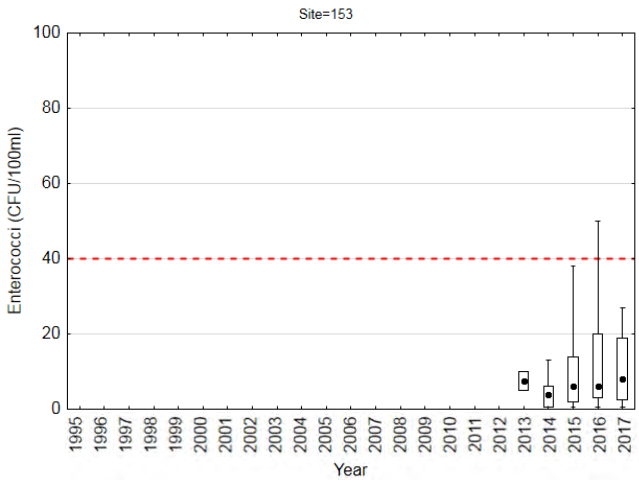

Site=153
Ammonium Nitrogen (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=153
Oxidised Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=153
Soluble Reactive Phosphorus (mg/L)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=153
Faecal Coliforms (CFU/100ml)
600
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=153
E. Coli (CFU/100mL)
24
22
20
18
16
14
12
10
8
6
4
2
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year


Site=153
Enterococci (CFU/100ml)
100
80
60
40
20
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year

RESULTS AND DISCUSSION

Climate Drivers

When interpreting local environmental monitoring data it is important to consider the climate that is driving temporal variations and ultimately influencing local trends and conditions. Weather in Australia, particularly rainfall, is affected over different regions and seasons by the following major climate drivers:

- El Niño-Southern Oscillation (ENSO)
    - El Niño and La Niña are phases of the ENSO
- the Indian Ocean Dipole (IOD)
- the Australian Monsoon and the Madden-Julian Oscillation
- the Southern Annular Mode.

In south-eastern Australia ENSO is particularly influential and is the dominant driver of rainfall extremes, both positive and negative (NCCARF, 2018). Under normal conditions, trade winds over the Pacific Ocean typically blow from east to west; if these winds are strengthened La Niña conditions occur bringing above average rainfall to much of Australia. If these winds weaken, or even reverse, El Niño conditions occur bringing drier conditions and warmer temperatures to much of eastern Australia, and if prolonged, can lead to drought (NCCARF, 2018).

The Millennium Drought that was experienced by Australia from late 1996 to 2010 was driven by El Niño conditions and the IOD. This was followed by widespread heavy rainfall in eastern Australia associated with La Niña conditions from 2010 to 2013 (NSW BOM, 2015). These drivers are happening with climate change in the background and with seasonal changes and individual systems in the foreground.

As Australia's climate continues to change, future projections show we are likely to see:

- more hot days and fewer cold days
- a warmer and more acidic ocean
- higher sea levels
- changes in rainfall pattern
- more intense extreme rainfall events, and
- fewer but more sever tropical cyclones (CSIRO & NSW BOM, 2015).

These changes will influence local conditions and subsequent waterway health in Hornsby Shire.

Influence of rainfall

Rainfall events can have a major impact on water quality, particularly in Australia which is well known for the extreme variability and unreliability of its rainfall, and subsequent stream flows. Native biota and the physical structure of our natural waterways have adapted to these periods of drought and flood; it is this natural variability (periodic flushing and recovery) that maintains the biodiversity of aquatic ecosystems (Lawrence & Breen in Wong, 2006).

Alterations to these stream flows have occurred through urbanisation where large areas of impervious surfaces are connected directly to pipe and channel drainage systems. Whilst periodic elevated stream flows (rainfall run-off) are essential for aquatic biodiversity, the increased frequency and intensity of flushing events associated with urban systems limits the ability of creeks to recover, ultimately resulting in deteriorated waterway health. In addition to altered stream flows (run-off quantity), urbanisation has had a significant effect on run-off quality with impervious surfaces facilitating the process of contaminant build-up

and wash-off (Duncan in Wong, 2006). This process is further discussed in the following section on Urbanisation.

Council's long-term monitoring program has primarily involved systematic sampling to a set monthly schedule which, over time, has included all seasons and representative wet and dry periods. Analysis of wet versus dry weather data is outside the scope of this Review, instead all data has been analysed to incorporate the full range of results. Pulse pollution incidents such as those caused by rainfall in urban areas are reflected by high data variability at a specific site.

Water Quality

Water quality is one of the prime indicators of waterway and overall environmental health. According to the national State of the Environment Report (2016), pressures on the Australian coast are largely related to land-use and climate change with the southern and eastern coasts most affected by urbanisation and agriculture (Clark 2016). This holds true for Hornsby Shire, with the most significant impacts on water quality evident in waterways associated with urban, industrial or rural land-use. The following discussion of results will examine these findings further.

Local reference conditions

One approach to measuring the impact of human activities on waterway health is to compare water quality data against a 'reference' condition. Data from reference sites demonstrate the natural variation of water quality in creeks with minimal human impact, thus providing a benchmark against which other sites can be compared. Due to the significant amount of land protected by National Parks in the Hornsby LGA, Council was able to establish two long-term reference sites which have primarily undisturbed bushland catchments; Murray Anderson Creek (036) and Smugglers Creek (037).

Ideally, reference sites should have similar geography, geology, soils and vegetation to the creeks to which they are being compared, however Murray Anderson Creek (036) and Smugglers Creek (037) reference sites are in the lower reaches of Hawkesbury sandstone dominated catchments. Development within Hornsby Shire historically began in areas with good quality soils suitable for farming and on ridge tops with shale derived soils. Subsequent urban development concentrated around these ridge-top areas and, as a result, there is a scarcity of unimpacted creeks draining these types of soils and geology. Despite this, Site 036 and Site 037 provide a good representation of local reference conditions.

These reference sites are characterised by low pH, low nutrient inputs, good clarity, low bacteria levels and minimal data variability. Trend analysis showed a significant long-term decrease in TSS and a long-term increase in TP at both sites, however the relationships are weak (i.e. low *tau* values) and results should be used accordingly. Nonetheless, these trends could continue and should be monitored into the future. The condition and trends evident in Murray Anderson (036) and Smugglers Creeks (037) exhibit the background temporal variation that might be expected at all sites, irrespective of additional anthropogenic pressures.

Urbanisation

Since commencement of the long-term monitoring program urbanisation has intensified throughout the entire Sydney Basin, including Hornsby Shire. Due to increased population, dwelling densities have increased resulting in the need for additional water services, including potable water supply, wastewater disposal and stormwater drainage. Subsequently there are significant changes to the natural water cycle in urban areas and substantial pressures on urban waterways. Natural watercourses have routinely been replaced with concrete pipes, drains and gutters, while development and supporting infrastructure has resulted in an increase in impervious surfaces. Consequently, elevated and unnatural levels of minerals accumulate and

are transported by stormwater into urban creeks, slowly altering the chemistry of the waterways (Wright 2012).

Monitoring sites associated with urban land-use in Hornsby Shire show symptoms of 'urban stream syndrome', including altered flow regimes and an increase in the volume of stormwater runoff (Vietz et al 2015). These waterways are typically characterised by elevated pH, EC, nutrient concentrations and bacteria, and supressed DO.

Urban sites in the upper Berowra Creek Catchment, Devlins Creek (008), Calna Creek (052) and Joe Crafts Creek (039) all have elevated but relatively stable pH levels. Trend analysis for the period 2012-2107 show significant increases in pH, however this fluctuation is not outside the historic data range (i.e. background temporal variation). Nevertheless, this increasing trend should be examined into the future as changing pH levels are expected to influence aquatic food webs, particularly microscopic algae, increase stress on sensitive fauna species, and ultimately reduce biodiversity (Wright 2012).

Long-term decreases in DO are evident at all urban sites. This could be problematic at Pyes Creek (005), Devlins Creek (008) and Calna Creek (052) where already low DO levels drop below the REHVs more regularly. Waitara Creek (023) exhibited particularly supressed DO levels between 2001 and 2007 which coincided with severe dry weather associated with the millennium drought. Increased pressure on water quality due to low flow conditions in combination with high organic load (evident in the persistently elevated bacteria counts) drives biochemical oxygen demand (BOD), subsequently decreasing the levels of available DO (Wong 2006).

Despite a long-term decreasing trend, albeit weak, in EC in urban sites in the upper Berowra Creek Catchment (Pyes Creek 005, Georges Creek 006, Joe Crafts Creek 039), Pyes Creek (005) and Georges Creek (006) levels are elevated and typically exceed the REHVs. EC in Devlins Creeks is also elevated, with a significant increase evident after 2014.

Long-term decreases in TSS indicate an improvement in clarity across all urban sites. This may be a result of improved sediment and erosion control measures throughout the catchments. Pyes Creek (005) and Georges Creek (006) showed significant reductions in both turbidity and TSS from 2004 onwards, however this has not been attributed to any specific action.

Despite some long-term reductions, nutrient concentrations remain elevated at all urban sites, with the exception of Joe Crafts Creek (039). Joe Crafts Creek (039) is located at the bottom of a heavily vegetated catchment with a relatively small urban area at the top of the catchment. It is likely that the bushland catchment in association with an intact riparian zone buffer the creek from influences of the urban catchment. In addition, the distance between the sample site and the upstream development allows for natural instream processes to absorb and assimilate pollutants. Berowra Creek (004), Georges Creek (006) and Joe Crafts Creek (039) had long-term reductions in NH_3-N concentrations. Long-term reductions in TN and NOx-N were also evident in the upper Berowra Creek Catchment (Berowra Creek 004, Pyes Creek 005, Georges Creek 006), however the relationship strengths (*tau* values) were weak.

Long-term median bacteria levels are elevated, though results are highly variable, at all urban sites, with the exception of Joe Crafts Creek (039). This data variability suggests that most sources of bacterial pollution are unlikely to be constant pressures, rather pulse pollution incidents such as spills, discharges or leaks. It is also likely that the pulses of pollution are associated with rainfall events and aging wastewater infrastructure in many locations.

Wastewater facilities

Wastewater infrastructure servicing the extensive development in Hornsby Shire includes a comprehensive sewer network, albeit aging in some parts, maintained by Sydney Water. There are two large WWTPs, one

at West Hornsby discharging to Waitara Creek and another at Hornsby Heights discharging to Calna Creek; both are tributaries of Berowra Creek. These plants provide tertiary treatment to sewage, which includes nitrogen and phosphorus removal and disinfection. Major upgrade works to both WWTPs began in 2001 and were completed in 2003. A smaller plant, located in Brooklyn began operating in December 2007. It discharges into the main arm of the Hawkesbury River under the old Peats Ferry Bridge.

Freshwater sites directly downstream of the West Hornsby and Hornsby Heights WWTPs (Berowra Creek 001 and 045, Calna Creek 043) are characterised by elevated pH, EC and nutrient concentrations, despite significant long-term reductions in N-based nutrient concentrations following treatment plant upgrades. DO levels also reduced and stabilised following the upgrades.

At the West Hornsby WWTP, effluent discharges have been relatively consistent since 2007, although volumes have increased from approximately 5000 ML/pa pre-2014 to approximately 6000 ML/pa post-2014. The concentrations and load of TN discharged since 2014 have also increased, (Sydney Water 2017). This coincides with some spikes in TN between 2014 and 2016 at downstream sites in Berowra Creek, namely Fishponds (045) and Galston Gorge (001).

At the Hornsby Heights WWTP, effluent discharges have also been largely consistent since 2007 with discharges of approximately 2000-2500 ML/pa, apart from a spike in discharge to approximately 3000ML/pa in 2011/12. The loads of N-based nutrients discharged have remained mostly consistent since 2007, although TP loads increased between 2011 and 2014 (Sydney Water 2017). At the downstream site of Calna Creek (043) our findings coincided with those of Sydney Water. A significant increase in TP concentration was evident post-WWTP upgrades, with particularly elevated concentrations between 2011 and 2014. Furthermore, there is an absence of any obvious patterns of increase in TP at the Calna Creek site (052) immediately upstream of the WWTP, suggesting the WWTP is a significant source of TP in the area.

Whilst the concentrations of TN and NOx-N at sites downstream of the WWTPs have been significantly reduced since the upgrades the current concentrations are still high and continued improvements in reducing nutrients have not been achieved as concentrations have stabilised. In addition, data variability indicates that pulse nutrient and bacteria events regularly occur at these sites, most likely coinciding with rainfall events that place significant pressure on sewage infrastructure. Collaborative investigations are continuing between Hornsby Shire Council and Sydney Water in identifying and rectifying wastewater leaks. However, much of the infrastructure occurs in bushland areas, on private land or under more recently developed infrastructure, making the identification and diagnosis of leaking wastewater infrastructure in many areas a difficult process that requires considerable resources.

Legacy pollutants

Other stressors, such as sewer overflows, wastewater treatment plant discharges and legacy pollutants (long-lived pollutants from earlier land-uses) can obscure the effects of stormwater runoff in urban areas (Walsh et al 2005). Gleeson Creek (Site 077) is an urban creek, however it is located directly downstream of the disused landfill site at Foxglove Oval. Water quality results at this site suggest that Gleeson Creek may be influenced by the incursion of leachate. Leachate results from the percolation of water through putrescible waste in landfill. It often has a high BOD, high concentrations of NH_3-N and heavy metals. NH_3-N is a strong indicator of leachate as it is produced during the decomposition of organic matter in an oxygen-poor environment (DEC 2004).

Gleeson Creek (077) is characterised by elevated pH, extremely elevated EC and nutrient concentrations, and severely suppressed DO (median concentrations approximately 50%). Gleeson Creek has the highest EC overall, with a long-term median value of 0.90mS/cm. Long-term decreases in N-based nutrients are evident, although concentrations remain extremely elevated. Bacterial levels in Gleeson Creek (077) are

also elevated but variable which suggests it may also be influenced by pulse events, such as spills, discharges or leaks in the catchment.

In, summary, some long-term improvements in water quality are evident at Gleeson Creek (077), however the site continues to have poor water quality. A leachate treatment plant has been operating at Foxglove Oval since 2010 to reduce nutrient levels and further investigations are under way to determine if all untreated leachate is contained on-site.

Industrial activities

Industrial land-use continues to place significant pressure on water quality in the Hornsby LGA. Monitoring sites adjacent to industrial areas at Thornleigh (Larool Creek 010), Hornsby (Hornsby Creek 012) and Mt Kuring-Gai (Sams Creek 013) are amongst the most impacted sites with consistently elevated pH, nutrient concentrations and bacteria levels.

The pH at industrial sites is highly elevated but relatively stable in relation to background temporal variation. The overall highest long-term median pH value of 7.74 was found in Hornsby Creek (010). These elevated pH levels may reflect the widespread use of alkaline products (e.g. concrete and surfactants) within industrial areas. Trend analysis does show a long-term decrease at Hornsby Creek (010) and Sams Creek (013), however the relationships are very weak (i.e. low *tau* values).

Nutrient levels are significantly elevated at sites adjacent to industrial areas and, despite long-term decreases in TP (Larool Ck 010 and Sams Creek 013) and TN (Sams Creek 013), nutrient sources remain a concern; of note is the significant increase in N-based nutrients in Larool Creek (010) between 2012 and 2017. Elevated nutrient levels in industrial catchments may be due to discharge of human waste, industrial and household chemicals, industrial processes and stormwater inputs (Wong 2006)

Median f.col counts are significantly elevated at all the industrial sites, however the data is highly variable. This variability is most likely attributed to rainfall events causing pulses of pollution associated with aging wastewater infrastructure in these areas.

Problematic clarity in Larool Creek (010) has improved with long-term medians reducing from 21.4 NTU to 8.3 NTU for turbidity, and 12 mg/L to 4 mg/L for TSS. A weaker long-term decreasing trend in clarity is also evident in Sams Creek (013). Turbidity levels in Hornsby Creek (012) increased in the period 2012 to 2017, however an associated increase in TSS was not evident. TSS at industrial sites would consist of both organic and inorganic loads. Organic material contributes to BOD, decreasing the levels of available DO, while inorganic contaminants are bound to suspended solids and transported to receiving waters (Wong 2006).

The long-term data shows DO levels to be supressed between 1999 and 2008 at both Larool Creek (010) and Sams Creek (013), which coincided with severe dry weather associated with the millennium drought. Increased pressure on water quality due to low flow conditions, in combination with a high organic load, drives BOD, subsequently decreasing available DO (Wong 2006). A long-term improvement in DO levels in Hornsby Creek (012) is evident, particularly after 2008 when data variability reduced considerably.

Rural land-use

Waterways associated with rural catchments in Hornsby Shire are generally characterised by elevated EC, bacteria and nutrient concentrations. Elevated concentrations of nutrients and bacteria are likely due to the use of on-site wastewater management systems (OWMS) in areas not connected to the sewer. Fertilisers, use of detergents, incorrect disposal of grey water and illegal septic tank discharges could also contribute to the high nutrient concentrations. Tunks Creek (002) and lower Colah Creek (063) both maintain relatively good water quality due to their distance from rural settlements, which allows natural instream processes to absorb and assimilate pollutants. The bushland catchment and intact riparian zone associated with these

sites also provides a buffer from the pressures of rural activities. Nevertheless, lower Colah Creek (063) still shows some rural influence including elevated pH, EC and nutrient concentrations.

Long-term data from the headwaters of Kimmerikong Creek (062) in Cowan show significant improvement in water quality with decreased EC, nutrient concentrations and TSS since the completion of the Cowan Wastewater Scheme in 2014. Although the catchment for this site contains mostly urban development, it has been considered a rural site in the scope of the monitoring program due to the previous use of OWMS. pH and TP remain elevated and pulses of bacteria pollution is evident (variable faecal coliform data).

Waterways associated with the Galston and Glenorie settlements (Colah Creek 042, tributary of Colah Creek 064, Glenorie Creek 080) have long-term improvements in EC and nutrient concentrations. Colah Creek (042) also has improved clarity and DO levels. Significant water quality improvements are expected at these rural sites following the expansion of the Sydney Water sewer network to Galston and Glenorie Villages in 2015. Some initial improvements are apparent in the 2016 and 2017 graphed data (see boxplots in individual site summaries).

A long-term increase in DO is also evident at Colah Creek (042), which exhibited particularly supressed DO levels between 2001 and 2007 coinciding with severe dry weather associated with the millennium drought. Increased pressure on water quality due to low-flow conditions, in combination with a high organic load, drives BOD, subsequently decreasing available DO (Wong 2006).

Upper Still Creek (049) is influenced by low density rural properties, as opposed to the more densely populated rural villages of Galston and Glenorie. This site is characterised by elevated pH, EC and nutrient concentrations indicating that rural land-use is still detrimental to water quality, but not to the extent of urban or industrial land-use. Long-term improvements in pH, EC, TSS and N-based nutrients are evident although the relationships are relatively weak (i.e. low *tau* value). Nevertheless, these potential improvements should be examined into the future.

Estuaries

Except for creeks in the Lane Cove Catchment, all of Hornsby Shire's waterways eventually flow into the lower Hawkesbury River estuary. Water quality in the estuary and its tributaries varies spatially, with relatively good water quality towards the mouth of the estuary to more impacted sites in the upstream reaches (e.g. TN in Figure D7). This is due in part to the effectiveness of tidal flushing at the mouth of the estuary and the geomorphology of the river, but also to more intense pressures from catchment inputs in the upper reaches.

The estuarine sites at the extent of the tidal limits in Berowra Creek (Crosslands Reserve 100) and Marramarra Creek (048) regularly have suppressed DO concentrations (between 70% and 80%). A long-term decreasing trend in DO is evident at Dangar Island, however results primarily remain within REHVs. Long-term increasing trends in pH were exhibited by most estuarine sites, however this is likely to be a reflection of the limited (shorter) data sets available for these sites, with the increase being consistent with the background temporal variation. Nevertheless, this trend should be monitored into the future.

Several sites in Berowra Creek (060, 061), Marramarra Creek (048) and the Hawkesbury River (038) exhibited a long-term decreasing trend in salinity. These sites are primarily in the upper tidal limits and this trend may be indicative of a reduction in tidal incursion. This could be a combination of estuarine infilling and tidal suppression by freshwater inflows from upstream. Sedimentation, or estuarine infilling, is a natural process in drowned river-valley estuaries, however anthropogenic pressures, such as catchment development, can accelerate this process. Berowra Creek sites (060, 061) have additional freshwater inflows from WWTP discharges as well as a significantly modified catchment. Sandbrook Inlet (038) has been modified with the railway causeway blocking the eastern opening of the inlet, this may have reduced flushing and increased sedimentation, ultimately reducing tidal incursion at this site. Although the

relationships are only moderate (i.e *tau* values ~-0.2) for sites exhibiting this trend, it should be examined into the future.

Marramarra Creek (048) and Sandbrook Inlet (038) have elevated levels of turbidity and TSS which could be due to limited tidal flushing and resuspension of sediments in shallow, muddy bottom sites. Sites in the main Hawkesbury River channel that also have elevated turbidity and TSS include Laughtondale (153), the Bar Island probe (151) and Milsons Passage (103), this is typical of areas with muddy bottom sediments and strong tidal flushing resulting in resuspension.

Elevated nutrient concentrations in estuarine sites are of most concern at Crosslands Reserve (100), Berowra Waters (060), Calabash Point (061) and Marramarra Creek (048). In upper Berowra Creek this is most likely related to WWTP discharges, however in Marramarra Creek (048) upstream rural activities are most likely driving elevated N-based nutrients. Whilst a significant long-term decrease in TN was evident in Berowra Waters (060), both TP and TN have been increasing at sites 060 and 061 in Berowra Creek since the completion of WWTP upgrades in 2003. TN and NOx-N are elevated in the upper Hawkesbury River (relative to the Hornsby LGA) (sites 151, 152, 153). In addition, Hawkesbury River sites at Laughtondale (153), Courangra Point (152), Milsons Passage (153) and Dangar Island (108) exhibit increasing trends in both TP and TN for the period 2007 to 2017. Sandbrook Inlet (038), Bar Island probe (151) and Gunyah Point (150) also show significant increases in TN between 2007 and 2017. These nutrient concentrations and temporal trends are reflective of pressures from a catchment that extends well beyond the Hornsby LGA.

Bacteria levels are low at all estuarine sites, with the exception of those in upper Berowra Creek (100, 060, 061) and Marramarra Creek (048). Median f.col levels at these sites are, however, still low, with REHV exceedances only occurring on 5 -15% of sampling occasions. 95th percentile enterococci levels are quite elevated but individual results still only exceed REHVs on 5 -15% of sampling occasions. Crosslands Reserve (100) and Marramarra Creek (048) sites are located adjacent to camping sites and National Park, whilst Berowra Waters (060) and Calabash Point (061) sites are close to riverside settlements so there is potential for the periodically elevated bacteria levels to be locally influenced. It is, however, more likely that the upstream pressures of aging sewerage infrastructure or pulse pollution events related to rainfall are driving bacteria levels in the Berowra Creek sites (Crosslands 100, Berowra Waters 060, Calabash Point 061). A significant increase in bacteria levels was evident at Gunyah Point (150), however this is due to spikes in bacteria levels in 2017, not necessarily an ongoing temporal trend.

The majority of estuarine sites are characterised by low Chl-a concentrations, compliant with the REHVs. Long-term data indicates that elevated Chl-a is of most concern at Calabash Point (061) in Berowra Creek and at Laughtondale (153) close to Wisemans Ferry, with long-term medians of 8.0 µg/L and 11.10 µg/L respectively. Other sites with only slightly elevated median levels include Berowra Waters (060) and Bar Island (151).

Harmful Algal Blooms

Nutrients in estuaries are essential for the growth of aquatic plants and phytoplankton that sustain ecosystems. However, changes in the balance of nutrients driven by anthropogenic inputs of primarily nitrogen and phosphorus may result in the growth of certain algal species to the detriment of other species (Rost et al 2003), this is often referred to as an algal bloom. Council monitors Chl-a concentrations in combination with other environmental parameters to manage the incidence of algal blooms. Chl-a concentration is considered to be a good indicator of phytoplankton biomass, however it does not distinguish between harmful and non-harmful blooms. To this purpose, algal species identification and enumeration is also carried out in the management of algal blooms. The analysis of algal data is not within the scope of this report.

Historically, algal blooms have most regularly occurred in Berowra Creek at Calabash Point (061). The unique bathymetry (deep 15m hole) and the environmental conditions at this site favour the occurrence of high algal biomass during the warmer months. Elevated concentrations of Chl-a have also regularly been detected at Laughtondale (153), although few harmful blooms have eventuated here.

Recreational use

Council has monitored water quality since 2004 at two estuarine sites specifically for the purpose of managing risks in recreational water; Brooklyn Baths on the Hawkesbury River (055) and Crossland Reserve (100) on Berowra Creek. These sites are frequently used by the community for activities such as swimming, fishing and kayaking. Brooklyn Baths (055) is located close to the mouth of the estuary, has strong tidal flushing and only exhibits impacts on water quality after significant rainfall events. Conversely, Crosslands Reserve (100) is located near the upper tidal limit of Berowra Creek and is highly impacted by catchment pressures and most rainfall events. In addition, lower flushing rates are characteristic of this site due to the distance from the estuary mouth and the geomorphology of the creek.

During rainfall events, freshwater inputs from the upper catchment change both the chemical and bacterial characteristics of estuarine sites. Rain events are often short and intense causing large volumes of fresh water to discharge into the estuary resulting in a decrease in water temperature, salinity and pH and an increase in DO, nutrient concentrations and bacteria levels. Consequently, significant rainfall events are known to result in poor water quality, temporarily leaving waterways unsuitable for recreational activities.

Analysis of data to assess human health risks associated with recreational use of waterways is outlined in the NHMRC (2008) Guidelines for Managing Risks in Recreational Water. Methods of data analysis recommended by the Guidelines (NHMRC 2008) are outside the scope of this report, however long-term data assessment for Crosslands Reserve (100) and Brooklyn Baths (055) has been undertaken here with regards to aquatic ecosystem health.

Hornsby Council currently uses a combination of routine catchment health, remote and event monitoring to advise the swimming conditions at estuarine sites across the lower Hawkesbury River. This information is available via the Council website www.hornsby.nsw.gov.au/waterquality.

Program Progression

Whilst physical, chemical and biological water quality monitoring and analysis provides a certain measure of waterway health, it is important to continue to add to our knowledge and understating of aquatic ecosystems and how they respond to changes, both anthropogenic and naturally driven. This Review has clearly demonstrated common land-use issues, identified temporal trends in specific water quality parameters and generated further monitoring and information requirements. The following Recommendation section will provide more detailed actions and recommendations for the progression of Council's Water Quality Monitoring Program.

RECOMMENDATIONS

Recommendations of this Review are presented in two sections: *Site Specific* recommendations, which are in direct response the long-term data analysis undertaken in this Review and, *Program Direction* recommendations, which are proposed to drive Council's Water Quality Monitoring Program in the most efficient and effective manner, particularly as Hornsby Shire Council transitions towards becoming a Water Sensitive City.

Site Specific

A set of 39 recommendations have been established in response to the results of the long-term data analysis undertaken in this Review. These site-specific recommendations broadly fall into four categories:

- Monitoring (program details in Appendix E)
- Research and investigation
- Education and collaboration
- Planning and compliance

Recommendations are listed in Table 5 with no specific order, as recommendations may be implemented simultaneously, or as resources and funding become available. Appendix F presents a list of these recommendations sorted by site.

Table 5 Site specific recommendations

No.	Recommendation	Site/s	Category
1	Collaborate with State Government agencies (i.e. EPA) to improve the management of industrial developments	010, 012, 013	– Education & collaboration – Planning & compliance
2	Continue monitoring for local reference conditions	036, 037	– Monitoring
3	Develop a partnership with Parramatta City Council to collaboratively manage Devlins Creek	008	– Education & collaboration
4	Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries	038, 048, 055, 060, 061, 100, 103, 108, 150, 151, 152, 153	– Planning & compliance
5	Educate and collaborate with holiday park operators to minimise impacts from these settlements	152, 153	– Education & collaboration – Planning & compliance
6	Educate and collaborate with landholders to minimise impacts from rural activities	002, 042, 063, 064, 080	– Education & collaboration – Planning & compliance
7	Educate and collaborate with marina operators and boat users to minimise impacts from these activities	038, 060, 152	– Education & collaboration – Planning & compliance
8	Educate and collaborate with riverside residents to minimise impacts from these settlements	038, 060, 061, 103, 151, 152, 153	– Education & collaboration – Planning & compliance
9	Engage with industry to identify opportunities to reduce sources of pollutants	010, 012, 013	– Education & collaboration – Planning & compliance
10	Further collaborative research specific to estuarine health and ecological responses	038, 048, 055, 060, 061, 100, 103, 108, 150, 151, 152, 153	– Research & investigation
11	Further investigate the influence of key SE Australian climate drivers on local reference conditions	036, 037	– Research & investigation
12	Identify further opportunities for WSUD in the catchment	001, 002, 004, 005, 006, 008, 010, 012, 013, 023, 039, 042, 043, 045, 049,	– Research & investigation

		052, 062, 063, 064, 080	
13	Implement stringent sediment and erosion control standards in the catchment	008	– Planning & compliance
14	Improve collaborative management of risks from Foxglove Oval legacy landfill	077	– Planning & compliance
15	Investigate sources of increasing nutrients in the Hawkesbury River	055, 103, 108, 150, 151, 152, 153	– Research & investigation
16	Investigate sources of nutrients and bacteria in the catchment	004, 005, 006, 010, 012, 013, 023, 048, 052, 077	– Research & investigation – Monitoring
17	Investigate sources of nutrients in the catchment	001, 039, 043, 045, 049, 063	– Research & investigation – Monitoring
18	Investigate the influence of wet-weather events on local conditions	001, 055, 100	– Research & investigation – Monitoring
19	Investigate the significance of local impacts and the suitability of the site for catchment health assessment	006, 042	– Research & investigation
20	Investigate variability in water quality data and the association with rainfall events	004, 005, 006, 052	– Monitoring – Research & investigation
21	Maintain high sediment and erosion control standards	010, 012, 013	– Planning & compliance
22	Monitor and assess bacteria levels to identify and manage risks in recreational waters	001, 045, 055, 100	– Monitoring
23	Cease monitoring at this location. Waterway health to be informed by the Ecohealth program in partnership with Parramatta City Council	008	– Education & collaboration
24	Continue collaborating with residents to minimise the impacts of OWMS	042, 064, 080	– Education & collaboration – Planning & compliance
25	Continue collaborating with stakeholders for a coordinated approach to the management of risks to local aquaculture and commercial fishing operations	150, 151, 152, 153	– Education & collaboration
26	Continue collaborating with Sydney Water to improve the management of wastewater	001, 008, 010, 012, 013, 023, 043, 045, 060, 061, 100	– Education & collaboration – Planning and compliance
27	Continue monitoring for catchment health assessment via the Ecohealth program	001, 002, 004, 005, 006, 036, 037, 039, 042, 043, 045, 048, 049, 052, 063, 100, 150, 152, 153	– Monitoring
28	Continue monitoring to identify and manage risks associated with algal blooms	060, 061, 100, 150, 151, 152, 153	– Monitoring – Research & investigation
29	Continue remote monitoring of estuarine conditions	061, 100, 150, 151, 152, 153	– Monitoring
30	Protect the bushland and riparian zones in the catchment to maintain buffering	002, 004, 039, 063	– Planning & compliance
31	Review of REHVs and suitability of long-term reference sites using targeted short-term reference site data	036, 037	– Research & investigation
32	Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved	010, 012, 013	– Planning & compliance – Monitoring
33	Cease routine monitoring at this location. Waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes	038, 060, 103, 108	– Monitoring
34	Suitability for recreational use to be advised on	048, 055, 100, 103, 108,	– Education & compliance

	Council's web-based swimming maps	150, 151, 152, 153	
35	Targeted monitoring to assess changes following the implementation of any management actions within the catchment	023	– Monitoring
36	Targeted monitoring to assess changes since the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality)	042, 064, 080	– Monitoring
37	Targeted monitoring to assess changes since the completion of the Cowan Wastewater Scheme (i.e. improved water quality)	062	– Monitoring
38	Targeted monitoring to assess the impacts of Foxglove Oval leachate on Gleeson Creek	077	– Monitoring
39	Undertake a review of all phytoplankton monitoring data	060, 061, 150, 151, 152, 153	– Research & investigation

Program Direction

Data collected under Council's Water Quality Monitoring program needs to be reliable, relevant and integrated with other Council programs to ensure the best outcomes for waterway health. In an ever-changing environment such as Local Government, it is imperative that monitoring programs adapt to address new and evolving issues. There are several decision-making tools available to assist Council in the design and implementation of programs that are effective in protecting community values, enhancing the natural environment and contributing to Hornsby Shire's transition towards a Water Sensitive City.

The following tools have been designed to assist with the strategic management and protection of waterway health:

- *The National Water Quality Management Framework* (ANZG 2018)
- *Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions* (Dela-Cruz, Pik & Wearne, 2017)
- Cooperative Research Centre Water Sensitive Cities (CRCWSC) *Transition Planning Process*

These frameworks use iterative processes to ensure that programs are appropriately evaluated and adapted to continuously improve program objectives. They will also assist to identify and prioritise appropriate management responses through Coastal Management Programs being developed for Sydney Harbour and the Hawkesbury River.

Decision-making Frameworks

National Water Quality Management Framework

The National Water Quality Management Strategy and associated Guidelines provide a national framework for managing water quality that can be adapted to state, regional and local scales. This includes a 10-step cyclical framework (Appendix G) that focuses on activities directly related to water and/or sediment quality. The framework is based around the understanding that natural resource managers can only develop suitable management strategies when they have a thorough scientific understanding of the impact of human activities on waterway health.

Use of the framework will support the process of ensuring clear community values, defining appropriate waterway objectives, assessing current local knowledge and identifying data gaps, developing appropriate programs to address these gaps, and feeding all knowledge and understanding into suitable management tools.

Risk-based Framework for Considering Waterway Health

NSW OEH and NSW EPA have developed the *Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions* (Dela-Cruz, Pik & Wearne, 2017) which is an adaptation of the National Framework to specifically guide strategic land-use planning decisions to protect waterways in NSW.

This is a 5-step framework (Appendix H), best implemented at the catchment or sub-catchment scale, to assist decision makers in managing the impact of land-use activities on the health of waterways in NSW.

Water Sensitive Cities

With a growing population, an increasing demand on water supply and wastewater services, continually changing catchments and uncertainty around the impacts of a changing climate, it is crucial that Council is positioned to protect Hornsby's highly valued waterways and natural environments.

To facilitate this, the CRCWSC has been engaged by Hornsby Council to develop a Water Sensitive Hornsby Transition Strategy. This process will inform the development of Hornsby Shire Council's Local Strategic Planning Statement (LSPS) in accordance with the NSW state review of council Local Environment Plans (LEP) and Development Control Plans (DCP).

Program Recommendations

It is recommended that:

- the *National Water Quality Management Framework* and the *Risk-based Framework for Considering Waterway Health* are used to ensure Councils Water Quality Monitoring Program is a dynamic program that maintains optimal design into the future
- Council's Water Quality Monitoring Program is aligned with the Water Sensitive Hornsby Transition Strategy
- Council reviews current and develops new planning controls and prescriptive measures for the protection of estuarine and freshwater ecosystems to inform Local Strategic Planning Statements, Local Environment Plans and Development Control Plans
- the findings and recommendations of the Waterway Health Review inform Coastal Management Program development for the Hawkesbury River and Sydney Harbour.

CONCLUSIONS

Specific conclusions are presented under the four key objectives of this Waterway Health Review:

Identify significant temporal trends in water quality monitored at freshwater and estuarine sites

- Overall, the water quality at most long tern freshwater sampling sites has remained relatively stable.
- Long-term improvements in water clarity have been achieved in many freshwater sites.
- Long-term improvements in phosphorus have been achieved at two out of three industrial sites.
- Significant improvements in nutrient concentrations in Berowra Creek were achieved by the WWTP upgrades completed in 2003 however no further improvements are evident.
- Nutrient concentrations are continually increasing in the main Hawkesbury River channel.

Determine the overall conformance of water quality against REHVs at freshwater and estuarine sites

- Conformance with REHVs was heavily dependent on associated land-use activities or point sources of pollution.
- The general trend for water quality in Hornsby Shire is that water quality conforms with REHVs where catchments remain primarily undisturbed (reference sites), usually in National Parks and Nature Reserves. Waterway health and conformance with REHVs declines downstream of urban and rural settlements, declining even further in close proximity to urban or rural developments with the most impacted water quality associated with industrial land-use.

Identify site specific risks to water quality and recommend management options to achieve water quality objectives

- Stormwater and sewage from overflows or failing infrastructure continue to be a problem in industrial and urban catchments where large areas of impervious surfaces and piped stormwater systems move catchment-based pollutants quickly and directly to receiving waterways.
- Management options to address waterway health need to be specific to waterways (or sub-catchments) and generally fall into the four categories: monitoring; planning and compliance; education and collaboration; and, research and investigation.
- Developing a range of management tools that include development controls to minimise risks to waterway health will be key to protecting community values and achieving the waterway objectives of Hornsby Shire.
- Identifying and mitigating diffuse sources of pollution in the wider Hawkesbury-Nepean Catchment is crucial to the protection of the Hawkesbury River.

Use knowledge gained from long-term water quality monitoring in association with established decision making frameworks to guide HSC's monitoring program into the future

The 10-step National Water Quality Management Framework (ANZG, 2018) focuses on activities directly related to water and/or sediment quality and will assist in the development of efficient and effective water quality monitoring programs.

- The NSW State Government's 5-step Risk-based Framework (Dela-Cruz, Pik & Wearne, 2017) specifically guides strategic land-use planning decisions to protect NSW waterways and should be used to inform planning decisions.
- The CRCWSC Transition Planning Process provides strategic guidance for cities and towns with a vision of a water sensitive future and should be used to guide Hornsby Shire Council during our transition to a Water Sensitive City.

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ACRONYMS

% NC	Percent Non-Conformance
ANZ WQG	Australian & New Zealand Water Quality Guidelines
BOD	Biochemical Oxygen Demand
CFU	Colony forming unit
CRCWSC	Cooperative Research Centre for Water Sensitive Cities
CRR	Catchment Remediation Rate
DCP	Development Control Plan
DO	Dissolved Oxygen
EC	Electrical Conductivity
ENSO	El Niño-Southern Oscillation
HSC	Hornsby Shire Council
IOD	Indian Ocean Dipole
LEP	Local Environment Plan
LGA	Local Government Area
LSPS	Local Strategic Planning Statement
NATA	National Association of Testing Authorities
NH_3-N	Ammonia Nitrogen
NO_X-N	Oxidised Nitrogen
NSW EPA	New South Wales Environment Protection Authority
NSW OEH	New South Wales Office of Environment and Heritage
OWMS	On-site Wastewater Management System
PSER	Pressure-Stressor-Ecosystem Receptor
QC	Quality Control
QA	Quality Assurance
REHV	Regional Environmental Health Value
SoJI	Statement of Joint Intent
SRP	Soluble Reactive Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WOE	Weight of Evidence
WSUD	Water Sensitive Urban Design
WWTP	Wastewater Treatment Plant

APPENDIX A – Extract of QA/QC Procedures

5.2 Quality Assurance/ Quality Control

5.2.1 Multi-Probe Calibration

To ensure accurate in-situ measurements, the Yeokal™ probe sensors are calibrated the morning of each sampling run using commercially available standard solutions and check tests (Table 5.2). Calibration is checked again in the afternoon following each sampling run. Correction factors are applied to probe data if sensor calibration drifted by more than accepted daily variation (Table 5.2).

At each sample site the date, time, site details, visual observations and probe readings are recorded for future reference.

5.2.2 Sample Handling

The contract laboratory supplies new bottles for sampling prepared with preservatives where required. The date and unique sample identification number is printed on waterproof adhesive labels prior to sampling (Figure 5.3). After the water samples are taken the sample bottles are immediately placed in eskies with ice and freezer blocks. After returning from the field the bottles are repacked on ice, a 'Chain of Custody' form is completed and attached to the esky. The samples are then couriered to the laboratory by 5pm the same day.

5.2.3 Duplicate and Field Blank Samples

A duplicate field sample is taken at one site each month. This effectively provides two samples (*A* and *B*) of the same water which are labelled differently. The results from the laboratory analysis provide an indication of combined variability of water quality at a site and variability of the laboratory testing procedures.

Further, a field blank is prepared each month and sent to the laboratory for analysis. Field blanks are sample bottles filled with deionised (DI) water before the sampling run. They are labelled and handled as other field samples, for example stored in a chilled esky. The blank samples are then sent to the laboratory with the other water samples for analysis of all parameters. They provide a check for potential contamination from either the sample bottles or transportation and handling. Field blanks can also provide a check of a laboratories handling, analysis and detection limits.

5.2.3 Laboratory Procedures

The contract laboratory has a comprehensive quality control program which is a requirement to retain national accreditation (NATA certification). With each daily batch of samples for each test parameter the laboratory includes extra Quality Assurance/Quality Control (QA/QC) samples including replicate tests, lab blanks, spiked samples and lab check samples, which must all pass in-house QC standards before results are released. Final reports provided to Council include QA/QC test results.

Figure 5.3: Sampling equipment used to measure water quality parameters. Sample are collected in bottles labelled with unique sample ID numbers.

Table 5.2: Calibration values and checks, and acceptable daily variation.

Probe Tests	Low Value Calibration		High Value Calibration		Check solution	Daily Calibration check	Accepted Daily Variation (±)
	Frequency	Calibration Range	Frequency	Calibration Range		*Before and after site visits*	
Temperature	Quarterly	3 – 7 °C	Quarterly	40 to 45 °C		One point check against standardised thermometer in water bath	0.2 °C
EC	Daily	0 µS/cm *(DI water)*	Daily	1413 µS/cm *(commercial solution)*	Sydney Tap water (approximately 200µS/cm)	Low and high point calibration check	15 µS/cm
Salinity	Daily	0 ppt *(DI water)*	Daily	35 ppt *(commercial solution)*		Low and high point calibration check	0.01 / 0.5 ppt
DO	Monthly	0 % sat *(zero DO sensor insert)*	Daily	100 % sat *(air bubbled in tank of tap water)*		Low and high point calibration check	5 %
pH	Daily	pH 7 *(commercial solution)*	Daily	pH 10 *(commercial solution)*	Daily pH 4 and pH 7 dilute x10 (commercial solution)	Low and high point calibration check	0.1 pH units. *Correct pH for temperature variation*

APPENDIX B – Site Descriptions

001 – Berowra Creek, Galston Gorge

Location: Lower freshwater reaches of Berowra Creek at Galston Gorge approximately 500m downstream of the Berowra Creek Bridge within Berowra Valley National Park.

Background: Initially sampled to monitor the impacts of the West Hornsby WWTP and upstream urbanisation on water quality within Berowra Creek. The site is also sampled to gain an understanding of the effects of rainfall events on swimming water quality at Crosslands Reserve located further downstream. This sampling site is approximately 6km downstream of the West Hornsby WWTP discharge point.

Catchment: Catchment area is approximately 5715 hectares with 35% zoned environmental protection, 34% residential and 19% rural land-use. Other land-uses in the catchment include recreation, special uses, industrial and business.

Sampled since: November 1994

002 – Tunks Creek, Galston Gorge

Location: Lower freshwater reaches of Tunks Creek immediately downstream of Tunks Creek Bridge in Galston Gorge and approximately 100m upstream from the confluence with Berowra Creek.

Background: Sampling aims to monitor rural run-off entering Berowra Creek via Tunks Creek tributary. The site is approximately 5km downstream of rural and urban sources.

Catchment: Catchment area is approximately 1689 hectares with 50% zoned environmental protection and 44% rural land-use. Other land-use in the catchment include recreation, special uses and residential.

Sampled since: October 1994

004 – Berowra Creek, Westleigh

Location: Upper freshwater reaches of Berowra Creek and upstream of its confluence with Pyes Creek. The site is located in Berowra Valley National Park bushland and is accessed via Benowie walking track at Barwood Close, Westleigh.

Background: Site is influenced by urban stormwater run-off from roads and residential development within the surrounding heavily urbanised upper Berowra Creek Catchment. The site is predominantly surrounded by bushland areas which buffer the influences of surrounding development by filtering stormwater pollution. The site is located upstream of the two WWTPs which discharge into Berowra Creek.

Catchment: Catchment area is approximately 992 hectares with 72% zoned residential and 16% environmental protection land-use. Other land-uses in the catchment include recreation, special uses and business.

Sampled since: October 1994

005 – Pyes Creek, Cherrybrook

Location: Lower freshwater reaches of Pyes Creek adjacent to Kristine Place, Cherrybrook and upstream of its confluence with Georges Creek.

Background: Site is located in the upper south-western corner of Berowra Creek Catchment. The surrounding catchment is predominately residential land-use and is monitored as a representative urban sewer catchment.

Catchment: Catchment area is approximately 385 hectares with 92% zoned residential land-use. Other land-uses in the catchment include recreation, special uses and business.

Sampled since: October 1994

006 – Georges Creek, Cherrybrook

Location: Lower freshwater reaches of Georges Creek adjacent to Fallon Drive, Cherrybrook and upstream of its confluence with Pyes Creek.

Background: Site is located in the upper south-western corner of the Berowra Creek Catchment. The surrounding catchment is predominately residential land-use. The sampling site is adjacent to a gabion wall, constructed to retain a sewage pumping station.

Catchment: Catchment area is approximately 453 hectares with 53% zoned rural 19% residential and 15% environmental protection. Other land-uses in the catchment include industrial, special uses, recreation and business.

Sampled since: October 1994

008 – Devlins Creek, Cheltenham

Location: Lower freshwater reaches of Devlins Creek adjacent to Sutherland Road, Cheltenham and upstream of its confluence with Byles Creek, approximately 200m downstream of the M2 Motorway crossing.

Background: This site was established to monitor urban land-use and the influence of the M2 Motorway within the Devlins Creek sub-catchment of the Lane Cove River Catchment. Since May 2016, a significant percentage of Devlins Creek Catchment (formerly within Hornsby Shire) now sits within Parramatta City Council LGA.

Catchment: Catchment area is approximately 1021 hectares and is shared between Parramatta City Council LGA (705 hectares) and Hornsby Shire Council LGA (315 hectares). Within Hornsby's 315 hectares, 71% is zoned residential and 20% recreation land-use with other land-uses being special uses, environmental protection and business.

Sampled since: October 1994

010 – Larool Creek, Thornleigh

Location: Upper freshwater reaches of Larool Creek about 100m from Sefton Road directly downstream of the Thornleigh Industrial Precinct in the upper southern corner of Berowra Creek Catchment.

Background: The catchment headwaters of Larool Creek are heavily urbanised with a significant portion comprising the Thornleigh Industrial Precinct. Monitoring was established at the site to determine the influence of industrial land-use on downstream water quality. Long-term water quality monitoring highlights Larool Creek to be one of the most polluted creeks in Hornsby Shire.

Catchment: Catchment area is approximately 38 hectares with 42% zoned residential and 40% industrial land-use. Other land-uses in the catchment include special uses, recreation and business.

Sampled since: October 1994

012 – Hornsby Creek, Hornsby

Location: Lower freshwater reaches of Hornsby Creek adjacent to Leighton Place, Hornsby about 30m upstream of the road bridge. This site is situated in the middle of the Hornsby Industrial Precinct and downstream of Westfield and the Hornsby CBD.

Background: Hornsby Creek is a tributary to Cockle Creek which flows through Ku-ring-gai Chase National Park to Bobbin Head and Cowan Creek. Hornsby Creek is subject to high-flow wet-weather events within this high density heavily urbanised catchment. The majority of Hornsby Creek has been piped with only a few sections of creekline upstream of the Industrial Precinct remaining unpiped. The sampling site receives run-off from commercial, residential and industrial land-uses. Extensive areas of impervious surfaces within the upper catchment contribute to pulses of high flow during rain that rapidly transport pollutants to the creek. A

sewerage line runs adjacent to the creek-line with designed overflow points. Monitoring was established at the site to determine the influence of industrial land-use.

Catchment: Catchment area is approximately 306 hectares with 64% zoned residential (comprising high, medium and low density), 13% business, 13% special uses (roads, rail and community), 6% industrial and 4% recreation land-use.

Sampled since: October 1994

013 – Sams Creek, Mount Kuring-gai

Location: Upper freshwater reaches of Sams Creek just downstream of Mount Kuring-Gai Industrial Precinct and accessed via Hamley Road, Mount Kuring-gai.

Background: Small sub-catchment dominated by ridgetop industrial precinct development draining to Sams Creek and Berowra Valley National Park before entering Berowra Creek about 3km downstream. Monitoring was established at the site to determine the influence of industrial land-use. The precinct originally relied on the pump out of effluent with premises progressively being connected to the sewer from 2008. Inspections undertaken in 2011 showed more than half the premises were connected, however some may still be relying on pump out. Any new development in the area is required to connect to the sewer.

Catchment: Catchment area is approximately 21 hectares with 82% zoned industrial and 12% environmental protection land-use. Other land-uses in the catchment include recreation and special uses.

Sampled since: October 1994

023 – Waitara Creek, Hornsby

Location: Lower freshwater reaches of Waitara Creek about 100m immediately upstream of the West Hornsby WWTP.

Background: The site receives run-off from the heavily urbanised south-eastern corner of Berowra Creek Catchment which includes residential, commercial and industrial land-uses which drain directly into Waitara Creek or via several tributary feeder creeks, including Larool Creek, which drains the Thornleigh Industrial Precinct.

Catchment: Catchment area is approximately 650 hectares with 69% zoned residential and 17% recreation land-use. Other land-uses in the catchment include environmental protection, industrial, special uses and business.

Sampled since: October 1994

036 – Murray Anderson Creek, Ku-ring-gai Chase National Park

Location: Lower freshwater reaches of Murray Anderson Creek (a tributary to Smiths Creek) within Cowan Creek Catchment and Ku-ring-gai Chase National Park. This freshwater sampling point is located a short walk upstream from where Murray Anderson Creek enters - via a small waterfall - the estuarine tidal waters of Smiths Creek.

Background: This site was established as a regional water quality reference site as it is predominately surrounded by undisturbed Ku-ring-gai Chase National Park bushland. Access is by boat via Smiths Creek.

Catchment: Catchment area is approximately 250 hectares of Ku-ring-gai Chase National Park bushland (located within Northern Beaches Council LGA and zoned environmental management).

Sampled since: January 1995

037 – Smugglers Creek, Marramarra National Park

Location: Lower freshwater reaches of Smugglers Creek (a tributary to Marramarra Creek) within Marramarra National Park and the northern corner of Berowra Creek Catchment. This freshwater sampling

point is located about a 500m walk upstream from where Smugglers Creek enters the estuarine tidal waters of Marramarra Creek.

Background: This site was established as a regional water quality reference site for the Hornsby LGA as it is predominately surrounded by undisturbed Marramarra National Park bushland. Access is by boat via Marramarra Creek or by vehicle via Smugglers Ridge Fire Trail.

Catchment: Catchment area is approximately 535 hectares of predominately Marramarra National Park bushland with 99% zoned environmental protection and 1% rural land-use.

Sampled since: January 1995

038 – Sandbrook Inlet, Brooklyn

Location: Lower Hawkesbury estuarine site located at the enclosed eastern end of Sandbrook Inlet navigation channel.

Background: This sampling site was established to monitor the effects of urban run-off and discharges from Brooklyn village, local marinas and moored vessels. The site is located downstream of the discharge point for the Brooklyn WWTP, which was commissioned in 2008.

Sandbrook Inlet is known locally as 'the Gut' due to its restricted tidal flushing brought about by the creation of a 'dead end' following the construction of the Hawkesbury River railway crossing. The Inlet is bounded by residential development and marina operations along its southern shore and Long Island Nature Reserve to the north. Heavily influenced by the marine industry, houseboats and moored vessels, the Inlet is characterised by a shallow mangrove-lined foreshore with numerous swing moorings located along a central navigation channel.

Sampled since: October 1994

039 – Joe Crafts Creek, Berowra Valley National Park

Location: Lower freshwater reaches of Joe Crafts Creek in the north-eastern corner of Berowra Creek Catchment approximately 100m upstream of its confluence with Berowra Creek.

Background: This site is located within Berowra Valley National Park approximately 4km downstream from the Berowra locality and receives both bushland and urban run-off. The site is characterised by a rocky substrate with large boulders throughout the creekline. Site is accessed by boat via Berowra Creek.

Catchment: Catchment area is approximately 690 hectares with 38% zoned environmental protection, 36% residential and 23% recreation land-use. Other land-uses in the catchment include special uses and business.

Sampled since: October 1994

042 – Colah Creek, Glenorie

Location: Upper freshwater reaches of Colah Creek at Glenorie immediately below Wylds Road Bridge.

Background: This site was established to monitor impacts of predominately rural land-use from Middle Dural, Glenorie, Galston and Arcadia.

Catchment: Catchment area is approximately 2308 hectares with 74% zoned rural and 16% environmental protection land-use. Other land-uses in the catchment include recreation, special uses, residential and business.

Sampled since: October 1994

043 – Calna Creek, Berowra Valley National Park

Location: Lower freshwater reaches of Calna Creek approximately 4km downstream of the Hornsby Heights WWTP and 1km upstream of the confluence with Berowra Creek estuary.

Background: This site is downstream of the Hornsby Heights WWTP discharge point and was established to provide an indication of the quality of water entering Berowra Creek from the Calna Creek Catchment. Dry weather flows in Calna Creek are dominated by WWTP discharge which typically contains high levels of oxidised nitrogen. This section of creek is shaded by riparian vegetation and the substrate consists of large sandstone boulders.

Catchment: Catchment area is approximately 1112 hectares with 47% zoned environmental protection and 40% residential land-use. Other land-uses in the catchment include recreation, special uses, industrial and business.

Sampled since: October 1994

045 – Fishponds, Berowra Creek

Location: Lower freshwater reaches of Berowra Creek at Fishponds Waterhole within Berowra Valley National Park not far from Hornsby CBD.

Background: This site is situated downstream of the confluence with Waitara Creek and is therefore influenced by run-off from both the upper Berowra Creek Catchment area (which includes Pyes and Georges Creek Catchments) and Waitara Creek Catchment. West Hornsby WWTP discharges into Waitara Creek approximately 1km upstream and accounts for a significant amount of the base flow at Fishponds Waterhole.

Catchment: Catchment area is approximately 3411 hectares with 54% zoned residential, 23% environmental protection and 10% rural land-use. Other land-uses in the catchment include recreation, special uses, industrial and business.

Sampled since: October 1994

048 – Marramarra Creek, Marramarra NP

Location: Upper estuarine reaches of Marramarra Creek adjacent to an old orange orchard within Marramarra National Park.

Background: The surrounding upstream catchment includes a large area of undisturbed bushland as well as the rural areas of Galston, Glenorie, Fiddletown, Arcadia, Forest Glen and Canoelands.

Catchment: Catchment area is approximately 8609 hectares with 65% zoned environmental protection and 30% rural land-use. Other land-uses in the catchment include recreation, special uses, residential and business.

Sampled since: October 1994

049 – Still Creek, Galston

Location: Upper freshwater reaches of Still Creek adjacent to Mansfield Road, Galston.

Background: This site was established to monitor inputs from rural areas with low density development.

Catchment: Catchment area is approximately 439 hectares with 84% zoned rural and 10% recreation land-use. Other land-uses in the catchment include environmental protection, special uses and residential.

Sampled since: October 1994

052 – Calna Creek, Hornsby Heights

Location: Upper freshwater reaches of Calna Creek at Hornsby Heights approximately 300m upstream of the Hornsby Heights WWTP.

Background: This site was established to determine the influence of urban land-use on the water quality of Calna Creek. Being located upstream of the WWTP discharge point, this site allows a comparison to be made with a second downstream sampling site (043) in order to identify changes in water quality due to treated wastewater discharge.

Catchment: Catchment area is approximately 276 hectares with 67% zoned residential, 17% environmental protection and 12% recreation land-use. Other land-uses in the catchment include special uses and business.

Sampled since: November 1995

055 – Brooklyn Baths, Hawkesbury River

Location: Estuarine site located at Brooklyn Baths on the Hawkesbury River at Brooklyn.

Background: Site was established due to it being a designated recreational swimming location. Brooklyn Baths has a shark-netted enclosure directly connected to the lower Hawkesbury River estuary.

Brooklyn Baths (site 55), Crosslands Reserve (site 100) and Bradleys Beach, Dangar Island (site 108) are popular swimming locations within Hornsby Shire. In addition to environmental health, water quality data from these sites provides information regarding public health and the suitability of the sites for recreational activities. Long-term monitoring data has been used to develop an online application providing daily updates on the suitability of swimming at different locations in the Hawkesbury estuary, which can be viewed at www.hornsby.nsw.gov.au/environment/waterways.

Sampled since: December 2004

060 – Berowra Waters, Berowra Creek

Location: Estuarine site located in the middle of Berowra Creek immediately downstream of the Berowra Waters Ferry.

Background: The site is characterised by the ferry crossing, marina operations, swing moorings and residential development along the foreshore and was originally established to monitor the influence of the marina and a small on-site wastewater treatment plant that ceased operation in 2010.

Sampled since: December 1994

061 – Berowra Creek, Calabash Point

Location: Estuarine site located in Berowra Creek at Calabash Point.

Background: This site is located in the middle of Berowra Creek near Calabash Point. The site has a depth of approximately 15m, which is unusually deep compared to the rest of Berowra Creek, and is subject to regular stratification. This deep hole has been identified as a likely origin site for algal blooms. In 2002, a water quality monitoring buoy was deployed to provide real-time data on chlorophyll-a, salinity and temperature. This data is used as an early-warning indicator for algal bloom detection and for swimming condition status reports.

For further information see www.hornsby.nsw.gov.au/environment/waterways

Sampled since: March 1997

062 – Kimmerikong Creek, Cowan

Location: Upper freshwater reaches of Kimmerikong Creek accessed via Alberta Avenue, Cowan.

Background: The site is located in the north-eastern corner of the Berowra Creek Catchment adjacent to Cowan township and is located upstream of a former quarry. The site was established to monitor base flow which is predominately run-off from the Cowan urban area.

Catchment: Catchment area is approximately 16 hectares with 53% zoned residential and 37% environmental protection land-use. Other land-uses in the catchment include special uses and recreation.

Sampled since: July 2002

063 – Colah Creek, Glenorie

Location: Upper freshwater reaches of Colah Creek accessed via Ben Bullen Fire Trail, Glenorie.

Background: The site is located in the north-western corner of the Berowra Creek Catchment and includes predominately rural land-uses and was established to monitor inputs from Middle Dural, Glenorie, Galston and Arcadia. Colah Creek is a tributary to Marramarra Creek with the confluence being downstream of the sampling site within Marramarra National Park.

Catchment: Catchment area is approximately 1017 hectares with 76% zoned rural land-use. Other land-uses in the catchment include special uses, recreation, environmental protection, residential and business.

Sampled since: July 2002

064 – Unnamed watercourse, Galston

Location: Lower freshwater reaches of an unnamed creek located off Sallaway Road, Galston.

Background: This small unnamed creek receives urban run-off from the Galston Village precinct and is a tributary to Colah Creek in the north-western corner of the Berowra Creek Catchment.

Catchment: Catchment area is approximately 144 hectares with 57% zoned rural and 30% residential land-use. Other land-uses in the catchment include special uses, recreation, business and environmental protection.

Sampled since: July 2002

077 – Gleeson Creek, Mount Colah

Location: Upper freshwater reaches of Gleeson Creek adjacent to Oxley Drive, Mount Colah.

Background: The site is approximately 200m downstream of Foxglove Oval with Gleeson Creek being a tributary to Calna Creek in the south-eastern corner of Berowra Creek Catchment. This site was established to monitor water quality in the predominately urbanised upper Gleeson Creek Catchment and to assess the impact of leachate run-off from the former Foxglove Oval landfill site, which closed in 1980. The landfill site was compacted, capped and converted into an oval in 1985. In the 1990s Council installed a water quality treatment process to reduce the impacts of the leachate leaving the site. With the leachate being treated to a quality suitable for irrigation, a water harvesting system was commissioned and completed in 2010.

Catchment: Catchment area is approximately 46 hectares with 77% zoned residential and 17% recreation land-use. Other land-uses in the catchment include special uses and environmental protection.

Sampled since: July 1999

080 – Glenorie Creek, Glenorie

Location: Upper freshwater reaches of Glenorie Creek adjacent to Tekapo Road, Glenorie.

Background: The site is located in the north-western corner of the Berowra Creek Catchment and was established to monitor for impacts from on-site wastewater treatment systems (i.e. septic tanks) on water quality within Glenorie Creek. Glenorie Village was connected to the sewer in 2015. The catchment area includes numerous market gardens and small animal/hobby farms. Glenorie Creek is a tributary to Colah Creek with the confluence being located downstream of the sampling site.

Catchment: Catchment area is approximately 133 hectares with 70% zoned rural and 8% residential land-use. Other land-uses in the catchment include special uses and recreation.

Sampled since: August 1999

100 – Crosslands Reserve, Berowra Creek

Location: Estuarine site located off the northern beach of Crosslands Reserve downstream of the confluence with Still Creek and situated within the upper tidal limit for Berowra Creek.

Background: Berowra Creek at Crosslands Reserve is a popular water-based recreation location and this site was established to monitor the effects of water quality on recreational activities.

Brooklyn Baths (site 55), Crosslands Reserve (site 100) and Bradleys Beach, Dangar Island (site 108) are popular swimming locations within Hornsby Shire. In addition to environmental health, water quality data from these sites provide information regarding public health and the suitability of the sites for recreational activities. Long-term monitoring data has been used to develop an online application providing daily updates on the suitability of swimming at different locations in the Hawkesbury estuary, which can be viewed at www.hornsby.nsw.gov.au/environment/waterways.

Sampled since: December 2005

103 – Milsons Passage, Hawkesbury River

Location: Estuarine site located in the Hawkesbury River at the eastern end of Milsons Passage.

Background: This site is influenced by the riverside settlement of Milsons Passage and sampled by boat. The site is immediately upstream of the Brooklyn WWTP discharge point. This site was established to monitor the impacts of the WWTP on upstream water quality.

Sampled since: June 2006

108 – Dangar Island, Hawkesbury River

Location: Estuarine site located off Bradley's Beach in the Hawkesbury River at Dangar Island.

Background: The site is located downstream of the Brooklyn WWTP discharge point and was established to monitor the impacts of downstream water quality. The site is close to Dangar Island's recreational swimming area at Bradley's Beach and is not far from the mouth of the Hawkesbury River. It is primarily a marine influenced estuarine environment highly affected by tidal movement.

Sampled since: June 2006

150 – Gunyah Point, Hawkesbury River

Location: Estuarine site located near the mouth of the Hawkesbury River at Gunyah Point.

Background: This site was established as an end-of-system monitoring site for the Hawkesbury River and includes a water quality buoy that provides real-time data on chlorophyll-a, turbidity, salinity and temperature. This data is used to monitor water quality, and predict swimming conditions and algal blooms. Council has deployed several remote water quality monitoring buoys along the salinity gradient of the Hawkesbury River estuary, from the freshwater of Wisemans Ferry to the marine waters off Gunyah Point. Water quality data collected at these sites is available at www.hornsby.nsw.gov.au/environment/waterways.

Sampled since: August 2008

151 – Bar Island, Hawkesbury River

Location: Estuarine site located in the Hawkesbury River on the western side of Bar Island.

Background: This site was established as it is a significant area for local oyster production and includes a water quality buoy that provides real-time data on chlorophyll-a, turbidity, salinity and temperature. This data is used to monitor water quality, predict swimming conditions and algal blooms. Council has deployed several remote water quality monitoring buoys along the salinity gradient of the Hawkesbury River estuary, from the freshwater of Wisemans Ferry to the marine waters off Gunyah Point. Water quality data collected at these sites is available at www.hornsby.nsw.gov.au/environment/waterways.

Sampled since: June 2010

152 – Courangra Point, Hawkesbury River

Location: Estuarine site located in the Hawkesbury River at Courangra Point.

Background: The site was established to monitor water quality and salinity gradients in the middle section of the lower Hawkesbury River estuary within the Hornsby LGA, and includes a water quality buoy that provides

real-time data on chlorophyll-a, salinity, turbidity and temperature. This data is used to monitor water quality, predict swimming conditions and algal blooms. Council has deployed several remote water quality monitoring buoys along the salinity gradient of the Hawkesbury River estuary, from the freshwater of Wisemans Ferry to the marine waters off Gunyah Point. Water quality data collected at these sites is available at www.hornsby.nsw.gov.au/environment/waterways.

Sampled since: August 2008

153 – Laughtondale, Hawkesbury River

Location: Estuarine site located in the Hawkesbury River at Laughtondale, which is near the western boundary of the Hornsby LGA.

Background: The site was established to monitor water quality and salinity gradients in the upper section of the lower Hawkesbury River estuary within the Hornsby LGA, and includes a water quality buoy that provides real-time data on chlorophyll-a, salinity and temperature. This data is used to monitor water quality, predict swimming conditions and algal blooms. Council has deployed several remote water quality monitoring buoys along the salinity gradient of the Hawkesbury River estuary, from the freshwater of Wisemans Ferry to the marine waters off Gunyah Point. Water quality data collected at these sites is available at www.hornsby.nsw.gov.au/environment/waterways.

Sampled since: August 2008

Kendall-tau values from analysis of the long-term data set. Significant values depicted in red font

Site No.	Temp (°C)	pH	DO (%sat)	EC (ms/cm)	Salinity (ppt)	Turbidity (NTU)	TSS (mg/L)	Chl-a (ug/L)	TP (mg/L)	TN (mg/L)	NH3-N (mg/L)	NOx-N (mg/L)	F.Coliforms (CFU/100ml)	Enterococci (CFU/100ml)
001	-0.023	-0.073	-0.270	-0.237		-0.138	-0.247		0.003	-0.427	-0.112	-0.419	-0.052	
002	-0.030	-0.081	-0.223	-0.130		0.015	-0.230		-0.099	-0.154	-0.327	-0.079	-0.117	
004	-0.012	0.017	-0.188	-0.080		-0.144	-0.220		0.024	-0.088	-0.132	-0.110	-0.059	
005	-0.019	0.028	-0.351	-0.109		-0.156	-0.312		0.077	-0.158	-0.020	-0.172	-0.035	
006	-0.032	0.051	-0.191	-0.094		-0.252	-0.295		-0.016	-0.156	-0.243	-0.123	0.017	
008	-0.058	0.022	-0.207	0.142		-0.040	-0.138		0.066	0.002	0.025	-0.026	0.003	
010	-0.079	0.188	0.026	-0.032		-0.403	-0.465		-0.378	0.029	0.124	0.193	-0.180	
012	-0.048	-0.099	-0.438	-0.036		-0.103	-0.163		-0.159	0.068	0.151	0.049	-0.036	
013	0.014	-0.090	-0.325	-0.021		-0.213	-0.284		-0.347	-0.273	-0.071	-0.195	-0.211	
023	0.007	-0.095	-0.111	-0.064		-0.035	-0.045		0.139	0.032	0.036	-0.010	-0.027	
036	-0.006	-0.263	-0.118	-0.026		0.051	-0.145		0.160	-0.036	-0.537	-0.461	0.111	
037	-0.002	0.265	-0.054	-0.088		0.117	-0.106		0.107	0.021	-0.468	-0.312	0.086	
038	0.025	0.102	-0.083		-0.217	0.089	-0.076	0.106	-0.020	0.247	-0.330	-0.053	-0.005	-0.204
039	0.009	-0.150	-0.108	-0.170		-0.030	-0.326		-0.088	0.001	-0.376	-0.001	0.019	
042	0.002	0.157	0.272	-0.140		-0.184	-0.291		-0.187	-0.225	-0.254	-0.095	-0.009	
043	0.028	0.227	-0.167	-0.241		-0.079	-0.246		0.020	-0.502	-0.203	-0.499	-0.156	
045	0.055	0.188	-0.091	-0.265		-0.196	-0.258		-0.096	-0.446	-0.223	-0.450	0.063	
048	0.001	0.032	-0.120		-0.127	-0.011	-0.069	0.004	-0.034	0.130	-0.082	0.068	0.116	-0.062
049	-0.019	-0.183	-0.313	-0.176		0.018	-0.134		-0.076	-0.117	-0.154	-0.052	-0.049	
052	-0.011	-0.128	-0.330	-0.011		0.004	-0.227		0.029	-0.062	0.080	-0.045	-0.058	
055	-0.252	0.174	0.002		-0.260	0.419	0.096	0.028	0.280	0.322	0.213	0.162	0.073	-0.050
060	0.001	-0.078	-0.182		-0.206	0.109	-0.061	0.069	0.027	-0.223	-0.116	-0.290	0.016	-0.006
061	0.023	0.048	-0.091		-0.175	0.149	-0.117	0.061	0.096	-0.089	-0.182	-0.213	0.094	0.000
062	0.098	-0.192	-0.055	-0.163		0.168	-0.029		-0.162	-0.099	0.176	0.002	0.087	
063	0.034	0.158	0.090	-0.149		0.038	-0.061		0.064	0.014	-0.138	0.001	0.008	
064	0.111	-0.012	0.030	-0.305		0.083	-0.091		0.054	0.034	0.062	0.057	0.126	
077	0.040	0.134	-0.116	-0.119		-0.037	-0.083		0.034	-0.111	-0.043	-0.128	0.021	
080	-0.004	0.172	0.056	-0.262		0.050	-0.084		-0.142	-0.147	-0.172	-0.122	-0.152	
100	-0.139	0.251	0.041		0.059	-0.218	-0.137	0.028	0.059	0.153	0.062	0.069	-0.088	-0.161
103	0.064	0.273	-0.065		-0.145	0.216	0.086	0.093	0.415	0.388	0.251	0.119	0.002	0.063
108	0.021	0.341	-0.204		-0.078	0.166	-0.066	0.132	0.399	0.316	0.164	0.131	-0.138	-0.141
150	0.036	0.255	0.049		0.091	0.191	0.024	-0.088	0.051	0.239	0.197	0.175	0.391	0.146
151	-0.004	0.203	-0.075		0.087	-0.086	-0.049	-0.055	0.153	0.332	0.113	0.211	0.075	0.049
152	0.035	0.064	-0.018		-0.034	0.056	0.172	-0.114	0.294	0.317	0.207	0.231	0.042	0.105
153	0.031	0.081	0.035		0.019	0.116	0.054	-0.180	0.279	0.318	0.107	0.243	0.161	0.170

Kendall-tau values from analysis of data from October 2012 to September 2017. Significant values depicted in red font.

Site No.	Temp (°C)	pH	DO (%sat)	EC (ms/cm)	Salinity (ppt)	Turbidity (NTU)	TSS (mg/L)	Chl-a (ug/L)	TP (mg/L)	TN (mg/L)	NH3-N (mg/L)	NOx-N (mg/L)	F.Coliforms (CFU/100ml)	Enterococci (CFU/100ml)
001	-0.002	0.358	0.092	0.004		0.027	0.005		-0.209	0.071	-0.005	0.062	0.132	
002	0.003	0.020	-0.140	-0.125		0.003	0.003		-0.026	-0.029	-0.057	-0.068	0.048	
004	0.020	0.186	0.173	-0.044		0.019	-0.076		-0.147	0.029	-0.021	0.110	-0.027	
005	0.032	0.208	0.116	0.095		0.089	0.058		0.048	0.024	-0.050	0.042	0.127	
006	0.038	0.132	0.087	-0.151		-0.016	-0.117		0.001	0.216	0.114	0.213	0.132	
008	0.010	0.302	0.077	0.256		0.032	-0.052		-0.127	0.056	0.090	0.150	0.102	
010	-0.002	0.079	-0.228	0.006		0.070	0.095		0.012	0.278	0.254	0.287	0.106	
012	0.043	0.296	0.078	-0.007		0.203	0.085		0.149	0.085	0.103	0.097	0.124	
013	-0.007	0.103	-0.124	-0.046		-0.022	-0.092		-0.296	-0.078	-0.142	-0.058	-0.045	
023	0.068	0.036	0.125	-0.129		0.145	-0.031		-0.089	0.095	-0.031	0.103	0.007	
036	-0.010	0.121	-0.067	-0.186		0.197	-0.071		-0.012	-0.094	-0.008	0.111	-0.114	
037	-0.046	0.212	0.308	-0.201		0.130	0.190		-0.129	-0.056	-0.028	0.217	-0.068	
038	-0.053	0.132	-0.089		-0.128	0.188	-0.015	0.078	-0.059	0.266	0.022	0.183	-0.010	-0.137
039	-0.033	0.304	0.006	-0.061		0.033	0.048		-0.035	-0.089	-0.045	-0.018	-0.121	
042	0.025	0.058	0.136	-0.304		-0.017	-0.063		-0.053	0.005	-0.117	-0.042	-0.049	
043	0.023	-0.006	0.087	-0.127		-0.128	-0.279		-0.386	-0.152	-0.210	-0.110	0.057	
045	-0.027	0.175	-0.043	0.057		-0.105	-0.021		-0.224	0.032	0.012	0.039	0.014	
048	-0.069	-0.120	0.014		-0.169	-0.093	-0.138	-0.125	-0.147	0.112	0.163	0.040	0.111	0.133
049	0.003	0.353	0.151	-0.146		-0.053	-0.161		-0.009	0.080	0.014	0.090	-0.044	
052	0.002	0.191	-0.009	-0.017		0.161	0.164		0.017	0.107	0.254	0.120	-0.048	
055	-0.001	0.050	-0.182		-0.195	0.087	0.004	0.002	0.182	0.211	-0.112	0.235	0.043	0.124
060	-0.019	0.016	-0.156		-0.123	0.001	-0.022	0.017	0.001	0.210	0.101	0.131	0.112	0.110
061	0.015	-0.007	-0.091		-0.118	0.147	-0.027	-0.001	0.091	0.258	0.099	0.120	0.076	0.186
062	0.110	0.313	0.193	-0.225		-0.019	-0.388		-0.291	-0.349	-0.262	-0.085	-0.074	
063	0.021	0.064	0.069	-0.247		0.171	-0.033		-0.025	0.044	0.091	0.024	-0.188	
064	0.056	-0.015	0.038	-0.125		0.050	-0.015		-0.006	-0.058	0.090	-0.031	0.016	
077	0.012	0.163	-0.108	0.131		-0.073	-0.119		-0.099	0.190	0.175	0.219	-0.093	
080	0.035	0.318	0.516	-0.210		-0.092	-0.100		-0.194	-0.391	-0.171	-0.360	-0.071	
100	0.127	-0.098	-0.065		-0.091	-0.112	0.010	0.204	-0.040	0.093	0.093	0.027	-0.046	-0.009
103	-0.005	0.159	-0.107		-0.136	0.063	0.031	-0.223	0.001	0.251	0.023	0.197	0.037	0.144
108	-0.033	0.193	-0.113		-0.091	0.062	-0.116	-0.169	-0.101	0.179	-0.048	0.165	0.049	-0.043

Kendall-tau values from analysis of data since WTP upgrades (post 2003). Significant values depicted in red font.														
Site No.	Temp (°C)	pH	DO (%sat)	EC (ms/cm)	Salinity (ppt)	Turbidity (NTU)	TSS (mg/L)	Chl-a (ug/L)	TP (mg/L)	TN (mg/L)	NH3-N (mg/L)	NOx-N (mg/L)	F.Coliforms (CFU/100ml)	Enterococci (CFU/100ml)
001	-0.006	-0.060	0.022	-0.195		-0.072	-0.093		0.049	-0.012	-0.090	-0.023	0.020	
043	0.018	-0.006	0.052	-0.264		0.015	-0.012		0.226	-0.093	0.140	-0.105	0.035	
045	0.017	0.195	0.178	-0.279		0.024	-0.059		0.074	-0.032	-0.182	-0.026	0.051	
060	-0.012	-0.042	-0.119		-0.259	0.173	-0.144	0.134	0.270	0.211	0.087	0.093	0.195	-0.006
061	0.007	0.100	-0.032		-0.151	0.196	-0.107	0.129	0.218	0.262	0.053	0.060	0.142	0.000

APPENDIX D – Spatial Representation of % Non-conformance and Trend

D1: pH percent non-conformance with REHVs and temporal trend

D2: Dissolved Oxygen (DO %sat) percent non-conformance with REHVs and temporal trend

D3: Electrical Conductivity (EC mS/cm) percent non-conformance with REHVs and temporal trend

D4: Turbidity (NTU) percent non-conformance with REHVs and temporal trend

D5: Total Suspended Solids (TSS mg/L) percent non-conformance with REHVs and temporal trend

D6: Total Phosphorus (TP mg/L) percent non-conformance with REHVs and temporal trend

D7: Total Nitrogen (TN mg/L) percent non-conformance with REHVs and temporal trend

D8: Ammonium-nitrogen (NH_3-N mg/L) percent non-conformance with REHVs and temporal trend

D9: Oxidised-nitrogen (NOx-N mg/L) percent non-conformance with REHVs and temporal trend

D10: Faecal coliforms (F.cols CFU/100ml) percent non-conformance with REHVs and temporal trend

D11: E.Coli (CFU/100ml) percent non-conformance with REHVs and temporal trend

D12: Enterococci (CFU/100ml) percent non-conformance with REHVs and temporal trend

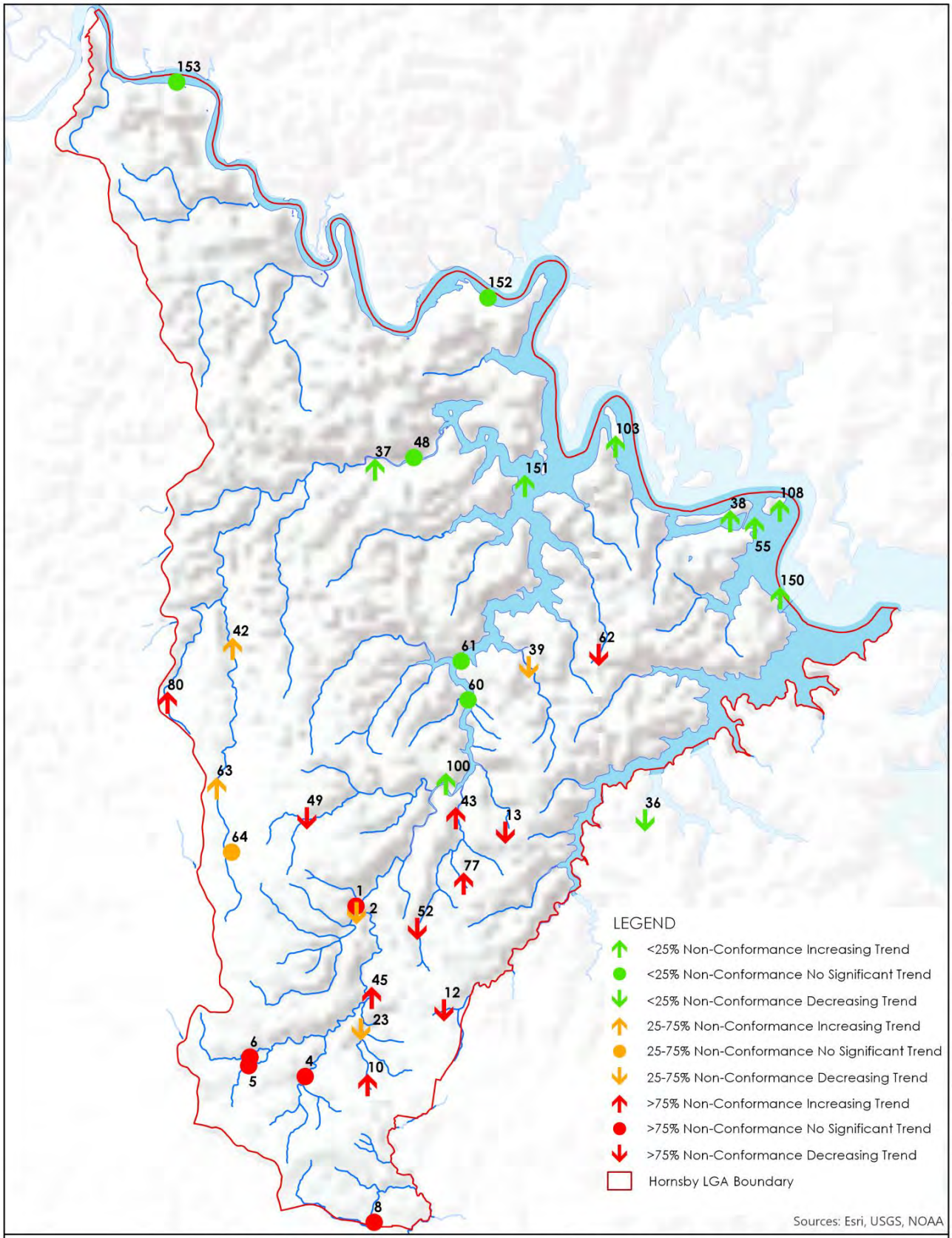

Figure D1: pH percent non-conformance with Regional Environmental Heath Values and temporal trend

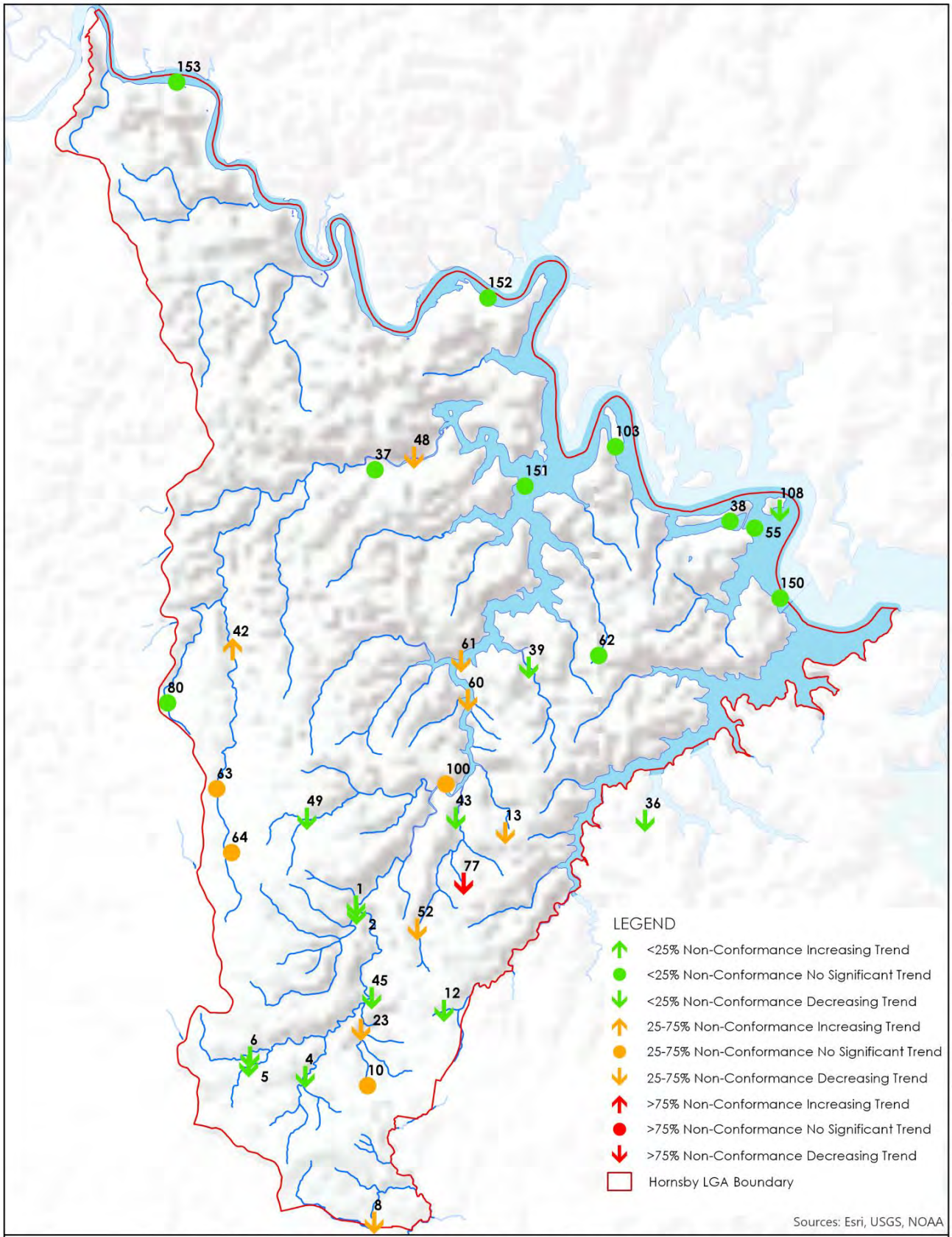

Figure D2: Dissolved Oxygen (% saturation) percent non-conformance with Regional Environmental Heath Values and temporal trend

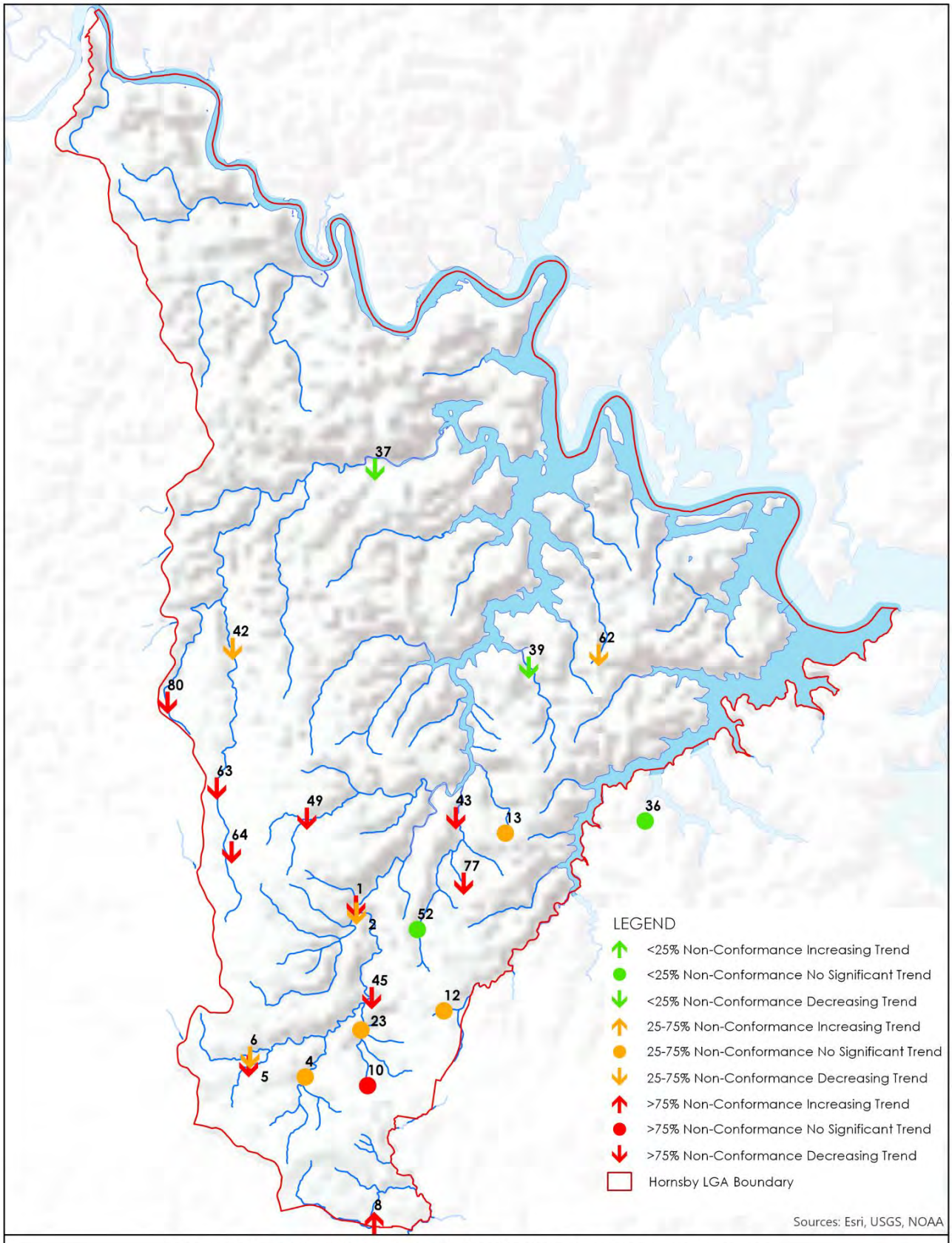

Figure D3: Electrical Conductivity (mS/cm) percent non-conformance with Regional Environmental Heath Values and temporal trend

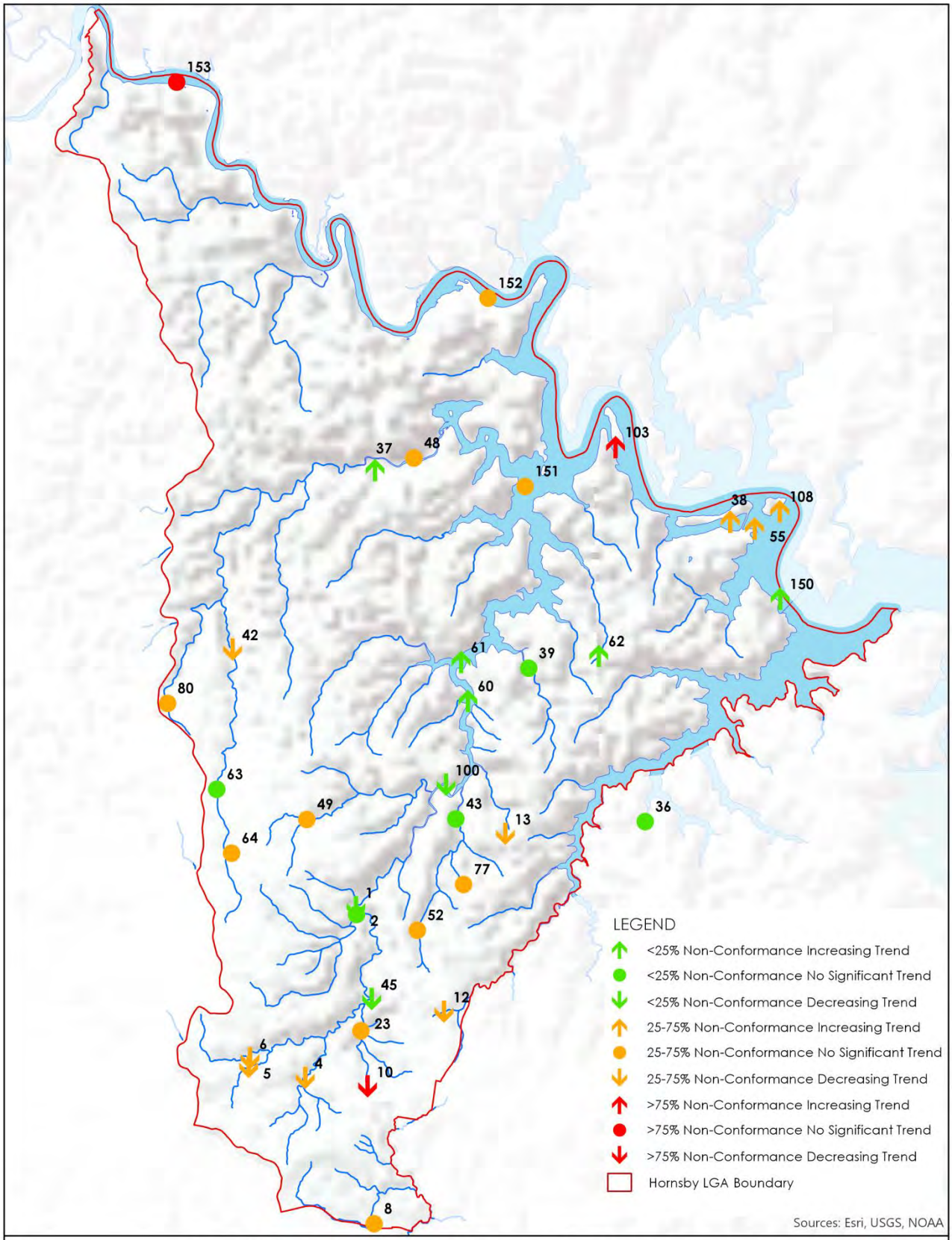

Figure D4: Turbidity (NTU) percent non-conformance with Regional Environmental Heath Values and temporal trend

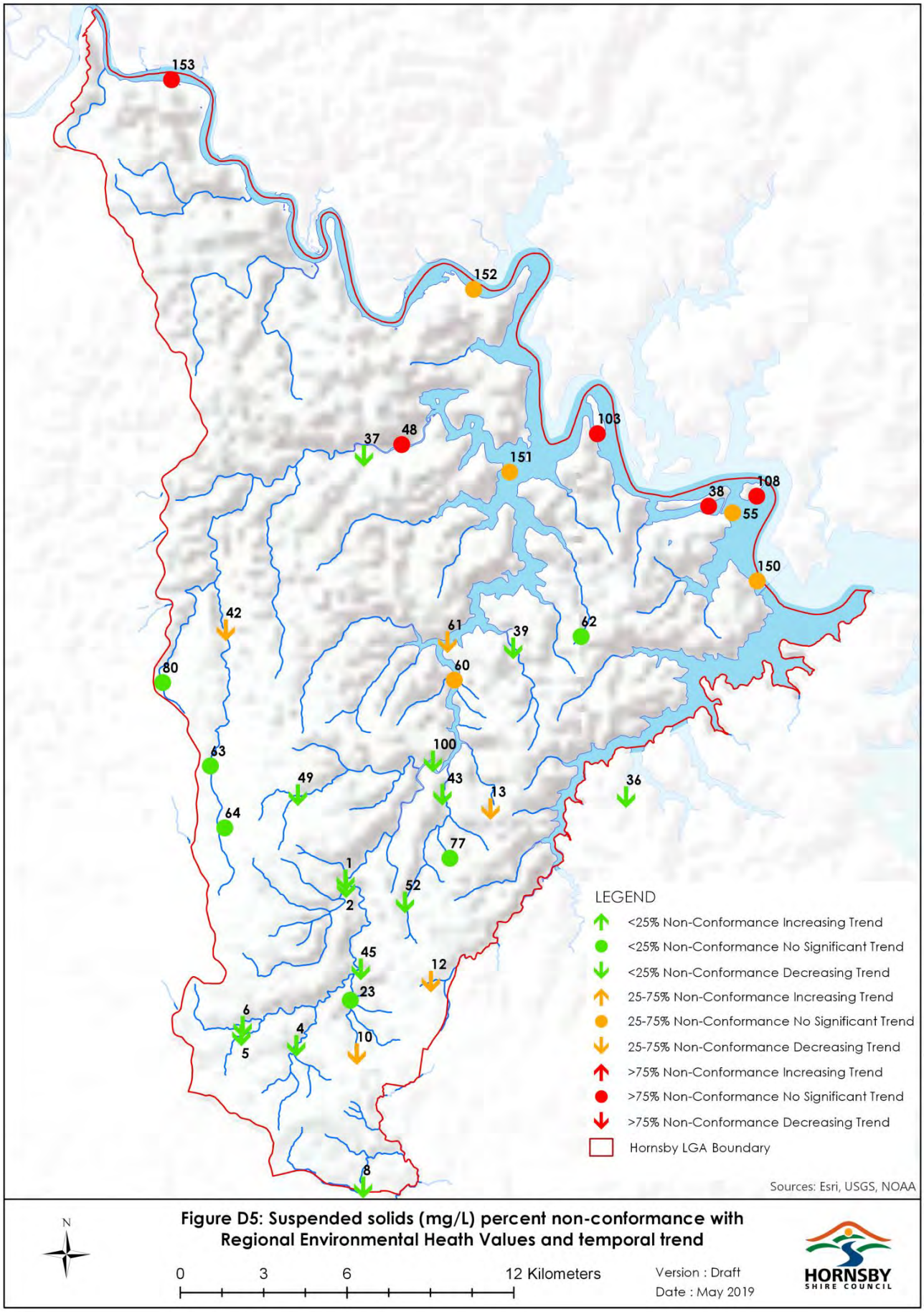

Figure D5: Suspended solids (mg/L) percent non-conformance with Regional Environmental Heath Values and temporal trend

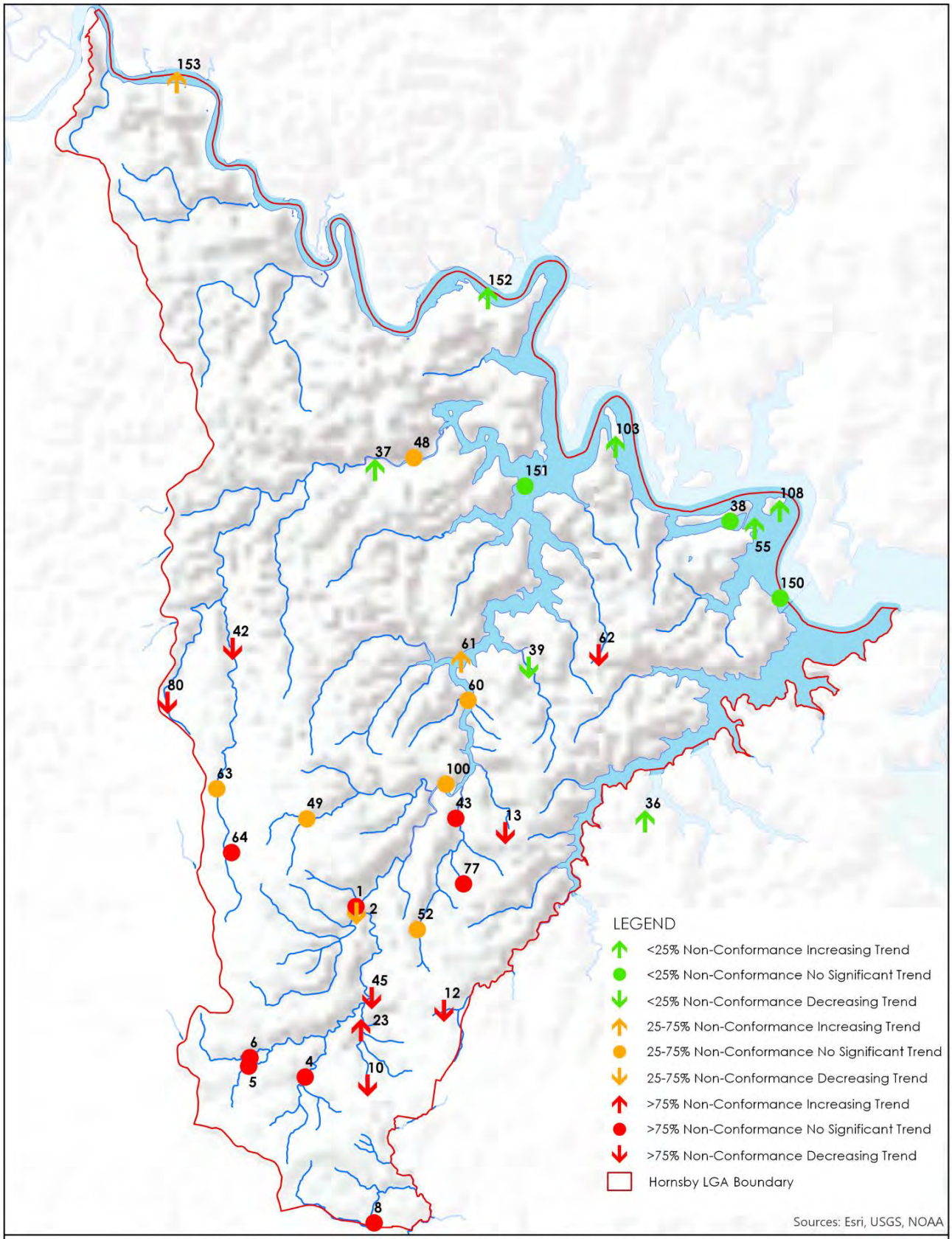

Figure D6:Total phosphorus (mg/L) percent non-conformance with Regional Environmental Heath Values and temporal trend

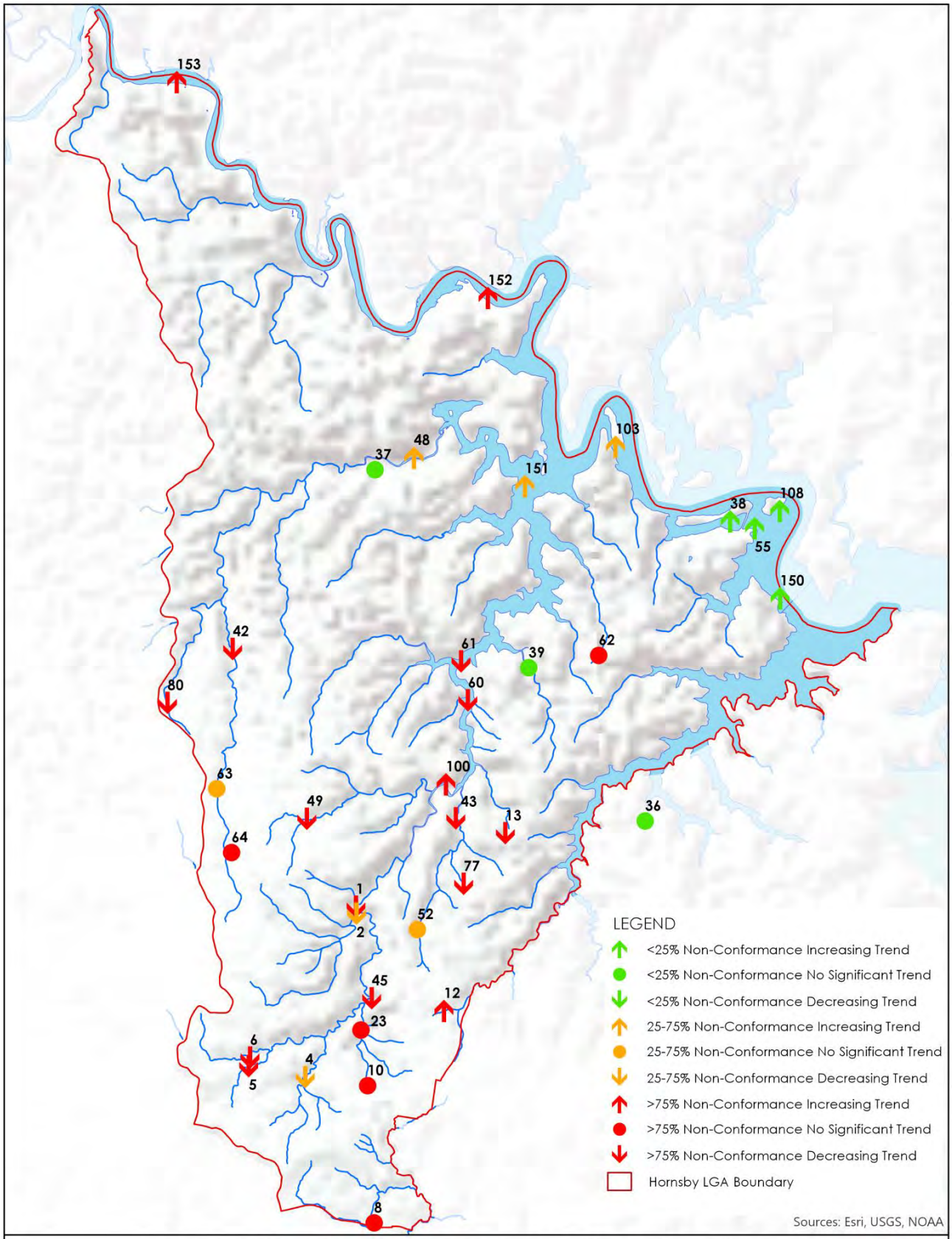

Figure D7: Total nitrogen (mg/L) percent non-conformance with Regional Environmental Heath Values and temporal trend

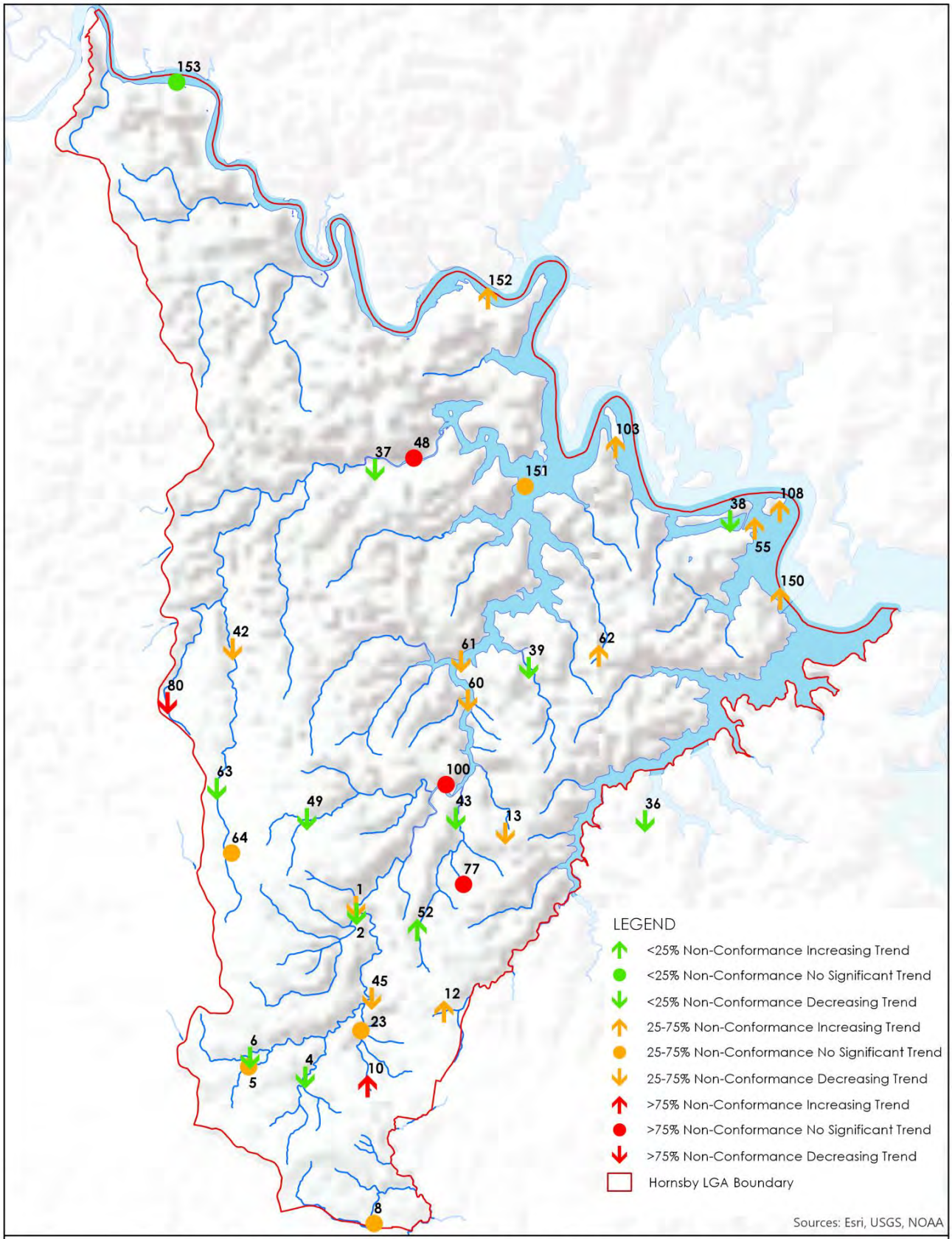

Figure D8: Ammonium-nitrogen (mg/L) percent non-conformance with Regional Environmental Heath Values and temporal trend

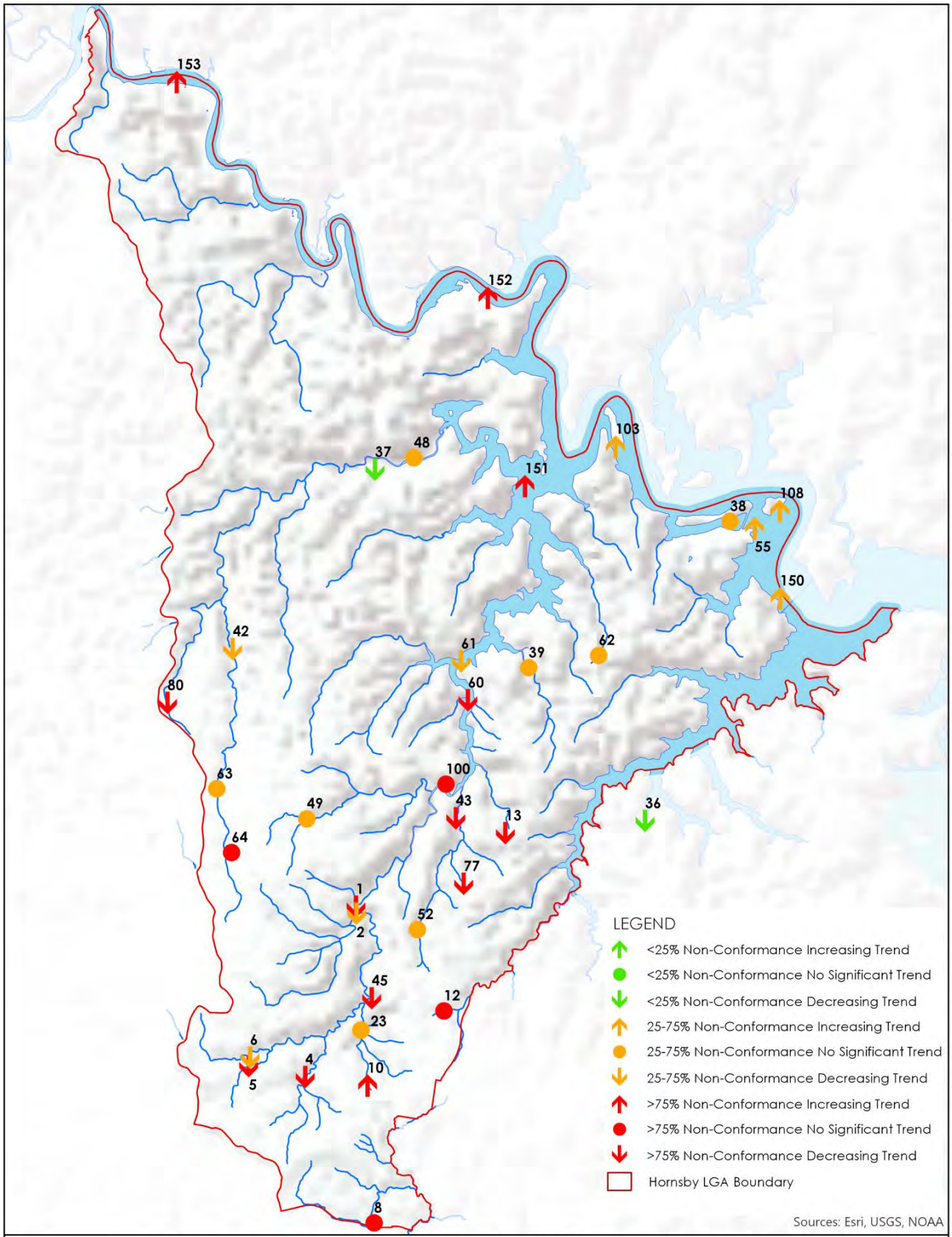

Figure D9: Oxidised nitrogen (mg/L) percent non-conformance with Regional Environmental Heath Values and temporal trend

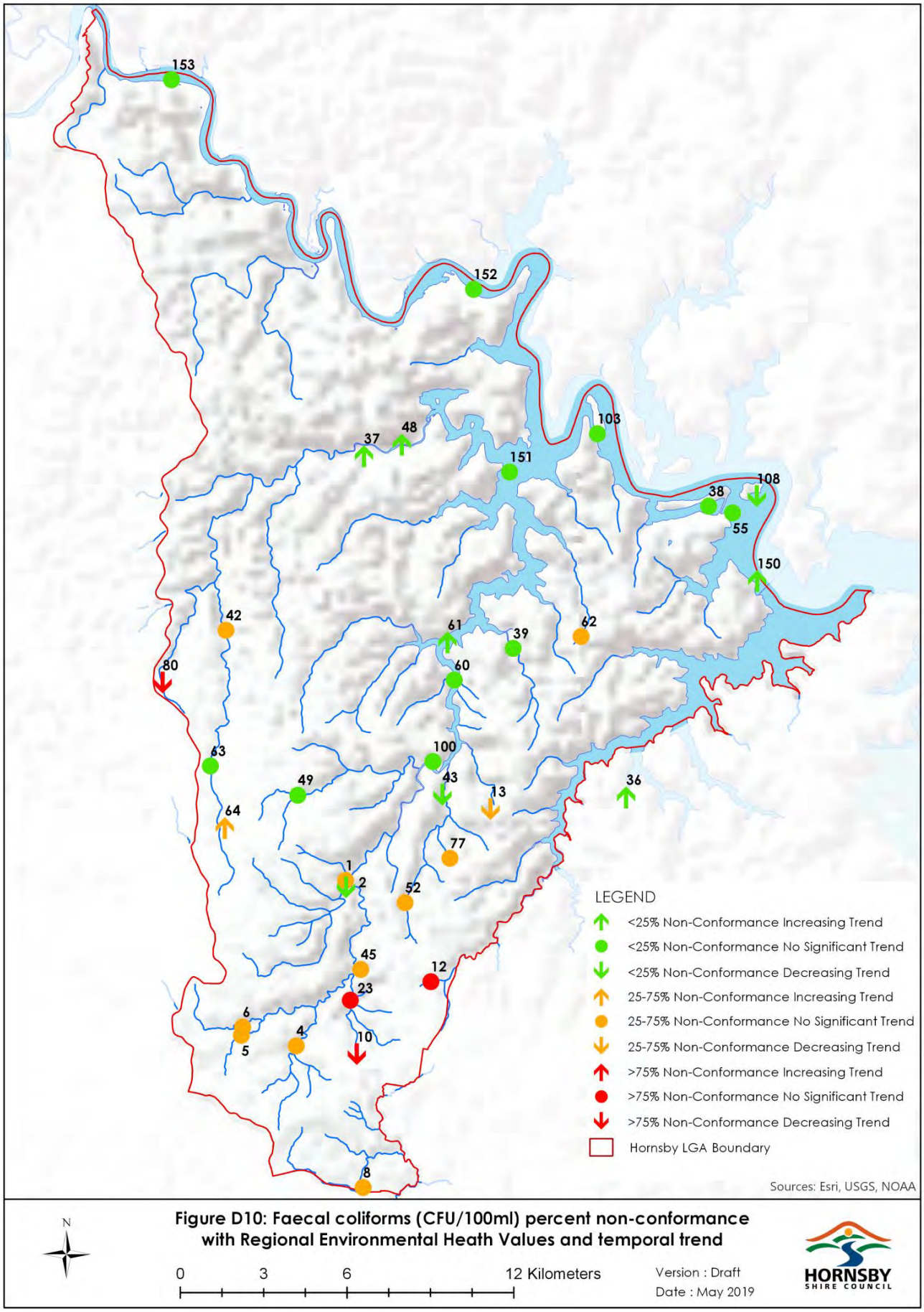

Figure D10: Faecal coliforms (CFU/100ml) percent non-conformance with Regional Environmental Heath Values and temporal trend

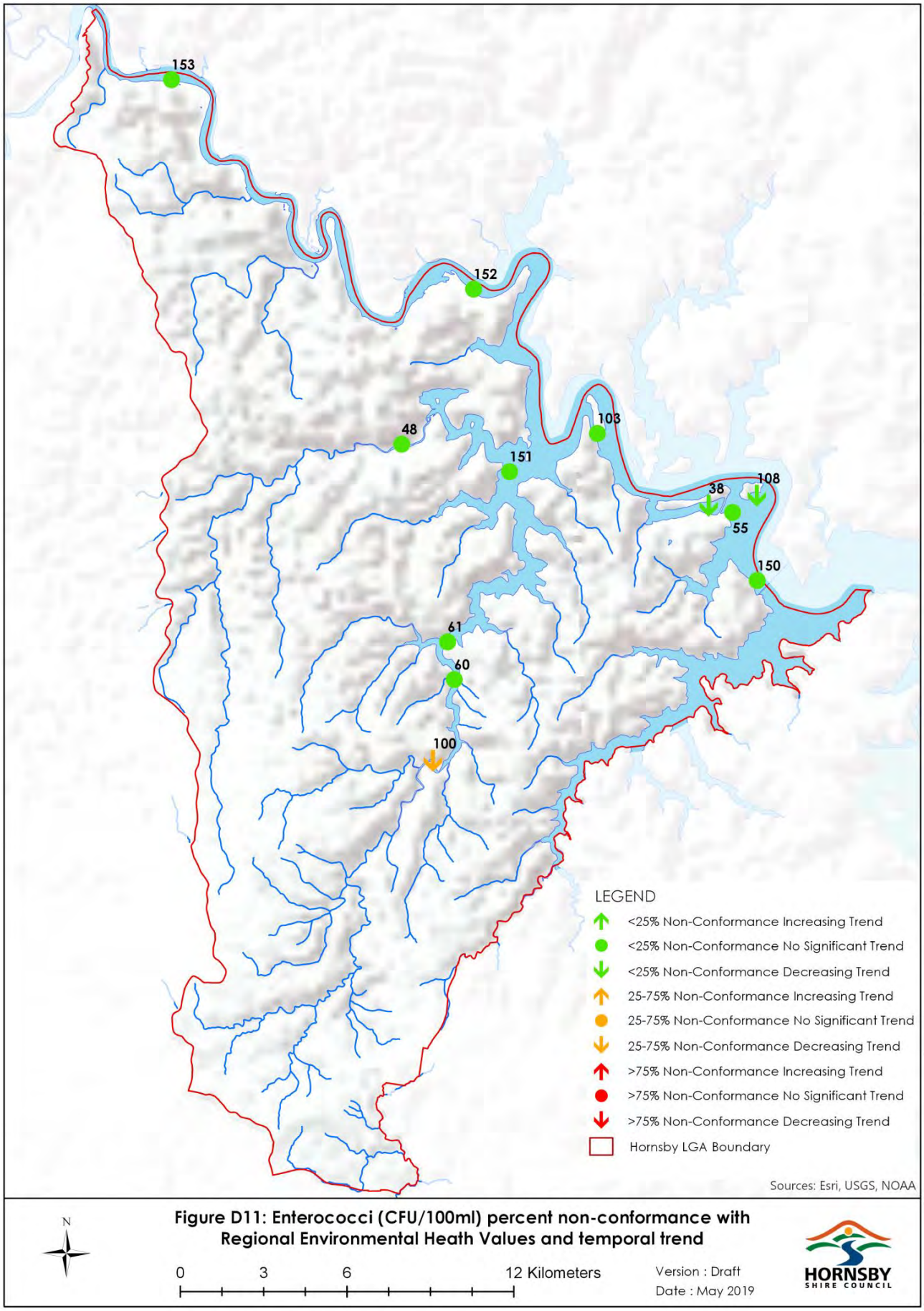

Figure D11: Enterococci (CFU/100ml) percent non-conformance with Regional Environmental Heath Values and temporal trend

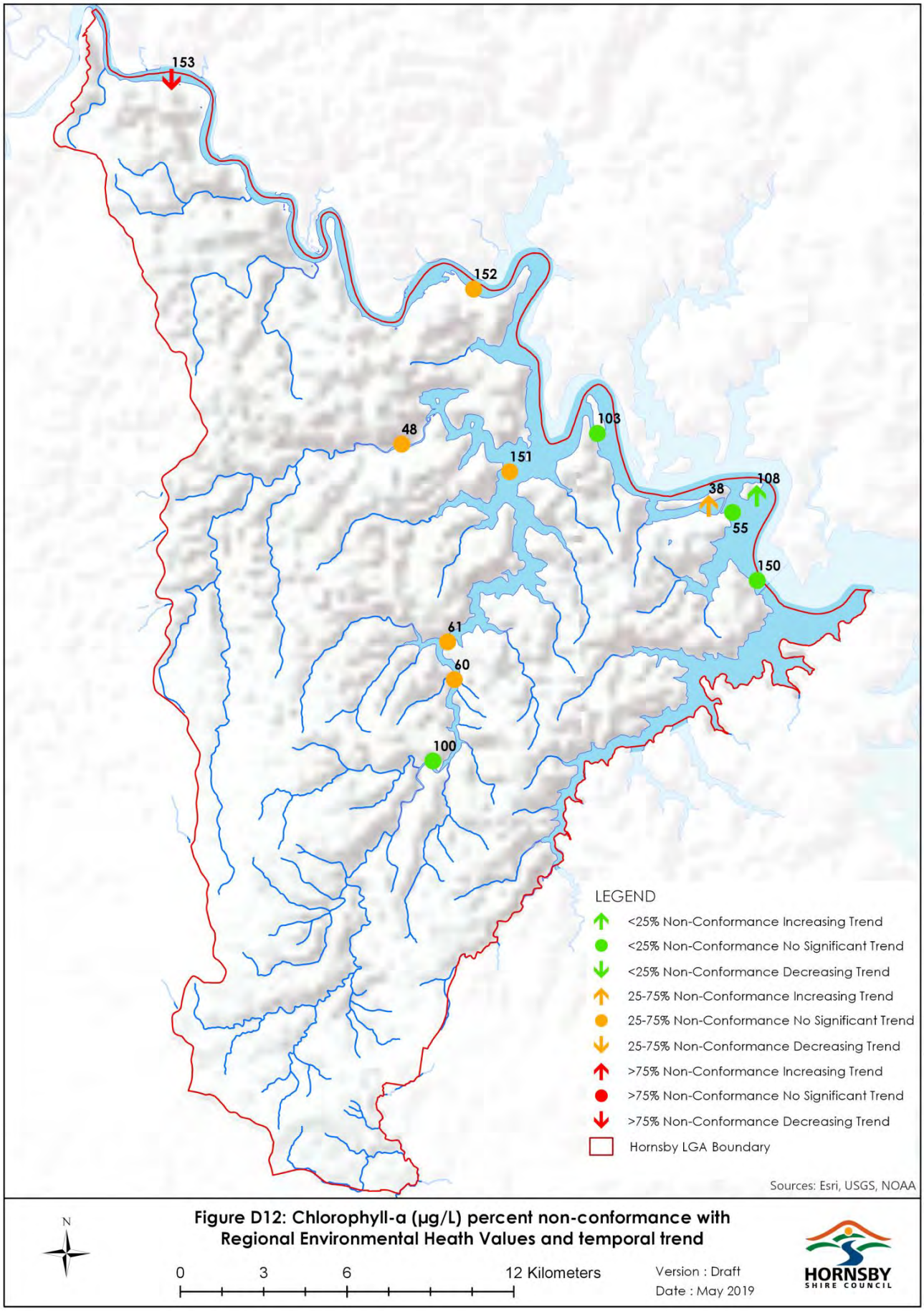

Figure D12: Chlorophyll-a (µg/L) percent non-conformance with Regional Environmental Heath Values and temporal trend

Program Name	Purpose	Freshwater or Estuarine	Site No	Sampling Frequency
Long term	Routine monitoring of water quality to assist in the protection of aquatic ecosystem health.	Freshwater Estuarine	001, 002, 004, 005, 006, 008, 010, 012, 013, 023, 036, 037, 038, 039, 042, 043, 045, 048, 049, 052, 055, 060, 061, 062, 063, 064, 077, 080, 100, 103, 108, 150, 151, 152, 153	Monthly
Ecohealth	Monitoring of water quality, macroinvertebrates, riparian vegetation condition and geomorphological characterisation to assist in managing catchment and waterway health.	Freshwater Estuarine	001, 002, 004, 005, 006, 036, 037, 039, 042, 043, 045, 048, 049, 052, 063, 064, 100, 150, 152, 153	Quarterly
Event	Monitoring to understand the impacts of rainfall events on waterway health.	Freshwater Estuarine	001, 055, 100,	Post rainfall event
Industrial	Monitoring to manage the impacts of industrial land use on waterway health.	Freshwater	010, 012, 013,	Monthly (subject to further review)
Targeted Assessment	Short term monitoring designed to answer a specific question. Analytes, frequency, analysis, reporting and evaluation are fit for purpose.	Freshwater Estuarine	023, 042, 062, 077, 080,	To be determined
Reference	Monitoring to	Freshwater	036, 037,	To be determined
Algae	Monitoring for the management of harmful algae blooms.	Estuarine	060, 061, 100, 150, 151, 152, 153	Variable
Remote	Monitoring undertaken by remotely deployed water quality monitoring stations for the management of estuarine health.	Estuarine	061, 100, 150, 151, 152, 153	Continuous
Recreational	Monitoring to manage risks associated with the recreational use of waterways.	Freshwater Estuarine	055, 100,	Variable

APPENDIX F – Site Specific Recommendations Grouped by Site

Site		Site Specific Recommendations
001	Berowra Ck, Galston Gorge	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment (other than those from the WWTP) – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Investigate the influence of wet-weather events on local conditions
002	Tunks Creek, Galston Gorge	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Protect the bushland and riparian zone in the catchment to maintain buffering – Identify further opportunities for WSUD in the catchment – Educate and collaborate with landholders to minimise impacts from rural activities
004	Berowra Ck, Westleigh	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events – Protect the bushland and riparian zone in the catchment to maintain buffering
005	Pyes Ck, Cherrybrook	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events
006	Georges Ck, Cherrybrook	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate the significance of local impacts and the suitability of the site for catchment health assessment – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients and bacteria in the catchment – Investigate variability in water quality data and the association with rainfall events
008	Devlins Creek, Cheltenham	– Implement stringent sediment and erosion control standards in the catchment – Develop a partnership with Parramatta City Council to collaboratively manage Devlins Creek – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Monitoring to cease at this location and catchment health to be monitored in partnership with Parramatta City Council
010	Larool Ck, Thornleigh	– Investigate sources of nutrients and bacteria in the catchment – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Collaborate with State Government agencies (i.e. EPA) to improve the management of industrial developments – Engage with industry to identify opportunities to reduce sources of pollutants – Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved – Maintain high sediment and erosion control standards
012	Hornsby Ck, Hornsby	– Investigate sources of nutrients and bacteria in the catchment – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Collaborate with State Government agencies (i.e. EPA) to improve the management of industrial developments – Engage with industry to identify opportunities to reduce sources of pollutants – Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved – Maintain high sediment and erosion control standards
013	Sams Ck, Mt Kuring-gai	– Investigate sources of nutrients and bacteria in the catchment – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Collaborate with State Government agencies (i.e. EPA) to improve the management of industrial developments – Engage with industry to identify opportunities to reduce sources of pollutants

		– Review water quality values and objectives relevant to industrial sites and continue monitoring until objectives are achieved – Maintain high sediment and erosion control standards
023	Waitara Creek, Hornsby	– Investigate sources of nutrients and bacteria in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Identify further opportunities for WSUD in the catchment – Conduct targeted monitoring to assess changes following the implementation of any management actions within the catchment
036	Murray Anderson Creek, Ku-ring-gai Chase National Park	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Continued monitoring for local reference conditions – Further investigate the influence of key SE Australian climate drivers on local reference conditions – Review of REHVs and suitability of long-term reference sites using targeted short term reference site data
037	Smugglers Creek, Marramarra National Park	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Continued monitoring for local reference conditions – Further investigate the influence of key SE Australian climate drivers on local reference conditions – Review of REHVs and suitability of long-term reference sites using targeted short-term reference site data
039	Joe Crafts Creek, Berowra Valley Regional Park	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Educate and collaborate with marina operators and boat users to minimise impacts from these activities – Educate and collaborate with riverside residents to minimise impacts from these settlements
042	Colah Creek, Arcadia	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Conduct targeted monitoring to assess changes since the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality) in 2015 – Identify further opportunities for WSUD in the catchment – Continue to collaborate with residents to minimise the impacts of OWMS – Educate and collaborate with landholders to minimise impacts from rural activities – Investigate the significance of local impacts and the suitability of the site for catchment health assessment
043	Calna Ck, Berowra Valley National Park	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Investigate sources of nutrients in the catchment (other than those from the WWTP)
045	Fishponds, Berowra Creek	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment (other than those from the WWTP) – Identify further opportunities for WSUD in the catchment – Continue to collaborate with Sydney Water to improve the management of wastewater – Monitor and assess bacteria levels to identify and manage risks in recreational waters
048	Marramarra Ck, Marramarra National Park	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate sources of nutrients and bacteria in the catchment – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps
049	Still Creek, Galston	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment – Identify further opportunities for WSUD in the catchment
052	Calna Ck, Hornsby Heights	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Identify further opportunities for WSUD in the catchment – Investigate sources of nutrients (particularly TP) and bacteria in the catchment

		– Investigate variability in water quality data and the association with rainfall events
055	Brooklyn Baths, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate the influence of wet-weather events on local conditions – Investigate sources of increasing nutrients in the Hawkesbury River – Monitor and assess bacteria levels to identify and manage risks in recreational waters – Suitability for recreational use to be advised on Council's web-based swimming maps
060	Berowra Waters, Berowra Creek	– Development of a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Continue to collaborate with Sydney Water to improve the management of wastewater – Educate and collaborate with marina operators and boat users to minimise impacts from these activities – Educate and collaborate with riverside residents to minimise impacts from these settlements – Ongoing (response) monitoring to identify and manage risks associated with algal blooms – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Undertake a review of all phytoplankton monitoring data
061	Calabash Point, Berowra Creek	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Continue to collaborate with Sydney Water to improve the management of wastewater – Educate and collaborate with riverside residents to minimise impacts from these settlements – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Undertake a review of all phytoplankton monitoring data
062	Kimmerikong Creek, Cowan	– Conduct targeted monitoring to assess changes since the completion of the Cowan Wastewater Scheme (i.e. improved water quality) in 2013 – Identify further opportunities for WSUD in the catchment
063	Colah Creek, Glenorie	– Ongoing monitoring for catchment health assessment via the Ecohealth program – Investigate sources of nutrients in the catchment – Protect the bushland and riparian zone in the catchment to maintain buffering – Identify further opportunities for WSUD in the upper catchment – Educate and collaborate with landholders to minimise impacts from rural activities
064	Unnamed tributary of Colah creek, Galston	– Conduct targeted monitoring to assess changes since the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality) in 2015 – Identify further opportunities for WSUD in the catchment – Continue to collaborate with residents to minimise the impacts of OWMS – Educate and collaborate with landholders to minimise impacts from rural activities
077	Gleeson Creek, Mount Colah	– Conduct targeted monitoring to assess the impacts of Foxglove Oval leachate on Gleeson Creek – Improve collaborative management of risks from Foxglove Oval legacy landfill – Investigate sources of nutrients and bacteria in the catchment (other than those from the legacy landfill site)
080	Glenorie Creek, Glenorie	– Conduct targeted monitoring to assess the changes since the completion of the Galston and Glenorie Wastewater Scheme (i.e. improved water quality) in 2015 – Identify further opportunities for WSUD in the catchment – Continue to collaborate with residents to minimise the impacts of OWMS – Educate and collaborate with landholders to minimise impacts from rural activities
100	Crosslands Reserve, Berowra Creek	– Monitor and assess bacteria levels to identify and manage risks in recreational waters – Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate the influence of wet-weather events on local conditions – Continue to collaborate with Sydney Water to improve the management of wastewater – Ongoing (response) monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions

		– Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps
103	Milsons Passage, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Educate and collaborate with riverside residents to minimise impacts from these settlements – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the estuary – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Suitability for recreational use to be advised on Council's web-based swimming maps
108	Bradleys Beach, Dangar Island, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Routine monitoring to cease at this location and waterway health to be informed by the Ecohealth program and ongoing remote monitoring probes – Suitability for recreational use to be advised on Council's web-based swimming maps
150	Gunyah Point, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Continue to collaborate with stakeholders for a coordinated approach to the management of risks to local aquaculture and commercial fishing operations – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data
151	Mouth of Marramarra, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Continue to collaborate with stakeholders for a coordinated approach to the management of risks to local aquaculture and commercial fishing operations – Educate and collaborate with riverside residents to minimise impacts from these settlements – Investigate sources of increasing nutrients in the Hawkesbury River – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data
152	Courangra Point, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Continue to collaborate with stakeholders for a coordinated approach to the management of risks to local commercial fishing operations – Educate and collaborate with riverside residents and holiday park operators to minimise impacts from these settlements – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data
153	Laughtondale, Hawkesbury River	– Develop a Coastal Management Program for the coordinated management of the lower Hawkesbury River and estuarine tributaries – Conduct further collaborative research specific to estuarine health and ecological responses – Investigate sources of increasing nutrients in the Hawkesbury River – Continue to collaborate with stakeholders for a coordinated approach to the management of risks to local commercial fishing operations

	– Educate and collaborate with riverside residents and holiday-park operators to minimise impacts from these settlements – Ongoing monitoring to identify and manage risks associated with algal blooms – Ongoing remote monitoring of estuarine conditions – Ongoing monitoring for catchment health assessment via the Ecohealth program – Suitability for recreational use to be advised on Council's web-based swimming maps – Undertake a review of all phytoplankton monitoring data

APPENDIX G – National Water Quality Management Framework

To protect the community values of waterways, the Water Quality Management Framework logically encompasses key requirements for long-term management strategies:

- *good understanding of links between human activity and water/sediment quality*
- *clearly defined community values or uses, including the setting of unambiguous management goals*
- *clearly identified and appropriate water/sediment quality objectives*
- *adoption of cost-effective strategies to achieve water/sediment quality objectives*

(ANZG ,2018)

10 steps to implement the Water Quality Management Framework

APPENDIX H – Risk-based Framework for Considering Waterway Health

The Purpose of the Framework is to:

- *Ensure the community's environmental values and uses for our waterways are integrated into strategic land-use planning decisions*
- *Identify relevant objectives for the waterways that support the community's environmental values and uses, and can be used to set benchmarks for design and best practice*
- *Identify areas or zones in waterways that require protection*
- *Identify areas in the catchment where management responses cost-effectively reduce the impacts of land-use activities on our waterways*
- *Support management of land-use developments to achieve reasonable environmental performance levels that are sustainable, practical, and socially and economically viable.*

(Dela-Cruz, Plk & Wearne, 2017)