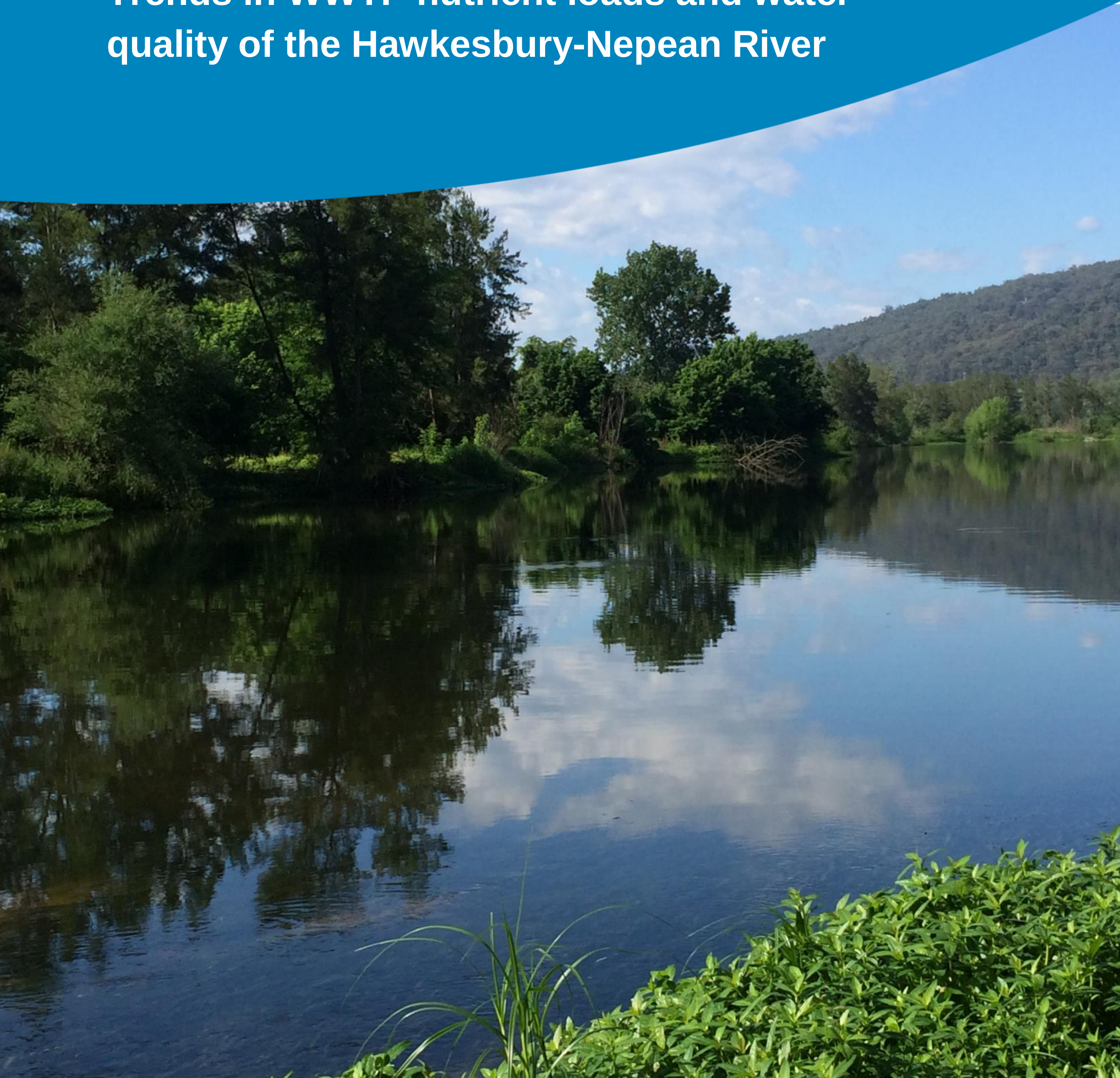
Sewage Treatment System Impact Monitoring Program

Interpretive Report 2016-17

Trends in WWTP nutrient loads and water quality of the Hawkesbury-Nepean River



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Report version: STSIMP Interpretive report 2016-17_revised final to EPA

Cover photo: Winmalee Lagoon (November 2015)

Executive summary

Purpose

A requirement of Sydney Water's Environment Protection Licences (EPLs) is to undertake an ongoing Sewage Treatment System Impact Monitoring Program (STSIMP) to identify and quantify environmental impacts associated with Sydney Water's wastewater services across our area of operations. The program aims to monitor the environment within Sydney Water's area of operations to:

- determine general trends in water quality over time
- monitor Sydney Water's performance
- determine where Sydney Water's contribution to water quality may pose a risk to environmental ecosystems and human health.

The sampling program is designed to provide a longitudinal and spatial dataset that allows the identification of statistically significant changes in water quality or ecosystem health parameters that may be related to discharges from wastewater systems.

The STSIMP generates two types of reports: an annual data report and an interpretive report. The annual data report presents the latest data from the monitoring program with limited interpretation. An interpretive report is compiled every four years to identify and assess water quality and ecological health trends that may be related to Sydney Water's wastewater systems. The report is based on the best available data and scientific understanding of waterway health mechanisms.

This 2016-17 Interpretive Report was compiled to analyse and assess both the long-term (1992-2017) and short-term (post major upgrade) wastewater treatment plant (WWTP) nutrient loads and receiving water quality trends in the Hawkesbury-Nepean catchment. It also explores factors driving change in concentrations of nutrients, chlorophyll-*a* and algae in the river and its tributaries.

Background

The STSIMP interpretive report is prepared every four years to satisfy condition M5.1 of the Environment Protection Licences (EPLs) for Sydney Water's WWTPs. The content of this 2016-17 Interpretive Report was negotiated and agreed with the Environment Protection Authority (EPA).

This year's focus is on the Hawkesbury-Nepean catchment where Sydney Water's 15 inland WWTPs discharge tertiary treated wastewater into the catchment. Comprehensive analysis and interpretation of the long-term WWTP discharge loads and instream water quality concentrations provide an understanding of current river conditions, trends and the influence of WWTPs on water quality. The findings from this report will inform the EPL review process and other catchment management projects.

Over the last 25 years, Sydney Water has implemented a number of improvements at its inland WWTPs to reduce the nutrient loads entering the Hawkesbury-Nepean catchment. This report assesses both long-term (~1992-2017) and short-term (~2011-2017) trends in key nutrient loads (nitrogen and phosphorus) from WWTPs and changes in water quality in the Hawkesbury-Nepean

River and its tributaries, particularly nutrient concentrations and algal growth. It also explores factors that contribute to high nutrients and chlorophyll-*a* concentrations and high algal biomass at 11 key sites. The key sites were selected based on consistent long-term datasets, a history of high nutrient concentrations or algal blooms and their location covering the entire river, and its tributaries where Sydney Water's WWTPs are discharging.

The long-term trend analysis presented in this report covers the last 25 years, from 1992 to 2017. Currently, 15 WWTPs and one Advanced Water Treatment Plant (St Marys AWTP) operate in the Hawkesbury-Nepean River catchment. Previously, an additional 10 WWTPs operated in the catchment, but were progressively decommissioned between 1993 and 2008. Receiving water quality is currently monitored at 14 locations on the main stream of the river from Maldon Weir on the Nepean River to Leets Vale on the Hawkesbury River. Monitoring is also undertaken at six other sites; five in major tributaries (Stonequarry, South, Cattai and Berowra creeks and the Colo River) and at one lagoon (Winmalee) (Figure ES-1).

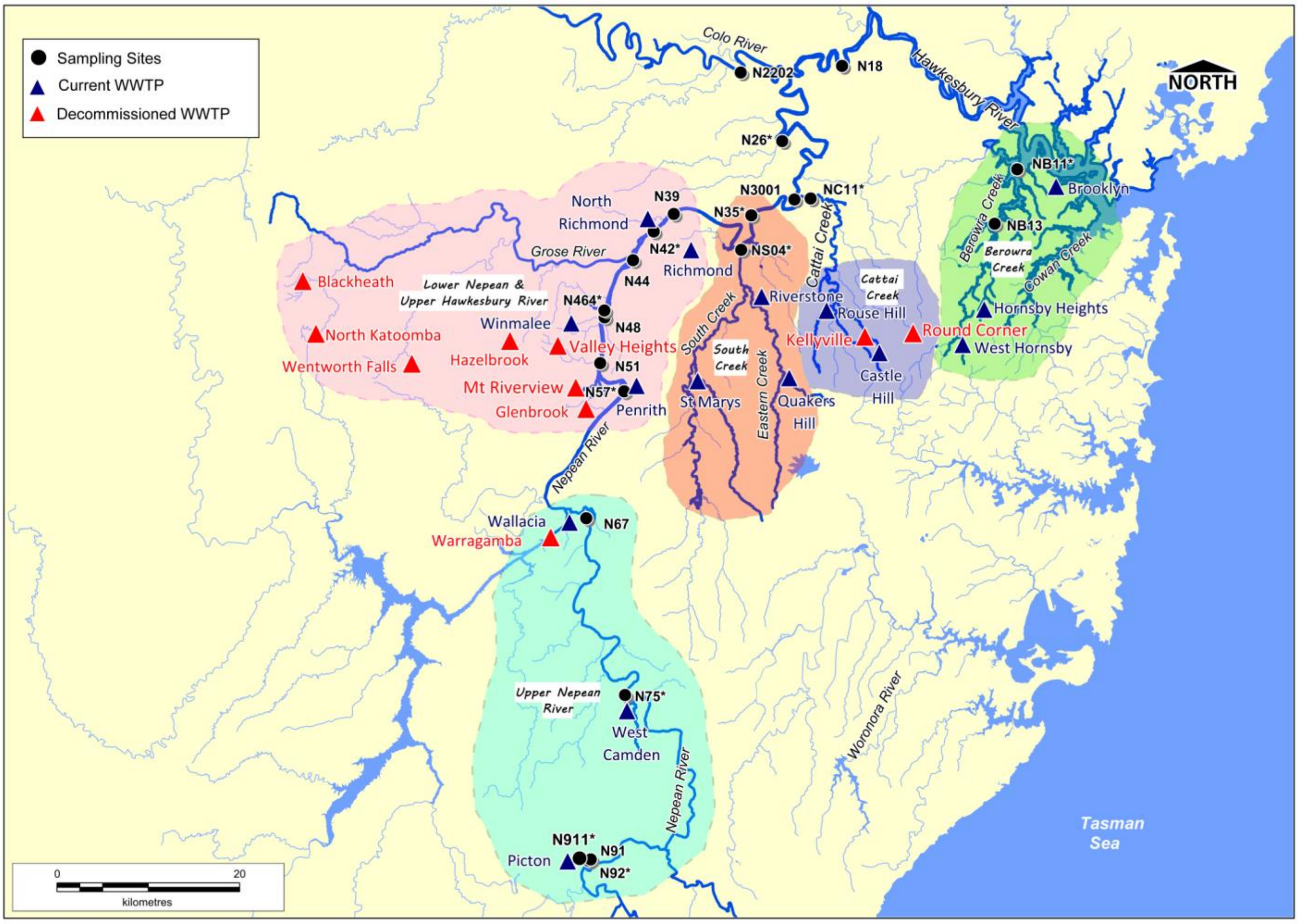

Figure ES-1 Location of Sydney Water WWTPs and water quality monitoring sites; shaded areas are five sub-catchments used to calculate nutrient loads

An appropriate and widely accepted statistical technique, the Seasonal Mann-Kendall Test (Gilbert 1987; McBridge 2005), was used to determine the trends in WWTP nutrient loads in five sub-catchments (Figure ES-1), as well as the total load discharged to the river from these WWTPs. These five sub-catchments are:

- the Upper Nepean River
- the Lower Nepean and Upper Hawkesbury River
- South Creek
- Cattai Creek
- Berowra Creek

The same test was also applied to flow-adjusted water quality data to determine the long-term trend in 13 water quality parameters including nutrients, chlorophyll-*a*, algal biomass and other physico-chemical indicators. Flow-adjusted data enables trends from anthropogenic changes to be identified by excluding the influence of flow or wet weather.

Trend analysis was conducted on the entire 25-year dataset, as well as on subsets before and after major events, such as WWTP upgrades or the introduction of environmental flow releases to the river. As these events heavily influenced or significantly changed the water quality, step trends analysis was conducted. The long-term trend provides a high-level picture, while the trends in the more recent period (or short-term trends) show the current outlook on nutrient loads and instream water quality.

Data for the last six years (2011-2017) were analysed using Spearman Correlation Analysis at the 11 key sites to explore the possible factors influencing the high chlorophyll-*a* and algal biomass. The test assessed the relationship between the site-specific WWTP nutrient loads, flow and actual nutrient concentrations with chlorophyll-*a* and algal biovolume.

Nutrient loads

Long-term trends

- Between 1992 and 2017, the total nitrogen load discharged from Sydney Water's inland WWTPs decreased by 76% and the total phosphorus load decreased by 94% whilst population grew by 73% over the same period in the Hawkesbury-Nepean River catchment

Since 1992, the total nutrient load discharged to the Hawkesbury-Nepean catchment considerably decreased in response to improvements to wastewater treatment processes and the relocation and decommissioning of older WWTPs.

The total nitrogen load consistently decreased from 1992, while the reduction in the phosphorus load was not evident until after 2002 when phosphorus improvement works at WWTPs were completed. At that time, phosphorus was considered the key nutrient responsible for potentially toxic blue-green algal blooms in the lower Hawkesbury River.

While the goal of reducing nutrient loads by improving Sydney Water's WWTPs has been realised, there are localised pockets where the total nitrogen load has increased in the long-term. In the Upper Nepean River and Cattai Creek sub-catchments, the total nitrogen load increased by 57% and 115%, respectively (Table ES-1). The total phosphorus load significantly decreased in four sub-catchments, with Cattai Creek the only sub-catchment where no significant trend in the total phosphorus load was evident. The increase in nutrient loads in the Upper Nepean River and Cattai Creek sub-catchments was likely related to population growth, with a more than 14% increase in population each year between 1992 and 2017. Higher inflows of wastewater entering WWTPs reduces the efficiency of treatment causing higher nutrient concentrations in the discharge.

Table ES-1 Summary of long-term and short-term trends in WWTP nutrient loads

Parameters	Upper Nepean	Lower Nepean and Upper Hawkesbury	South Creek	Cattai Creek	Berowra Creek	Total
Long-term period	1992-2017	1992-2017	1992-2017	1992-2017	1992-2017	1992-2017
Total nitrogen load	[Significant increasing]	[Significant decreasing]	[Significant decreasing]	[Significant increasing]	[Significant decreasing]	[Significant decreasing]
Total phosphorus load	[Significant decreasing]	[Significant decreasing]	[Significant decreasing]	[Insignificant]	[Significant decreasing]	[Significant decreasing]
Short-term period	2008-2017	2011-2017	2011-2017	2009-2017	2005-2017	2011-2017
Total nitrogen load	[Significant increasing]	[Significant increasing]	[Significant increasing]	[Significant increasing]	[Significant increasing]	[Significant increasing]
Short-term period	2009-2017	2011-2017	2011-2017	2011-2017	2005-2017	2011-2017
Total phosphorus load	[Significant increasing]	[Significant decreasing]	[Significant increasing]	[Significant increasing]	[Significant increasing]	[Significant decreasing]

Legend

- Insignificant trend in nutrient load
- Significant decreasing trend in nutrient load
- Significant increasing trend in nutrient load

Short-term trends

- Since 2011, there has been an overall increase in the total nitrogen load discharged to all five sub-catchments, and total phosphorus load to four sub-catchments with the exception of the Lower Nepean/Upper Hawkesbury River sub-catchment. Despite the increasing trends, loads remain within the current Environment Protection Licence load limits and well below pre-1992 figures

The short-term trends in WWTP nutrient loads were determined for the period since the last major WWTP upgrades were completed. The short-term analysis generally covered the 2011 to 2017 period but varied based on respective nitrogen and phosphorus upgrades at WWTPs (Table ES-1).

The increase in nutrient loads since 2011 was likely associated with population growth, which produced increased volumes of wastewater placing stress on the treatment process and decreasing treatment efficiency. The population in the five sub-catchments increased on average by 2% per year in the short-term recent period (range 0.2% to 6.7%). Despite the increased loads, the nutrient concentrations in the discharge were mostly within the specified EPL limits.

Comparison with other sources

- The total nitrogen and total phosphorus loads discharged to the freshwater section of the Hawkesbury-Nepean River from Sydney Water's WWTPs in 2016-2017 were approximately 885 kg/day and 9 kg/day, respectively. This represents approximately 27.7% and 1.5% of the total nitrogen and total phosphorus loads from all agricultural activities[1]

Sydney Water's WWTP nutrient loads discharged to the Hawkesbury-Nepean catchment are notably less than those from agricultural activities and other diffuse sources. However, the WWTP discharge is constant and can form the majority of flow in some waterways during dry weather. Other catchment associated inputs are sporadic and mostly weather dependent. Based on gross estimates from limited monitoring data, it is estimated that approximately 86% of the total nitrogen load from WWTPs is in a readily available form (dissolved inorganic nitrogen) for photosynthesis by algae and macrophytes. Approximately 51% of the total phosphorus load is in a readily available form (soluble reactive phosphorus).

Water quality

The water quality of the Hawkesbury-Nepean River varied considerably between the upstream and downstream reaches and tributaries in 2016-17. The overall water quality of the upstream Nepean River at the Maldon Weir reference site was good for many of the parameters monitored. This site receives environmental flow releases from upstream water storage dams in protected drinking water catchments. The water quality deteriorated with increased distance downstream where the river widens and receives nutrient rich runoff from urbanised catchments and discharges from multiple WWTPs. The water quality of the lower Hawkesbury River and the South Creek confluence was comparatively poorer, with high concentrations of nutrients, chlorophyll-*a* and algal biomass. The median chlorophyll-*a*, total nitrogen and total phosphorus concentrations in these sub-catchments were highest compared to other parts of the river and above the Healthy River Commission (HRC 1998) objectives. Water quality was variable in the estuary as it is influenced by tidal flushes. The median chlorophyll-*a* at Leets Vale and the two estuarine Berowra Creek sites were also above the HRC 1998 objectives. Typically, water quality in the Colo River was good due to the large pristine catchment with minimal anthropogenic inputs.

Long-term trends

- Total nitrogen, dissolved inorganic nitrogen, total phosphorus and filterable total phosphorus concentrations significantly decreased between 1992 and 2017 at most monitoring sites (13% to 72% decrease)
- Despite the reduced nutrient loads from WWTPs since 1992 and the reduced instream nutrient concentrations, chlorophyll-*a*, a key indicator of algal biomass, showed little change

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[1] based on agricultural load calculations by the NSW Office of Environment and Heritage (Haine *et al* 2011)

The long-term nutrient load reduction from Sydney Waters WWTPs as well as other government initiatives to reduce diffuse run-off to the river, is reflected in reduced nutrient concentrations in the downstream river and its tributaries. Total nitrogen, dissolved inorganic nitrogen, total phosphorus and filterable total phosphorus have decreased significantly over the long-term in the order of 13% to 72% at most monitoring sites. Localised long-term increasing trends in total phosphorus and/or filterable total phosphorus concentrations were identified in the Nepean River at Penrith Weir, Hawkesbury River at Leets Vale and Berowra Creek off Square Bay (Table ES-2).

Despite the significant long-term reduction in nutrient concentrations, chlorophyll-*a*, a key indicator of algal biomass, showed little change at most monitoring sites. A long-term decreasing trend in chlorophyll-*a* was identified at two sites (Winmalee Lagoon outflow and Hawkesbury River at Sackville Ferry), while a significant increasing trend was detected at three sites (Nepean River at Penrith Weir, Hawkesbury River at Leets Vale and Berowra Creek off Square Bay). These three sites also showed increasing trends in total phosphorus and/or filterable total phosphorus concentrations. Blue-green algal biomass significantly decreased in the lower Hawkesbury-River at Sackville Ferry where frequent algal blooms have historically occurred.

Significant changes in other physico-chemical water quality parameters were also identified (Table ES-2). In summary:

- there was an increasing long-term trend in conductivity at three tributary sites (Stonequarry Creek, South Creek and the Colo River), with two other sites (Nepean River at Smith Road and Hawkesbury River at Leets Vale) showing decreasing trends
- Seven of the 21 sites showed a significant long-term decline in pH
- Water temperature changed over the long-term period with 10 out of the 21 sites showing an increasing trend
- Long-term water clarity improved as indicated by decreased turbidity at 10 sites

Short-term trends

- Since 2011, there has been an increase in total nitrogen and dissolved inorganic nitrogen concentrations at approximately half the river and tributary monitoring sites. Total phosphorus and filterable total phosphorus concentrations remained static or decreased
- The increasing nitrogen concentration have shown no influence on chlorophyll-*a* concentrations, with chlorophyll-*a* decreasing at 40% of sites

Since 2011, increased nitrogen loads in WWTP discharge were aligned with increased total nitrogen concentrations at half of the monitoring sites (10 out of 20 sites) and increased dissolved inorganic nitrogen at seven sites (Table ES-3). In contrast, total phosphorus and filterable total phosphorus concentrations decreased at some upstream sites (between Stonequarry Creek and North Richmond). The decrease in total phosphorus loads from WWTP discharges aligned with the decrease in total and/or filterable phosphorus concentrations at five sites of the Upper Nepean River and Lower Hawkesbury-River sub-catchment. The increased total phosphorus loads in the WWTP discharge was not reflected in the phosphorus concentrations at three sites of the Upper Nepean

River sub-catchment. This may indicate the benefit of other catchment measures and/or already low phosphorus concentrations in the WWTP discharge.

Table ES-2 Summary of long-term water quality trends from upstream to downstream sites along the Hawkesbury-Nepean River and tributaries

Site	Key site	Chlorophyll-*a*	Total algal biovolume	Blue-green algal biovolume	Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Filterable total phosphorus	Conductivity	pH	Dissolved oxygen	Dissolved oxygen saturation	Temperature	Turbidity
N92: Maldon Weir	Key site	Insignificant	Increasing #	Increasing #	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Increasing	Increasing	Insignificant	Insignificant	Decreasing
N911: Stonequarry Ck.	Key site	Insignificant	Insufficient data	Insufficient data	Decreasing	Insignificant	Decreasing	Decreasing	Increasing	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing
N91: Maldon Br		Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Increasing	Insignificant	Insignificant	Insignificant	Decreasing
N75: Sharpes Weir	Key site	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Increasing	Decreasing
N67: Wallacia Br		Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing
N57: Penrith Weir	Key site	Increasing	Increasing #	Insignificant	Insignificant	Insignificant	Increasing	Increasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
N51: Op. Fitzgeralds Ck		Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Increasing
N48: Smith Road		Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Increasing	Insignificant
N464: Winmalee Lagoon	Key site	Decreasing	Increasing #	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Increasing	Decreasing
N44: Yarramundi Br		Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Increasing	Increasing	Increasing	Increasing	Decreasing
N42: North Richmond	Key site	Insignificant	Insignificant	Insignificant	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
N39: Freemans reach		Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
NS04: South Ck	Key site	Insignificant	Increasing #	Insignificant	Decreasing	Decreasing	Decreasing	Decreasing	Increasing	Insignificant	Increasing	Insignificant	Insignificant	Decreasing
N35: Wilberforce	Key site	Insignificant	Increasing #	Insignificant	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing
NC11: Cattai Ck	Key site	Insignificant	Increasing #	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Increasing
N3001: Off Cattai SRA		Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing	Increasing	Decreasing
N26: Sackville Ferry	Key site	Decreasing	Increasing #	Decreasing ##	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant
N2202: Colo R.		Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Insignificant	Increasing	Decreasing	Decreasing	Decreasing	Increasing	Insignificant
N18: Leets Vale		Increasing	Insufficient data	Insufficient data	Insignificant	Decreasing	Insignificant	Increasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Increasing
NB11: Berowra Ck off Square Bay	Key site	Increasing	Insignificant	Insignificant	Decreasing	Decreasing	Decreasing	Increasing	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Insignificant
NB13: Berowra Ck Calabash Bay		Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Insignificant

Legend

- Insignificant trend for parameter
- Significant decreasing trend for parameter
- Significant increasing trend for parameter
- Insufficient data or not a key site
- Key site

\# Increasing trends include error due to algal samples not counted for low chlorophyll-*a* samples

\## Decreasing trend represents much stronger trend as algal counts were not performed on low chlorophyll-*a* samples

Table ES-3 Summary of short-term water quality trends from upstream to downstream sites along the Hawkesbury-Nepean River and tributaries

Site	Chlorophyll-*a*	Total algal biovolume	Blue-green algal biovolume	Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Filterable total phosphorus	Conductivity	pH
N92: Maldon Weir									
N911: Stonequarry Ck.									
N91: Maldon Br									
N75: Sharpes Weir		#							
N67: Wallacia Br									
N57: Penrith Weir									
N51: Op. Fitzgeralds Ck									
N48: Smith Road									
N464: Winmalee Lagoon									
N44: Yarramundi Br									
N42: North Richmond									
N39: Freemans reach									
NS04: South Ck									
N35: Wilberforce									
NC11: Cattai Ck									
N3001: Off Cattai SRA									
N26: Sackville Ferry									
N2202: Colo R.									
N18: Leets Vale									
NB11: Berowra Ck off Square Bay									
NB13: Berowra Ck Calabash Bay									

Legend

- Insignificant trend for parameter
- Significant decreasing trend for parameter
- Significant increasing trend for parameter
- Insufficient data or not a key site
- Key site
- \# Increasing trends include error due to algal samples not counted for low chlorophyll-*a* samples

Chlorophyll-*a* concentrations in the Hawkesbury-Nepean River decreased in the short-term despite increased nitrogen concentrations at many sites. This occurred at eight sites from the upper Nepean River (Sharpes Weir) to the Hawkesbury River at Sackville Ferry (Table ES-3). Some of these sites also had decreasing phosphorus concentrations. The environmental flow releases from mid-2010 may have contributed to the improved chlorophyll-*a* concentrations and algal biomass, especially at the upper Nepean River sites.

Significant short-term changes (~2011-2017) in some physico-chemical water quality parameters included an increasing trend in conductivity at eight sites and decreased pH at 12 sites (Table ES-3).

Factors contributing to high nutrients, chlorophyll-*a* and algal biomass

- Between 2011-2017 there were no significant correlations between the site-specific WWTP nitrogen loads and downstream nitrogen concentrations at most sites. However, WWTP phosphorus loads correlated with instream phosphorus concentrations, despite contributing a small proportion compared to loads from other catchment sources
- Flow was identified as the key driver controlling algal biovolume and chlorophyll-*a* concentrations at nine of the 11 key monitoring sites ie flow was negatively correlated with the chlorophyll-*a* concentrations and/or algal biovolume demonstrating a wash-out during high flow conditions and algal growth during static low flow conditions

Statistical analysis using the Spearman Correlation Analysis on the 2011-2017 dataset revealed variations in water quality, notably, chlorophyll-*a* in relation to other influencing factors.

The relationship between the nutrient loads from Sydney Water's WWTPs and downstream nutrient concentrations was variable. There was no correlation between nitrogen concentrations with WWTP nitrogen loads at seven out of the 10 sites. This suggests other possible sources of nitrogen from the catchment are influencing nitrogen concentrations at these sites. In contrast, WWTP phosphorus loads were found to be positively correlated with the instream phosphorus concentrations at the majority of sites (six out of 10), despite the WWTPs providing a small proportion of phosphorus compared to other catchment sources.

The nutrient versus chlorophyll-*a* and/or algal biomass relationship gave a negative correlation at many sites from the upper Nepean River at Maldon Weir to the Hawkesbury River at Sackville Ferry. This negative correlation was much stronger for dissolved inorganic nitrogen, chlorophyll-*a* concentrations and/or algal biovolume indicating probable utilisation of nitrogen from other non-available sources or as an unmeasured continuous supply.

Total phosphorus and/or filterable total phosphorus correlated positively with chlorophyll-*a* and/or algal biovolume at three sites, namely Stonequarry Creek, Berowra Creek and the Hawkesbury River at North Richmond. At Berowra Creek, chlorophyll-*a* also correlated positively with the total nitrogen. These sites have high instream nutrients available for algal growth.

Seasonality in chlorophyll-*a*, algal biovolume and nutrient concentrations, especially dissolved inorganic nitrogen, was evident at most sites. Chlorophyll-*a* and algal biovolume positively correlated with water temperature, while total nitrogen and/or dissolved inorganic nitrogen concentrations negatively correlated with water temperature. This was expected as algal growth is more prevalent in warmer weather, utilising long day light hours. In contrast, lower water temperatures and shorter day light hours cause nitrogen to remain in the water column due to less uptake.

The influence of high flows on downstream nutrient concentrations showed a positive correlation at most sites. That is, diffuse runoff in response to rainfall is driving the elevated levels of nutrients at many sites. The Winmalee Lagoon was the only exception where a negative correlation was found between the flow and total nitrogen/dissolved inorganic nitrogen, indicating an influence of nitrogen discharged from Winmalee WWTP.

Way forward

Sydney Water has consistently complied with the vast majority of EPL conditions on wastewater discharge volumes, nutrient concentrations and overall loads to the Hawkesbury-Nepean catchment. However, since 2011 there has been an increase in nutrient loads from some WWTPs, especially for total nitrogen. This is likely due to increasing population pressures for many sites. The rapid population growth planned for the catchment over the next 40 years means that these pressures, and nutrient loads, are likely to increase.

Population growth will impact many other sources of nutrients in the catchment, not just wastewater discharges. The future of the Hawkesbury Nepean River therefore requires a 'whole of catchment' approach to nutrient management that will integrate water cycle management solutions.

To assist in planning for growth we need robust scientific evidence to inform management decisions and protect the environment. The current STSIMP is limited in its ability to discern the impact of wastewater discharge from diffuse sources. Sydney Water is reviewing the ability of the current monitoring plan to target the impact of wastewater discharge on the environment, and considering new emerging technologies. Improved monitoring data, supported by the NSW Government Hawkesbury Nepean Model, will enable evidence-based decisions to protect the iconic Hawkesbury-Nepean River.

Contents

List of figures

List of tables

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1 Introduction

1.1 Background

The Hawkesbury-Nepean River is one of the longest coastal rivers in Eastern Australia and its catchment covers approximately 21,400 km^2. The catchment provides a major source of drinking water for 4.8 million people living across Sydney, the Blue Mountains and the Illawarra. It also supports a diverse range of industries including agriculture, mining, recreation and tourism. The long stretches of the river are ideal for recreational uses such as swimming, water skiing, canoeing and fishing.

The river is sustained by flows from its catchment via multiple tributaries along the river, spilling over or controlled releases (environmental flows) from upstream water storages and regular discharges of treated wastewater from multiple wastewater treatment plants.

Historically there have been concerns and media coverage about the deteriorating water quality of the Hawkesbury-Nepean River due to algal blooms and excessive macrophyte growth (Sun Herald 1992, Sydney Morning Herald 1993, Sydney Morning Herald 1994; Sydney Morning Herald 2003, Sydney Morning Herald 2004, Industry and Investment 2009). In recent years, multiple government agencies, including Sydney Water, along with private stakeholders have been working collaboratively to reduce the nutrient loads and improve the water quality of the river (OEH 2009a, WaterNSW 2013).

Algal blooms and excessive macrophyte growth are direct consequences of a combination of river morphology and excessive nutrients entering the river system from various diffuse and point sources. The main diffuse sources include runoff from agriculture and urban areas, while the main point sources include wastewater treatment plant discharges, agricultural waste, council swimming pool backwash effluent and colliery waste.

Sydney Water operates 15 inland wastewater treatment plants (WWTPs) and one Advanced Water Treatment Plant (St Marys AWTP) in the Hawkesbury-Nepean River catchment. For simplicity, these are called WWTPs here after in this document. In 2016-17, an average of 184 ML/day of treated wastewater (including highly treated recycled water) was discharged daily into the river and its tributaries from these WWTPs. Hawkesbury City Council also operate two WWTPs that discharge to the river near Windsor. While the overall load of nutrients discharged from WWTPs is small compared to diffuse runoff, they provide a continuous source of nutrients in dry weather when other sources of pollutants are sporadic or weather dependent.

Since the early 1990's, Sydney Water has invested heavily in a series of improved wastewater treatment and operational strategies to reduce the nutrient loads from its wastewater activities into the Hawkesbury-Nepean River catchment. The benefit of these strategies has been a significant decrease in overall nutrient loads from Sydney Water operational activities to the river. This is due to improved wastewater treatment processes, the production of recycled water and decommissioning of poor performing WWTPs. A previous case study on long-term trend analysis demonstrated total nitrogen and total phosphorus loads from Sydney Water's wastewater discharges to the river decreased significantly, 60 to 90%, between 1994 and 2011 (Sydney Water 2012). That study also found that total nitrogen and total phosphorus concentrations at key water quality sites decreased by about 40 to 60%, and dissolved inorganic nitrogen by more than 80%. However, chlorophyll-*a* showed only a 25% reduction at key downstream Hawkesbury River sites between 1994 and 2011.

The ongoing wastewater monitoring program indicated a reverse trend in wastewater discharge quality in more recent years at some WWTPs resulting in increased nutrient loads to the river. Total nitrogen concentrations in the discharge from seven inland WWTPs increased significantly between 2007 and 2016 (Sydney Water 2016). However, the water quality and stream health data did not show conclusive evidence of the impact these increased nutrients concentrations and loads had.

This detailed study was conducted to explore both the long-term and short-term trends in Sydney Water's WWTP nutrient loads and water quality of the Hawkesbury-Nepean River. The study also aimed to interpret the site-specific conditions with respect to wastewater related nutrient loads and downstream water quality especially in terms of nutrients, chlorophyll-*a* and algal biomass.

1.2 Purpose

Sydney Water undertakes an ongoing Sewage Treatment System Impact Monitoring Program (STSIMP) to identify and quantify environmental impacts associated with Sydney Water's wastewater services across our area of operations. This program is a requirement of our environment protection licences (EPLs) but is also a valuable input to long term wastewater servicing strategies.

The sampling program is designed to provide a longitudinal and spatial dataset that allows the identification of statistically significant changes in water quality or ecosystem health parameters that may be related to discharges from wastewater systems. Adverse trends may be further investigated through bespoke sampling campaigns that are specifically designed to identify the factors that are contributing to the issue and the relative impact from wastewater systems.

The STSIMP generates two types of reports: an annual data report and an interpretive report. The annual data report presents the latest data from the monitoring program with limited interpretation. An interpretive report is compiled every four years to satisfy EPL condition M5.1. This report documents a contemporary assessment of environmental impacts that may be related to Sydney Water's wastewater systems. The report is based on the best available data and scientific understanding of waterway health mechanisms.

The content of the 2016-17 interpretive report was negotiated and agreed with the Environment Protection Authority (EPA). This year's focus was on the Hawkesbury-Nepean River where all inland WWTPs continuously discharge tertiary treated wastewater. In addition to this, the catchment is subject to a wide range of diffuse pollution sources. A comprehensive analysis and interpretation of the long-term dataset will enable Sydney Water to understand the current conditions, trends and potential influence of wastewater discharge on downstream water quality. The findings from this report are intended to inform the EPL review process and other catchment management projects.

This 2016-17 interpretive report was compiled to analyse and assess both the long-term (~1992-2017) and short-term (~2011-2017) WWTP nutrient loads and receiving water quality trends in the

Hawkesbury-Nepean catchment. It also explores factors driving changed concentrations of nutrients, chlorophyll-*a* and algal biomass in the river and its tributaries.

1.3 Aim

The aim of this assessment is to understand how the implementation of Sydney Water's wastewater strategies has influenced the nutrients, chlorophyll-*a* and algal condition of the Hawkesbury-Nepean River. In-order to achieve this key aim, the following specific tasks were carried out:

- briefly assess the current spatial trends in nutrient loads discharged from Sydney Water's WWTPs operating in the Hawkesbury-Nepean River catchment
- determine the long-term trends in nutrients loads from these WWTPs over the last 25 years and assess the benefit of past capital programs
- determine the short-term trends in WWTP nutrient loads for the period since the last major WWTP upgrades were completed
- briefly summarise the longitudinal variation in current water quality along the Hawkesbury-Nepean River and selected tributaries
- determine the long-term and short-term trends in water quality at all current monitoring sites of the river and it's tributaries
- assess the long-term performance of each site and identify the potential reasons for differences between sites
- explore possible factors influencing the occurrences of high chlorophyll-*a* and algal blooms at selective sites of the river and tributaries

2 Monitoring program and methods

2.1 Monitoring programs

This study used data collected under multiple current and historical monitoring programs.

Environment Protection Licences (EPL) for each WWTP and St Marys AWTP detail specific monitoring requirements for discharge volume and discharge quality in terms of key nutrients, suspended solids, faecal indicator bacteria etc. A comprehensive monitoring program is in place to comply with the EPLs and routinely collect data for these components (Sydney Water 2016a).

The STSIMP is another core monitoring program which measures the impacts of Sydney Water's wastewater operations on the environment (Sydney Water 2010). It details monitoring activities and methods for all catchments in Sydney Water's area of operations. The STSIMP Hawkesbury-Nepean sub-program collects a range of physico-chemical parameters including nutrients, chlorophyll-*a* and algal species data (only for samples when chlorophyll-*a* is greater than 7 µg/L) from 21 monitoring sites along the river and its tributaries.

The STSIMP succeeded the earlier Environmental Indicators Monitoring Program (EIMP, Sydney Water 1995) which had similar broad objectives. It ran consistently for a period of 14 years from July 1994 to June 2008. Under this program, algal species were determined for samples where the chlorophyll-*a* exceeded 10 µg/L.

The water quality of the Nepean River at the North Richmond Water Filtration Plant (WFP) offtake is collected routinely under a separate monitoring program to assess the suitability of raw water prior to treatment for use as potable water (Sydney Water 2017). Monitoring at this site is conducted weekly with samples analysed for algal species regardless of chlorophyll-*a* concentrations.

Sydney Water has also conducted multiple site-specific monitoring programs in relation to capital work projects such as WWTP amplification or upgrades, the Replacement Flows Program and Pollution Reduction Programs.

2.2 Monitoring sites and frequency of monitoring

Fifteen WWTPs and the St Marys AWTP are currently operating and discharge into the Hawkesbury-Nepean River catchment. An additional 10 WWTPs discharged into the catchment in the past, but were progressively decommissioned from 1993 to 2008. The locations of these WWTPs is shown in Figure 2-1. A complete list of currently and historically operating WWTPs discharging into the Hawkesbury-Nepean catchment since 1992, with information on discharge locations, operating history and data availability is included Appendix B (Table B-1).

Treated or partially treated wastewater discharge volumes from each WWTP was monitored or currently being monitored continuously by *in-situ* electronic data loggers. Nutrient concentrations in the treated wastewater are measured every six days on a 24-hour composite sample collected from the discharge point. Additional nutrient data was also included from non-routine monitoring, with monitoring frequencies as low as daily.

Sydney Water's water quality monitoring of the Hawkesbury-Nepean River is generally focused on areas where Sydney Water's WWTPs are discharging. Therefore, there are large stretches of the river and its tributaries where monitoring does not occur. This makes evaluation of other catchment influences on river water quality more challenging.

The river water quality is currently monitored at 14 sites from Maldon in the upper Hawkesbury-Nepean River, to Leets Vale in the lower Hawkesbury-Nepean River. An additional six sites are monitored from five major tributaries (Stonequarry, South, Cattai and Berowra creeks and the Colo River) and at one lagoon (Winmalee). The locations for all sites are shown in Figure 2-1 with further site details such as description, significance, data history etc. listed in Appendix B (Table B-2).

The current water quality monitoring frequency under the STSIMP is three weekly. Prior to July 2008 under the EIMP, monitoring frequency was at four weekly intervals.

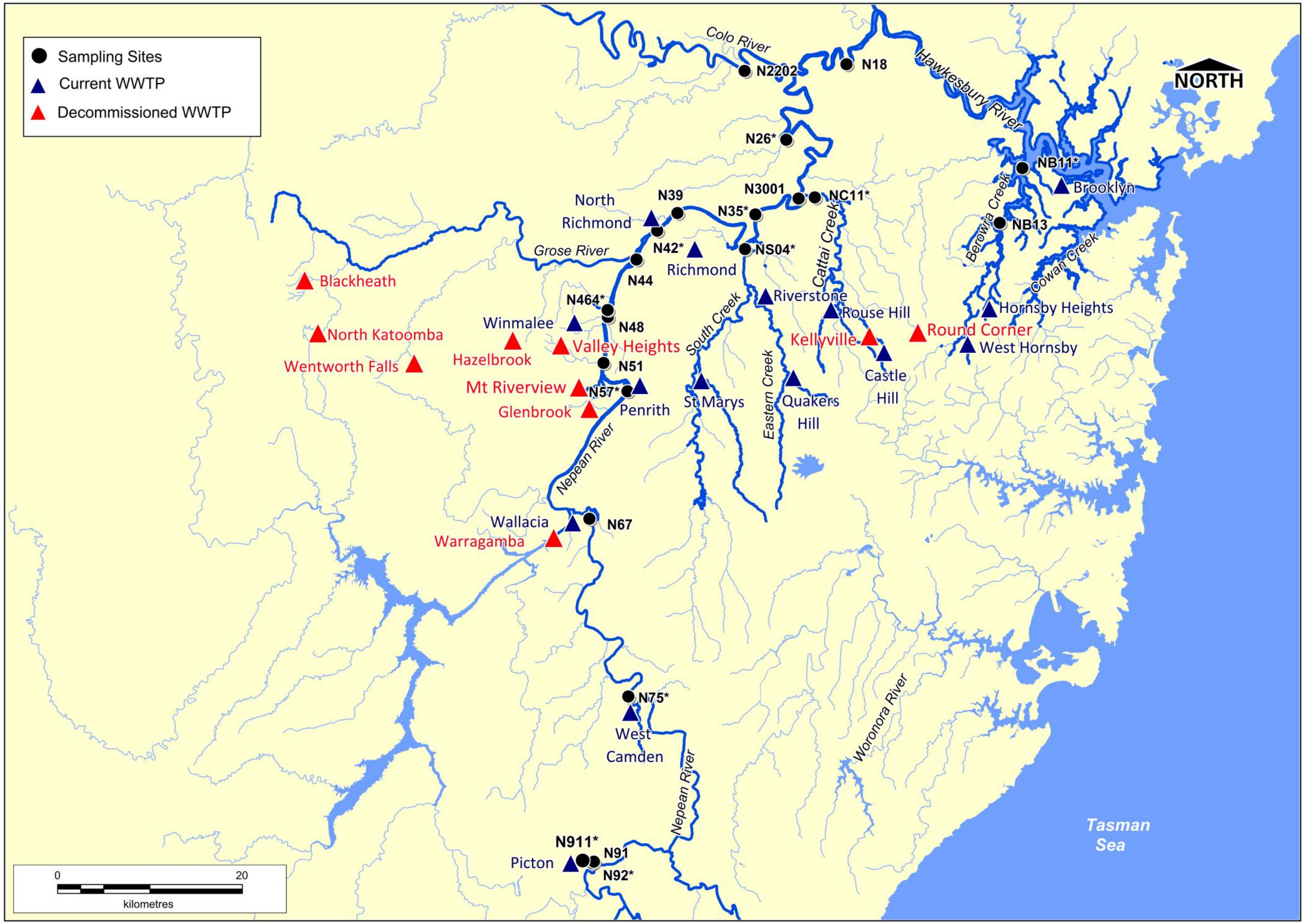
Daily flow data (KL/day) from 14 *in-situ* hydrometric monitoring stations in the Hawkesbury-Nepean River catchment was used for this study (Appendix B: Figure B-1). Six of these stations are currently owned and operated by WaterNSW, further details about these stations are included in Appendix B (Table B-3).

2.3 Analytes and methods of measurement

The treated wastewater is analysed for a variety of pollutants as specified in the EPL for each WWTP. For this study, nutrients such as total and dissolved available forms of nitrogen and phosphorus were considered as key parameters. A list including the details of analytical method for these analytes are presented in Appendix B. (Table B-4). Only total nitrogen and total phosphorus concentrations were analysed consistently for all WWTPs throughout the period (1992-2017). There were large gaps in data for ammonia nitrogen, oxidised nitrogen and soluble reactive phosphorus.

The STSIMP collects duplicate water quality samples to minimise the local variability (Appendix B: Table B-5). Field measurements of conductivity, turbidity, pH, dissolved oxygen, dissolved oxygen saturation and temperature are mostly taken on a single sample/location at each sampling point (Appendix B: Table B-5). As stated previously, algal biovolume and species count data was not continuous as this analysis was chlorophyll-*a* dependent.

The earlier EIMP also followed the same sampling methodology, that is, collected duplicate samples from each site for all the analytes that are monitored currently. The other non-routine programs usually collect duplicate samples from each site but are composited into a single sample for analysis.



* Key sites for this study

Figure 2-1 Location of Sydney Water WWTPs and water quality monitoring sites

3 Data analysis methods

3.1 Spatial trends in nutrient loads

3.1.1 Preparation of data

Data collected between July 2016 and June 2017 was used to understand the variability in nutrient loads currently discharged from Sydney Water's WWTPs into the Hawkesbury-Nepean River catchment. Total nitrogen and total phosphorus concentrations are monitored at all 16 WWTPs. Ammonia nitrogen, oxidised nitrogen and soluble reactive phosphorus were monitored non-routinely at several WWTPs for various ongoing pollution reduction programs (PRP) or capital works projects. Considering the importance of available nitrogen to plant growth, an additional variable, dissolved inorganic nitrogen which is the sum of ammonia nitrogen and oxidised nitrogen concentrations was derived.

To estimate daily nutrient loads, the every 6th day nutrient concentration was used to patch data for the five preceding days, therefore assuming the concentration remained stable during these non-monitoring days. The daily total discharge volume for each WWTP was created by combining the regular treated discharge volume with the partially treated discharge volume (if any).

3.1.2 Calculation of nutrient loads

The daily nutrient loads (total nitrogen, dissolved inorganic nitrogen, total phosphorus and filterable total phosphorus) for each WWTP were determined by using following equation:

Nutrient load (kg/day) = [(c*d)/1000)]

where: c = concentration of nutrients (mg/L)

d = total discharge volume (KL/day)

The yearly median value for each WWTP was regarded as the yearly nutrient load.

Nutrient loads for the different sections of the Hawkesbury-Nepean River and its major tributaries were calculated by combining loads from multiple WWTPs grouped in the following sub catchments:

- Upper Nepean: WWTPs discharging between Maldon and the Warragamba River
- Lower Nepean and Upper Hawkesbury: WWTPs discharging between Glenbrook to Richmond
- South Creek: WWTPs discharging in the South Creek catchment
- Cattai Creek: WWTPs discharging in the Cattai Creek catchment
- Berowra Creek: WWTPs discharging in the Berowra Creek catchment. For simplicity, this variable also included minor loads from Brooklyn WWTP discharging to the estuarine section of the Hawkesbury River at Kangaroo Point
- Total: combining loads from all WWTPs

Each of these river sub-catchments is shown in Figure 3-1 and further details on the calculation protocol and population served by these WWTPs is included in Appendix C (Table C-1).

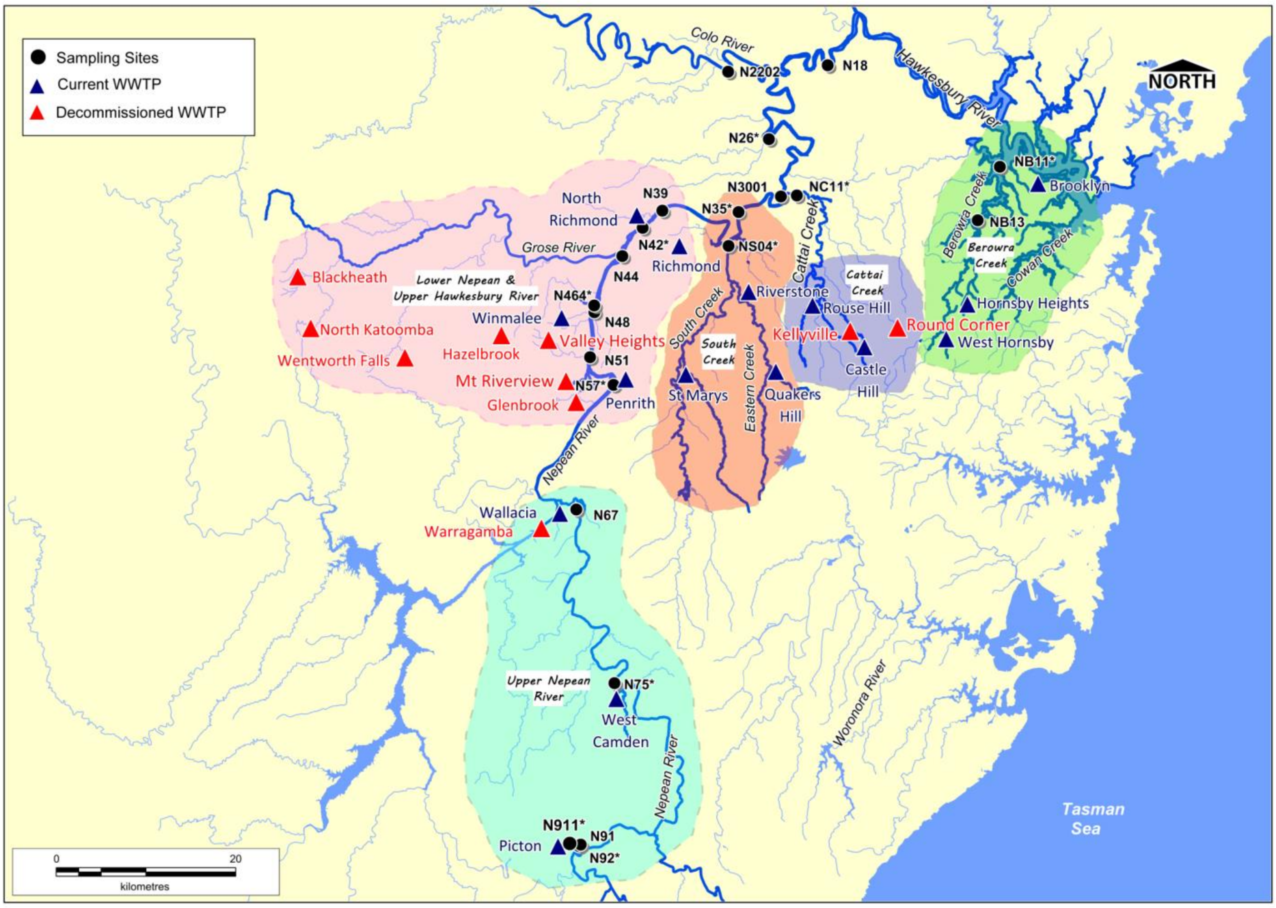


Figure 3-1 Five sub-catchments of the Hawkesbury-Nepean River used to calculate nutrient loads

3.2 Temporal trends in nutrient loads

3.2.1 Method of analysis

The Mann-Kendall analysis (Gilbert 1987; McBridge 2005) was used to determine the long-term trends in nutrient loads from Sydney Water's WWTPs and river water quality. This type of non-parametric test is appropriate for these datasets as they are not normally distributed, have outliers or extreme values, missing or censored data and/or influenced by seasonal factors (Loftis *et al* 1991, Hirsch *et al* 1991).

A modified SAS software program originally written by Winkler (2004) was used for the analysis. The minor modifications were made to accommodate the changes in the recent version of SAS (9.4). The program uses monthly data to determine if seasonality was present and if it was, a Seasonal Kendall test was then conducted. If seasonality was not found in the monthly data, the non-seasonal test was then conducted. The program provides an estimate of the magnitude of trend as a Sen slope estimation including upper and lower confidence limits on the slope.

Long-term trends in total nitrogen and total phosphorus loads were determined using this Seasonal Kendall test. This technique analyses monthly time series for trend by comparing all pairs of observations from the same month (but over different years). The analysis determines whether the difference between the number of pairs demonstrating an increase with time and the number of pairs demonstrating a decrease with time, is statistically significant, thus indicating an actual increasing (or decreasing) trend with time.

For this study, statistically significant trends were reported to occur when the significance level was less than 0.05 (p-value <0.05). For parameters and sites containing sufficient data observations, the seasonal Kendall slope estimator was also calculated. This is a value that estimates the rate of change. A positive slope indicates an increasing trend and a negative slope indicated a decreasing trend. Ninety five percent confidence intervals for slope were also estimated.

3.2.2 Preparation of data

Historical wastewater discharge volume and quality data is available in Sydney Water's electronic platforms from as early as 1986. However, for pre-1992 data, the quality is occasionally poor, with data gaps for multiple WWTPs. For quality, completeness and consistency, this study only used long-term wastewater data for the last 25 years: July 1992 to June 2017.

Consistency in data is essential for long-term trend analysis, therefore the patchy dissolved inorganic nitrogen and soluble reactive phosphorus load data was not considered suitable for the long-term trend analysis.

The sampling and analytical methods must also be consistent and reliable over the time-period so that actual trends in the data can be determined. The sampling techniques and analytical methods used for wastewater volume and quality data were similar throughout the 25-year period. In earlier years, wastewater quality was determined as ammonia nitrogen, oxidised nitrogen and Total Kjeldahl Nitrogen (TKN). Total nitrogen concentrations were derived from this data by adding TKN and oxidised nitrogen concentrations.

Where data was reported as being less than the detection limit, (for example ammonia nitrogen, oxidised nitrogen and total nitrogen as <0.01 mg/L, soluble reactive phosphorus and total phosphorus as <0.002 mg/L), all such data points were converted to half the detection limit.

The trend analysis by the Seasonal Kendall test only allows one observation per month. Therefore, where multiple observations were reported during a month, the median of the observations was used as the representative value for that month.

The daily total discharge volume variable was then created by combining the regular treated discharge volume with the partially treated discharge volume (if any). The monthly nutrient loads (total nitrogen and total phosphorus) for each WWTP were then determined using the following simple equation:

$$\text{Nutrient load (kg/day)} = [(c*d)/1000)]$$

where: c = monthly median concentration of nutrients (mg/L)

d = monthly median discharge volume (KL/day)

WWTP nutrient loads from different sub-catchments in the Hawkesbury-Nepean River and its tributaries were calculated by combining possible loads for those sub-catchments (as outlined in section 3.1.2 and in Appendix C: Table C-1)

For the trend analysis, season was defined into three categories: warm, mild and cold. The warm season was defined as the months from November to February; cold season as the months from May to August with the remaining four months, March, April, September and October defined as mild.

The nutrient load parameters were log-transformed (Log_{10}) before trend analysis to improve the normal distribution of the data.

3.2.3 Step trends

Step-trends are suitable when data collected before a specific time is clearly from a distinctly different population than the data collected after that time. So, it is more appropriate to use them when there is a known event that has occurred at a specific time and has likely to have resulted in a significant change in water quality (Hirsch *et al* 1991). In this situation, the data should be divided into 'pre' and 'post' periods at the time of this known event.

Step-trend analysis was considered more appropriate for the wastewater loads that were directly influenced by staged upgrade projects at WWTPs and where nutrient concentrations drop sharply after scheduled works. Considering the key dates when the major WWTP upgrades were completed, nutrient datasets were divided into historical (pre-upgrade) and short-term (post-upgrade) categories. In some cases, a mid-term category was also applied as the upgrade process heavily altered the data. For example, phosphorus load data for the South Creek sub-catchment was split into the three following categories: historical July 1992 to December 1999; mid-term January 2000 to June 2011 and short-term 2011 to June 2017.

By June 2011 and soon after the commissioning of the St Marys AWTP, Sydney Water had completed all major planned WWTP upgrade works. Since then, no major upgrade work has been carried out at any WWTP. Therefore, data collected between July 1992 and June 2011 was defined as 'historical' period, and between July 2011 and June 2017 as 'short-term' nutrient load in most cases.

There were other region-specific upgrades which significantly influenced the nutrient loads within that region. For example, the upgrade and amplification at West Camden WWTP reduced the nitrogen concentrations significantly from October 2008 onwards, whereas, the second stage upgrade completed by March 2009 saw significant phosphorus reductions. Similarly, the nitrogen upgrade at Berowra WWTPs caused a significant shift in nitrogen concentrations from July 2005 onwards.

The planned phosphorus upgrade works to the major WWTPs discharging into South and Cattai creeks was completed in two stages creating three distinct datasets. Data collected up until December 1999 was considered as 'historical' data, while data collected between January 2000 to June 2011 was considered as mid-term data, with data collected after June 2011 defined as 'short-term' data.

Further details on how the date was used to categorise the data for different regions of the Hawkesbury-Nepean River catchment are given in Appendix C (Table C-3). For completeness and comparison, long-term trends for the 25 year period were also determined for each sub-catchments and nutrient load parameters.

3.2.4 Trend analysis outcome and trend plots

The results of the long-term and step trend analysis for nutrient load data is presented in Appendix D (Table D-1).

Trend plots were drawn on total nitrogen and total phosphorus loads by different sub-catchment of the Hawkesbury-Nepean River catchment. All nutrient load trend plots are included in Appendix D (Figure D-1) with several plots that were considered important also presented in Chapter 4.2. In these plots, all log-transformed data were transformed back to original unit formats. The trend line shown in these plots is the predicted value from the residual plus the median value for each wastewater load variable.

3.2.5 Rate of change

The long-term trends (1992-2017) were also expressed as percentage changes (increase or decrease) from baseline values or concentrations. The baseline period was considered as the first 24 months for the long-term (10-25 years) dataset and the first 12 months for the short-term (<10 years) datasets. The method of percentage change calculation was based on Ebersole (2002) using the following formula for the log transformed data:

$$\% \text{ change} = \frac{[\exp(mn + s*n) - \exp(mn)]*100}{\exp(mn)}$$

Where: s = Sen slope estimator

n = number of years

mn = baseline mean

3.3 Spatial trends in water quality

Data collected from July 2016 to June 2017 was used to understand the current longitudinal variability in water quality conditions in the Hawkesbury-Nepean River and selected tributaries. This data is presented as box plots (Appendix E: Figure E-1; Chapter 4.3) to show the overall variability in water quality from upstream to downstream along the river and its tributaries.

The box plots graph the 25th percentile value, the mean (dot), the median/50th percentile (line) and 75th percentile values. The whiskers point to the 5th (bottom line) and 95th (top line) percentile values. The number of observations or samples is noted at the bottom of each box (Figure 3-2).

These box plots also include one or multiple relevant guideline values (Appendix C:Table C-7) as a horizontal line for comparison. Dissolved oxygen saturation and pH values were mainly compared to the Australian and New Zealand *Guidelines for Fresh and Marine Water Quality* as specified by the Australian and New Zealand Environment and Conservation Council (ANZECC 2000). For chlorophyll-*a*, total nitrogen and total phosphorus analytes, site-specific guidelines for the Hawkesbury-Nepean River were applied. These are the special nutrient limits set by the *Healthy River Commission* (HRC 1998) to meet the water quality objectives of this riverine catchment. Blue-green algae (Cyanobacteria) alert levels for recreational waters NHMRC (2008) were used to compare limited algal data.

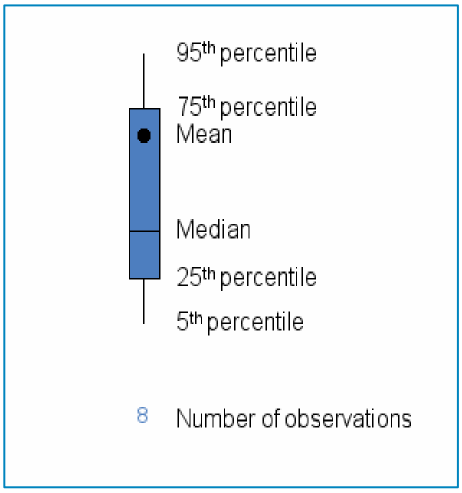


Figure 3-2 Explanation on box plots

3.4 Temporal trends in water quality

3.4.1 Overview

Trend analysis has been widely used as a useful tool in determining an improvement or deterioration in water quality parameters over time. The occurrence and magnitude of long-term trends in surface water quality of NSW rivers and streams were determined to provide guidance to management authorities to address pollution sources and other emerging issues (Overton *et al* 2000). The Western Australian Government's Department of Water used trend analysis as an essential tool for state wide assessment of river water quality (DW 2008). A similar type of analysis was conducted on water quality data collected from Queensland rivers, streams and dams (Bloedel *et al* 2000). WaterNSW (formerly Sydney Catchment Authority) used trend analysis to determine the long-term trends in water quality of Sydney's drinking water catchment streams, lakes and water filtration plant data to provide future management direction (WaterNSW 2009).

In the USA, long-term trend analysis has been used to understand the benefits of improved management practices to reduce nutrient load to waterways and to control eutrophication and algal blooms (Johnson *et al* 2009, Daroub *et al* 2009, Graham *et al* 2010).

Similarly, this study is intended to determine the actual long-term and short-term trends in water quality of the Hawkesbury-Nepean River catchment in response to Sydney Water's wastewater strategies and nutrient load reduction programs.

3.4.2 Method of data analysis

The long-term and short-term trends in water quality were determined using the Seasonal Kendall test as explained in Chapter: 3.2.1. Trend analysis on flow-adjusted water quality data can reveal the actual upward or downward trends because of anthropogenic inputs to the river system. Some water quality parameters such as conductivity and nutrient concentrations in waterways are generally influenced by rainfall events. The runoff water with low salt content can significantly reduce the conductivity levels at downstream sites due to its dilution effect. Similarly, runoff with influx of nutrient rich materials from upstream can increase the nutrients concentrations at downstream locations. Therefore, a year with higher frequency or intensity of storm events is likely to produce flows with increased nutrient concentrations compared to those observed in flows from drier years. The influence of hydrological variation on instream nutrient concentrations must be accounted for and adjusted prior to trend analysis.

3.4.3 Preparation of data

Data availability

Water quality data for the Hawkesbury-Nepean River is available from the early 1980s, but there are periods when either data is missing or there is inconsistency in monitoring sites, monitoring frequency, type of analytes or analytical methods. Based on data quality, completeness and consistency, this study used long-term wastewater and water quality data for a 25 year period from July 1992 to June 2017. Unfortunately, data for that entire period was only available for 10 out of the 21 selected sites, therefore the following data periods were also considered for the analysis for the remaining 11 sites:

- 23 years (July 1994 to June 2017): Hawkesbury River at Cattai Road (N3001) and Sackville Ferry (N26)
- 22.5 years (January 1995 to June 2017): Berowra Creek off Square Bay (NB11)
- 21.5 years (January 1996 to June 2017): Hawkesbury River at Freemans Reach (N39) and Leets Vale (N18)
- 20.5 years (January 1997 to June 2017): Stonequarry Creek (N911) and Berowra Creek at Calabash Bay (NB13)
- 9 years (July 2008 to June 2017): Nepean River at Fitzgeralds Creek (N51), Cattai Creek (NC11) and Colo River (N2202)

Data for the majority of the water quality parameters was available for the above periods, however several exceptions were found for some physico-chemical parameters including:

- Dissolved oxygen saturation data was only available from January 1996 for most of the sites while it was only collected for Stonequarry Creek (N911) from July 1997, for

Hawkesbury River at Sackville Ferry (N26) from July 1998 and for South Creek (NS04) from July 2000

- Berowra Ck at Calabash Bay (NB13): All physico-chemical parameters (conductivity, pH, dissolved oxygen, dissolved oxygen saturation, temperature and turbidity) data was available from July 2000 onwards
- Berowra Ck off Square Bay (NB11): Dissolved oxygen saturation was available from July 1998, turbidity from July 2008
- Hawkesbury River at Leets Vale (N18): Turbidity data was available from July 2008 onwards

Long-term trend analysis using the Seasonal Kendall test is the most appropriate method to determine temporal trends even if there are gaps in data or missing periods. However, as algal analyses were only carried out when chlorophyll-*a* levels were high there were considerable gaps. Therefore, the algal dataset was not ideal for any trend analysis for most sites except for Hawkesbury River at North Richmond (N42) where algal analysis was routinely carried out. Although taking this limitation into account, trend analysis was performed on algal data collected from five other main river sites (N92, N75, N57, N35, N26), one lagoon site (N464) and four tributary sites (N911, NS04, NC11 and NB11). These are the sites classified as key sites for this study because datasets for these sites are more complete compared to other sites. They also represent a good spread along the river and tributaries, and include one upstream reference site, five sites in tributaries where Sydney Water's WWTP discharges and two in the Nepean River and three in the Hawkesbury River.

On occasions, daily flow data was missing for short periods of time because of instrument malfunction or calibration problems. Where missing periods occurred, data was substituted with calculated values using the correlation co-efficient of the linear relationship between the flow data for that station with the flow data for a nearby station. For example, missing Maldon Weir flow data was substituted with a calculated value by multiplying the Camden Weir flow with a regression coefficient of 0.6155 (r^2=0.88).

Sampling and analytical methods

As previously mentioned, the sampling and analytical methods for a parameter over the entire period must be consistent and reliable so that actual trends in the data can be determined. Both the sampling techniques and analytical methods have not significantly changed throughout the 25 years.

The exact sampling location of the South and Cattai creek sites were reviewed in 2011 following safety and accessibility concerns. The South Creek site at Fitzroy Bridge (NS04) was moved to the nearby Fitzroy pedestrian bridge (NS04A). The Cattai Creek site (NC11) was moved from Cattai Road to a new location 100 metres downstream (NC11A). For each new site, duplicate datasets were collected for comparison for up to the first five sampling occasions with results indicating no statistical differences. This study used both datasets but only refers to them under the previous site codes, NS04 and NC11.

Until December 1995, chlorophyll-*a* samples were analysed by the sonication extraction method. Since then, the grinding extraction method has been employed. The relationship between sonication and grinding extraction was previously established and documented (AWT 1997a) and based on this relationship, a correction factor of 1.18 times was applied to the pre-December 1995 chlorophyll-*a* data to make this dataset compatible for long-term analysis.

Censored data

Some data was reported as being less than the detection limit, for example chlorophyll-*a* as <0.2 μg/L, ammonia nitrogen, oxidised nitrogen and total nitrogen as <0.01 mg/L, filterable total phosphorus and total phosphorus as <0.002 mg/L. All such data points were converted to half of the detection limit. Data points less than the detection limit were rare except for ammonia nitrogen concentrations, where about 10% of the total data points were less than the detection limit. Trend analysis was carried out on dissolved inorganic nitrogen data, which is the sum of ammonia nitrogen and oxidised nitrogen. Less than 2% of the total dissolved inorganic nitrogen results contained ammonia and oxidised nitrogen levels less than the detection limit. Therefore, this is not expected to influence the trend analysis results.

Calculation of monthly data

As previously mentioned, the Seasonal Kendall test only allows one observation per month, therefore, where multiple data points per month were observed, the median was chosen as the representative value for that month. This method was recommended (Helsel and Hirsch 1992) for situations when multiple observations in a month occur randomly with respect to time as in the case of all Sydney Water's monitoring data.

Median monthly flow values were calculated slightly differently as daily flow data was available unlike water quality data where data was collected at three to four weekly intervals. Firstly, the three day moving average flow data (72 hours moving average, 9am to 9am on the day sample was collected) were merged with water quality data by date. This method accommodated the influence of preceding flows on water quality. Finally, the dates without any water quality values were excluded before the median monthly flow was calculated.

A site-specific flow variable was created for each of the water quality monitoring locations from the river flow data of adjacent and/or upstream locations. For example, flow for the Nepean River at Sharpes Weir (N75) site was determined by combining flow from the Camden Weir and Matahil Creek sites. The detailed method for all water quality sites is included in Appendix C (Table C-5).

Similar to the nutrient load method, season was defined into three categories: warm, mild and cold (Chapter 3.2.2). A combined nitrogen variable or dissolved inorganic nitrogen, was derived from all forms of nitrogen readily available to algae and was calculated by adding ammonia nitrogen and oxidised nitrogen concentrations.

All parameters except pH were log-transformed (Log_{10}) before analysis to improve normality of the data.

3.4.4 Flow adjustment

The use of flow-adjusted data is a widely-used practice in determining the actual underlying trend in long-term water quality data (Hirsch *et al* 1991, Smith *et al* 1996, DW 2008). The flow-adjusted concentration is defined as the residual (actual minus conditional expectation) based on a regression of concentration on some function of discharge. The resulting 'flow-adjusted' data provides management with an improved perception of trends occurring in the waterway that are not linked to changes in hydrology or climate. According to Hirsch *et al* (1982), a trend that is detected in water quality data after the removal of stream flow effects implies a trend in the process by which the constituent enters and is transported by the river.

The LOWESS (locally weighted scatterplot smoothing) procedure is considered more appropriate than the Ordinary Least square regression, because the relationships between flow and constituent concentration are usually nonlinear (Hirsch *et al* 1991). A pre-specified smoothing factor of 0.5 is used as suggested by Bekele and McFarland (2004).

All water quality parameters were flow adjusted prior to trend analysis by the Seasonal Kendall test. As expected, the detection of trend was greatly influenced by flow adjustment. The LOWESS procedure with a smoothing factor of 0.5 was conducted for each site and water quality variable in SAS (9.4) software. A strong relationship was evident between site-specific flows (log-transformed) and water quality parameters (log-transformed, except pH). Conductivity decreased significantly with the increased flows at North Richmond (N42) on the Hawkesbury River (Figure 3-3). For the remaining 12 parameters, one best example of the LOWESS plot are included in Appendix C (Figure C-1). As expected, chlorophyll-*a*, total algal biovolume, blue-green algal biovolume, pH, dissolved oxygen and dissolved oxygen saturation decreased with increased flows. While total nitrogen, dissolved inorganic nitrogen, total phosphorus, filterable total phosphorus and turbidity increased with the increase in flow. Temperature is the only variable which showed no visible influence from flow.

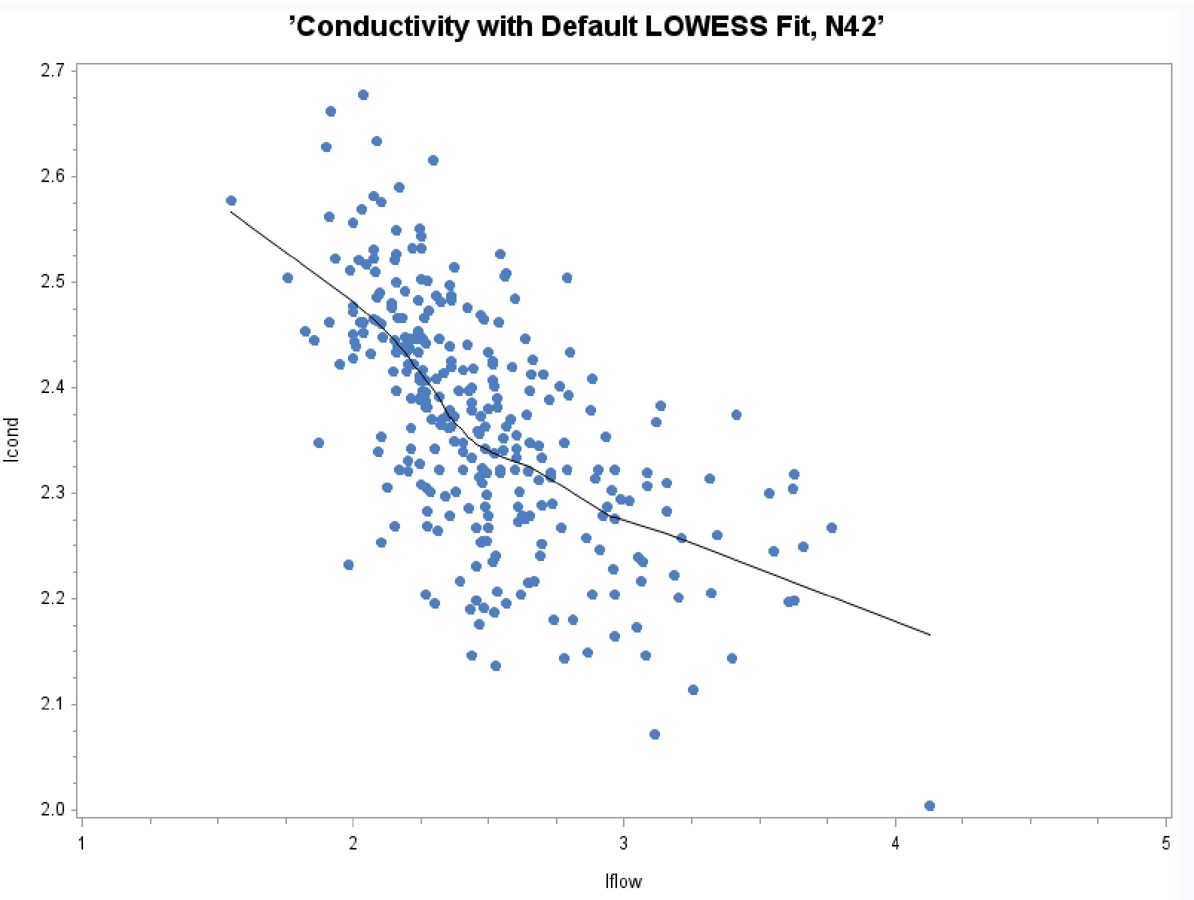
3.4.5 Step trends

As discussed in Chapter 3.2.3, step-trends are suitable when data collected before specific times are from a distinctly different population than the data collected after that time. It is more appropriate when there is a known event that has occurred at a specific time that is likely to have resulted in a significant change in water quality (Hirsch *et al* 1991). In this situation, the data should be divided into 'pre-upgrade' and 'post-upgrade' periods at the time of this known event.

Step-trend analysis is also considered important for water quality where a distinct change in water quality is evident based on WWTP upgrades or other process changes. The Nepean River water quality at Maldon (N91 and N92) was influenced by the commencement of environmental flow releases from the upper Nepean dams in July 2010. At the same time, the precautionary discharges from the Picton WWTP intensified compared to previous years. Therefore, the Stonequarry Creek (N911) water quality data was also divided into 'historical' and 'short-term' using the June 2010 mark. The West Camden WWTP upgrade in 2008 and 2009 influenced the water quality at Sharpes Weir (N75). Berowra Creek data was influenced by the West Hornsby and Hornby Heights WWTP upgrade in 2005. Similarly, water quality data for all other Hawkesbury-Nepean River and tributary sites were influenced after the completion of the St Marys AWTP in late

2010, when few other upgrade works were completed. These data were split in to two groups 'historical' or 'short-term' with data collected before and after June 2011. Further details on determining how data was split by date for different water quality monitoring sites are given in Appendix C (Table C-4).

For completeness and comparison, long-term trends for the entire 25-year period was also determined for each water quality parameter. Step trends were considered important for nine water quality parameters where an impact or influence can be demonstrated. These included chlorophyll-*a*, total algal biovolume, blue-green algal biovolume, total nitrogen, dissolved inorganic nitrogen, total phosphorus, filterable total phosphorus, conductivity and pH. It was not considered meaningful performing step trend analysis for the remaining four water quality parameters (dissolved oxygen, dissolved oxygen saturation, temperature and turbidity).



Smoothing of raw data against flow by LOWESS Method, dot= observed value, fitted line = Predicted value

Figure 3-3 Relationship between flow and conductivity: Hawkesbury River at North Richmond (N42)

3.4.6 Trend plots

Trend plots were created for the 11 key sites in the Hawkesbury-Nepean River and tributaries as listed in section 3.4.3. Both step trends and long-term trends for the entire period were drawn on the nine parameters as listed in section 3.4.5. All water quality trend plots from the upstream to downstream sections of the Hawkesbury-Nepean River are included in Appendix E (Figure E-2 to Figure E-12). Some trend plots for the 11 key sites and parameters are also presented in Chapter 4.4. Like nutrient load plots, all log-transformed data (except pH) were transformed back to original units. The trend line shown in these plots is the predicted value from residual plus the median value for each wastewater load variable.

The results for the long-term trend analysis of water quality, ordered from upstream to downstream, in the Hawkesbury-Nepean River is presented in Appendix E (Table E-1).

3.4.7 Rate of change

The long-term trends were also expressed as percentage change (increase or decrease) from baseline values or concentrations. The baseline period was considered as the first 24 months for the long-term (10-25 years) dataset or first 12 months for the short term (<10 years) dataset. The method for percentage change calculation was based on Ebersole (2002), using following formulas for the non-transformed and log-transformed data:

Non-transformed data (pH)

$$\% \text{ change} = [(s*n)/mn)]*100.$$

Where: s = Sen slope estimator

n = number of years

mn = baseline mean

Log-transformed data (All other parameters):

$$\% \text{ change} = \frac{[\exp(mn + s*n) - \exp(mn)]*100}{\exp(mn)}$$

Where: s = Sen slope estimator

n = number of years

mn = baseline mean

3.5 Algal species diversity

As explained previously, algal species data were limited to where chlorophyll-*a* levels exceeded 7 µg/L, except for the Hawkesbury River at North Richmond (N42). Algal species and biovolume data for all 21 sites were collated for the entire 25-year period. To understand the algal species variability over time, the algal biovolume data by the following five key taxonomic groups were plotted as a percent composition of the total and were included in Chapter 4 (example: Figure 4-20).

- Blue-greens: total biovolume of all species of the blue-green algae (cyanobacteria); Family: Cyanophyta
- Greens: total biovolume of all species of green algae; Family: Chlorophyta
- Diatoms: total biovolume of all species of diatoms; Family: Bacillariophyta
- Monads: total biovolume of all species of flagellated monads algae; Families: Cryptophyta (cryptomonads), Euglenophyta (euglenoids), Chloromonadophyta (chloramines)
- Others: total biovolume of all other groups; Families: Dinophyte (dinoflagellates), Cryophyte and Xanthophytes

3.6 Spearman Correlation Analysis

3.6.1 Method of analysis

The Spearman Correlation Analysis (McBridge 2005) was conducted to understand the relationships between chlorophyll-*a*, algal biovolume, flow, nutrient loads from wastewater discharges, nutrient concentrations and other water quality parameters. This is a non-parametric test that is suitable when both parameters are not normally distributed, as was the case for wastewater and water quality data. It is important to note that, correlation analysis does not identify a cause and effect but merely suggests that a linear relationship may exist.

Spearman Correlation Analysis was conducted using PROC CORR SPEARMAN in SAS (9.4) software. The analysis was repeated for the 11 key sites along the Hawkesbury-Nepean River and tributaries, as listed in section 3.4.3. The most consistent, long-term datasets were available for these sites with several of the sites known to have high nutrients and algal blooms. These sites also represent the variation in sections along the Hawkesbury-Nepean catchment from the upstream control site in the upper Nepean River to the furthermost downstream site in the lower estuarine section.

The relationship between pairs of parameters was considered significant when the p-value was less than 0.05. The level of relationship was considered in the following three categories:

- Strong: Rho>0.50 and p<0.0001
- Moderate:
  - Rho>0.50 and p=0.0001 to 0.05
  - Rho=0.30 to 0.50 and p<0.0001
- Weak: Rho=0.30 to 0.50 and p=0.0001 to 0.05

The detailed results from the Spearman Correlation Analysis is presented in Appendix F and summaries in Chapter 5.3.

3.6.2 Preparation of data

Water quality data collected in the last six years from July 2011 to June 2016 was considered more appropriate for the Spearman Correlation Analysis as it was more representative of the recent conditions. Thirteen parameters were selected for the Spearman Correlation Analysis that may be related to each other and influence the chlorophyll-*a*, algae and nutrient concentrations at each site (Appendix C: Table C-6).

Unlike trend analysis, monthly data was not used for this analysis as it has the potential to alter the real-time relationship between parameters. All water quality data that was collected at a frequency of three to four weeks was used directly. However, where two results were obtained from duplicate samples collected on the same date, results were converted to a mean value. Representative values of flow and wastewater nutrient loads was then merged with this dataset by date.

As wastewater nutrient quality was only measured at six-day intervals, the 6th day nutrient concentration was used to patch the preceding five days data to calculate relevant nutrient loads and to merge with the water quality data. Site-specific nutrient load data for the 11 key water quality monitoring sites were derived using likely influence of nutrient loads at that site from upstream WWTPs. The detailed method for this calculation is presented in Appendix C (Table C-2).

For river flow, the three-day moving average flow data (actual and preceding two days, 72 hours to 9am on the day) was considered appropriate to account for residual impact from upstream to downstream of a particular site. This reduced the extreme variability and considered the lag time for water travel from actual flow gauging stations to water quality monitoring locations and their subsequent impact on water quality.

Finally, the water quality dataset was merged with daily site-specific flow and wastewater nutrient load datasets by date. Any dates without a corresponding water quality data were deleted.

All parameters were log-transformed (Log_{10}) before analysis to improve normality of data.

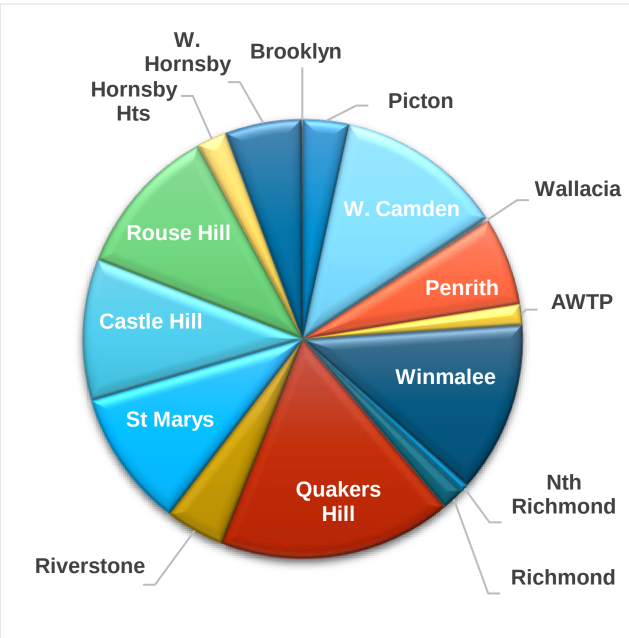
4 Results and discussion

4.1 Spatial trends in nutrient loads

A summary of the 2016-17 nutrient loads from each of Sydney Water's 15 WWTPs and St Marys AWTP to the Hawkesbury-Nepean River and three of its major tributaries is presented in Table 4-1. The proportion of the total nitrogen and total phosphorus loads discharged by each WWTP is shown in Figure 4-1. During 2016-17, 962 kg/day of total nitrogen and 10 kg/day of total phosphorus was discharged to the Hawkesbury-Nepean River catchment from Sydney Water's 15 WWTPs and St Marys AWTP. It is estimated that about 86% of this total nitrogen is in a readily available form (dissolved inorganic nitrogen) for photosynthetic organisms. The estimated readily available form of phosphorus (soluble reactive phosphorus) is about 51% of the total phosphorus.

The three South Creek sub-catchment WWTPs, namely Quakers Hill, Riverstone and St Marys, contributed approximately one third (32%) of the total nitrogen load to the river system. The Lower Nepean River and Upper Hawkesbury River sub-catchment between Penrith and Richmond received the largest proportion (42%) of total phosphorus loads in 2016-17.

Quakers Hill, Winmalee and West Camden WWTPs also contributed the high loads of total nitrogen with about 17%, 13% and 12% respectively of the total load (Figure 4-1). For total phosphorus loads, the three largest contributors are Winmalee (27%), Quakers Hill (21%) and Penrith (13%) WWTPs.



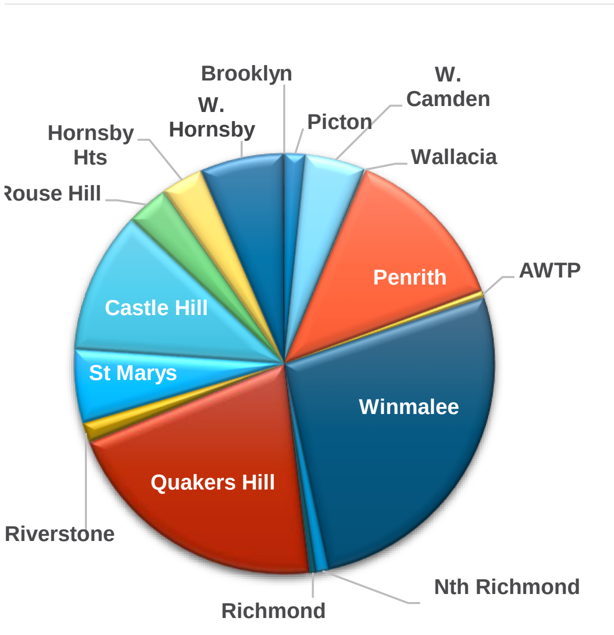


Figure 4-1 Proportion of total nitrogen (left chart) and total phosphorus (right chart) loads by each WWTPs (upstream to downstream catchment, clockwise)

Table 4-1 Summary of WWTP nutrient load results (2016-17)

WWTPs/ Sub-catchments	Total nitrogen		Dissolved inorganic nitrogen load (kg/day)	Total phosphorus		Soluble reactive phosphorus loads (kg/day)
	load (kg/day)	% total load		load (kg/day)	% total load	
Upper Nepean WWTPs						
Picton	32.61	3.4%	nc	0.16	1.6%	nc
West Camden	118.42	12.3%	105.98	0.46	4.6%	0.19
Wallacia	2.65	0.3%	nc	0.01	0.1%	nc
Lower Nepean and Upper Hawkesbury WWTPs						
Penrith	62.28	6.5%	nc	1.31	13.1%	nc
St Marys AWTP	14.27	1.5%	13.34	0.05	0.5%	nc
Winmalee	121.53	12.6%	110.95	2.68	26.7%	nc
Nth Richmond	5.25	0.5%	4.45	0.10	1.0%	nc
Richmond	16.08	1.7%	nc	0.05	0.5%	nc
South Creek WWTPs						
Quakers Hill	165.57	17.2%	138.71	2.09	20.8%	0.84
Riverstone	41.84	4.4%	nc	0.15	1.5%	nc
St Marys	97.12	10.1%	71.99	0.57	5.7%	0.11
Cattai Creek WWTPs						
Castle Hill	100.25	10.4%	94.61	1.10	10.9%	1.03
Rouse Hill	107.56	11.2%	nc	0.33	3.3%	nc
Berowra Creek WWTPs including Brooklyn						
Hornsby Heights	21.41	2.2%	14.93	0.32	3.2%	nc
West Hornsby	53.69	5.6%	42.84	0.64	6.4%	nc
Brooklyn	0.93	0.1%	nc	0.01	0.1%	nc
Nutrient loads by each sub-catchment of the river						
Upper Nepean	153.67	16.0%	nc	0.64	6.3%	nc
Lower Nepean and Upper Hawkesbury	219.41	22.8%	nc	4.19	41.8%	nc
South Creek	304.53	31.7%	nc	2.81	28.0%	nc
Cattai Creek	207.81	21.6%	nc	1.42	14.2%	nc
Berowra Creek (including Brooklyn)	76.03	7.9%	nc	0.97	9.7%	nc
Total	**961.46**	**100%**	**597.81**	**10.03**	**100%**	**2.16**
Adjusted total ===================→			**824.02**			**5.15**
Available nutrient as % of total =====→			**86%**			**51%**

nc: not computed because nutrient concentration data is not available

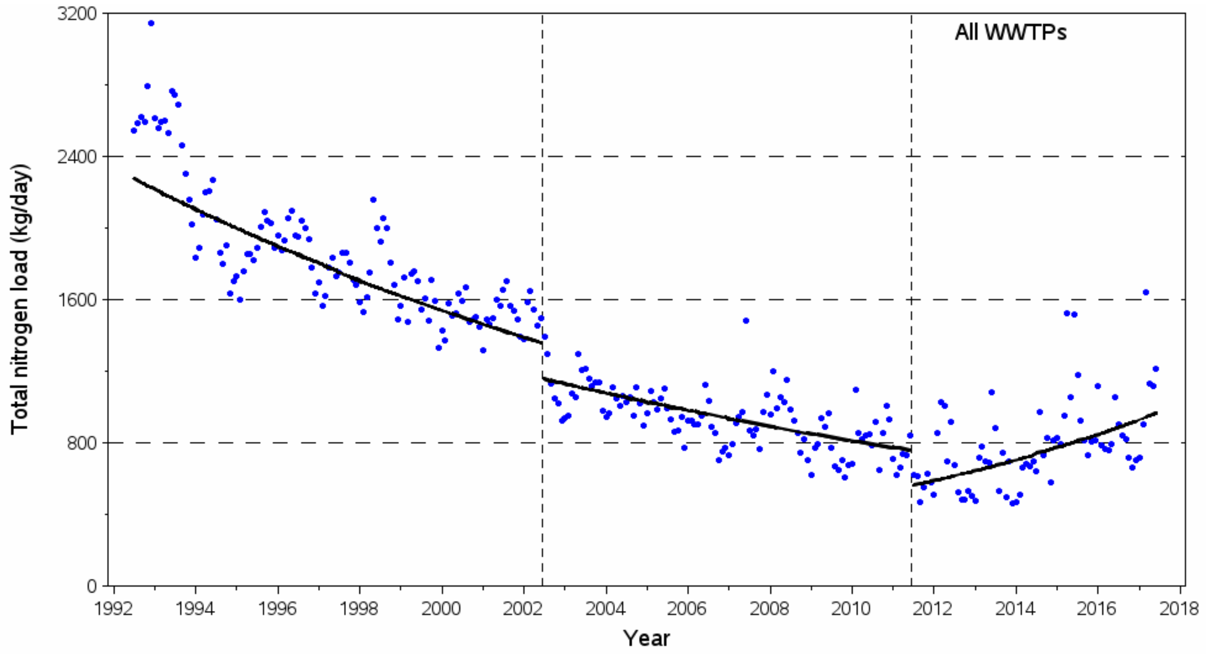
4.2 Temporal trends in WWTP nutrient loads

Detailed results of the long-term trends and step trends for the WWTP nutrient loads by each sub-catchment is included in Appendix D (Table D-1). Nutrient load trend plots for the entire 25-year period and step trend plots for each of the different sub-catchments of the Hawkesbury-Nepean River and tributaries are included in Appendix D (Figure D-1). The Seasonal Kendall test identified both seasonal and non-seasonal variation in nutrient load parameters. Among the 44 long-term trend/step trend analyses performed for all WWTPs and for sub-catchment specific nutrient load data, 40 significant trends (15 upward and 25 downwards) were identified with p-values<0.05.

4.2.1 Total nutrient loads from all Sydney Water WWTPs

The total population served by Sydney Water's WWTPs in the greater Hawkesbury-Nepean River catchment has increased by 73% over the past 25 years with an average yearly increase of 2.9% (Appendix C: Table C-1). Despite this increase, a large reduction in nutrient loads has been achieved through the implementation of improved wastewater strategies. The total nitrogen load has significantly decreased by 76% and the total phosphorus load by 94% in the last 25 years.

During the first stage of WWTP upgrade works that were completed by 2002, the total nitrogen loads reduced significantly (40%, historical) with a further 34% reduction achieved by the millennium draught (mid-term). By 2011 all nutrient removal upgrades were completed (Figure 4-2). An increase in population growth, a return to wetter climate conditions and a major asset failure at West Camden WWTP resulted in the total nitrogen loads discharged into receiving waters increasing (71%, short-term). However, these WWTPs are still maintaining discharge quality in line with the EPL requirements.

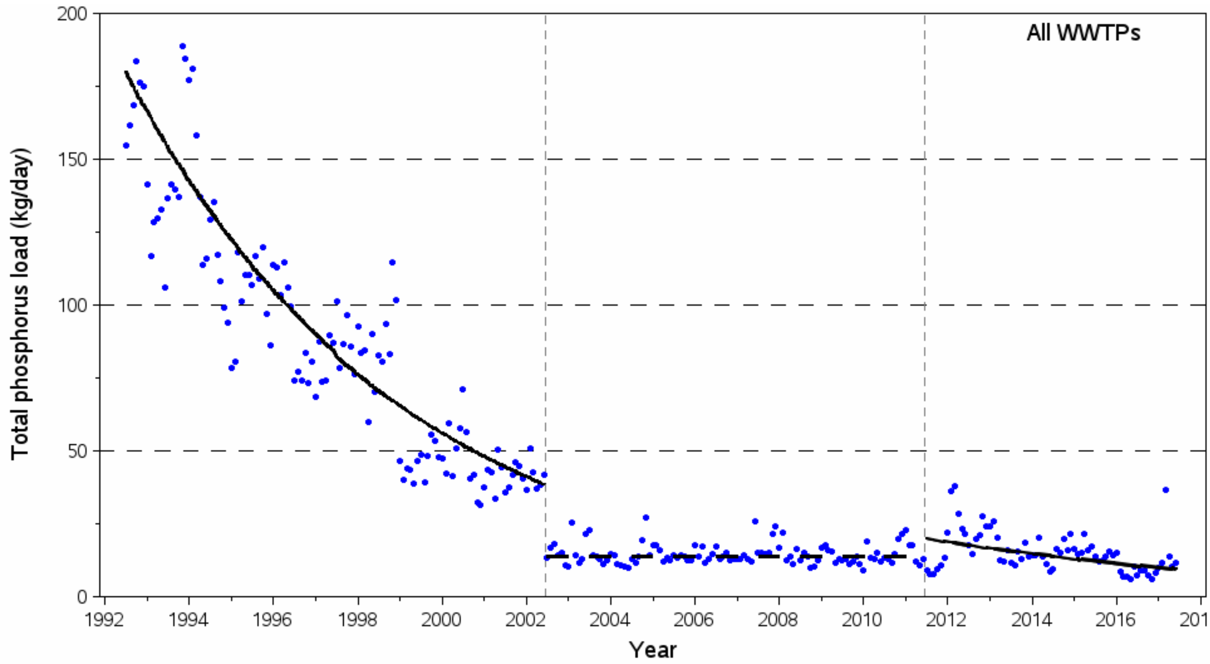


Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-2 Step trends in total nitrogen loads from all Sydney Water's WWTPs discharging to Hawkesbury-Nepean River and tributaries

Phosphorus upgrade projects were given priority between 1998 to 2002 as phosphorus was believed to be the major trigger for algal blooms. This is reflected in trend analysis outcomes with a 78% load reduction in total phosphorus between 1992 and 2002 (mid-term) when the major WWTP upgrade projects were completed (Figure 4-3). There were no further significant reductions during the next nine years from 2002 to 2011 (mid-term). Sydney Water has focused on improving phosphorus removal at Winmalee WWTP which was the single largest contributor of phosphorus to the river. This optimisation work at Winmalee has resulted in a 51% reduction in the total phosphorus loads into the river over the last six years to 2017 (short-term).

Trends in both the nitrogen and phosphorus nutrient loads discharged to the two Hawkesbury-Nepean River sub-catchments and the three major tributaries did not always reflect overall river system trends. This is presented in sections 4.2.2 to 4.2.6.



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-3 Step trends in total phosphorus loads from all Sydney Water's WWTPs discharging to Hawkesbury-Nepean River and tributaries

4.2.2 Nutrient loads from the Upper Nepean River WWTPs

The combined nutrient loads from Picton, West Camden, Warragamba (decommissioned) and Wallacia WWTPs were considered in assessing the nutrient load for this upper sub-catchment of the Nepean River.

The first stage of the phosphorus upgrade work to the Warragamba WWTP was completed in 2002, prior to decommissioning in September 2006 when flows were transferred to the new Wallacia WWTP. At West Camden WWTP, the nitrogen upgrade work was completed in September 2008 and phosphorus upgrade in March 2009.

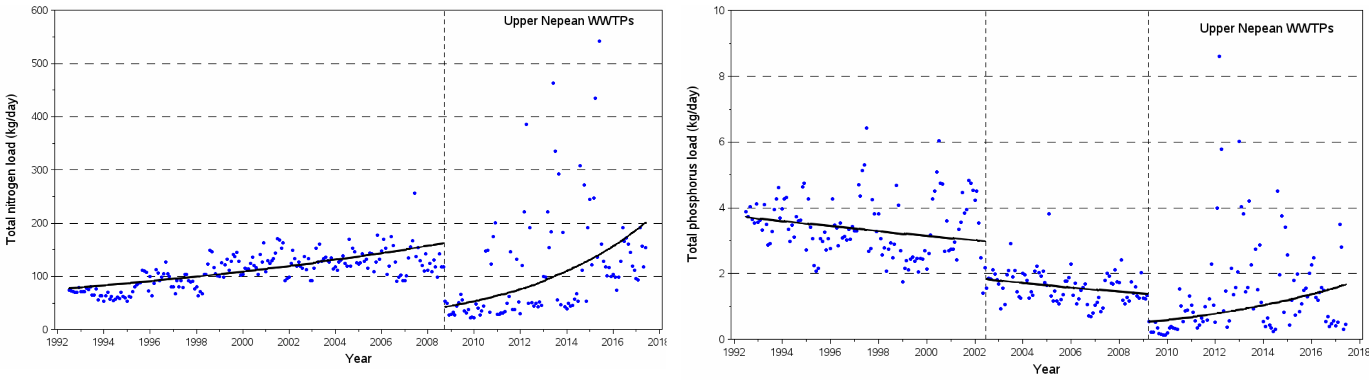
Despite these upgrades, the overall long-term trend in total nitrogen loads showed a significant increase (57%) in this sub-catchment. The increase in total nitrogen loads is likely related to three potential causes:

- a large increase in population (355% over the 25 years or an average yearly increase of 14%) connecting to Sydney Water's wastewater system in this sub-catchment
- Picton WWTP reaching its capacity, leading to more precautionary discharges to Stonequarry Creek
- an increase in the number of process failures at the West Camden WWTP (due to structural failure of the IDAL) in recent years (now fixed)

The large population increase in this sub-catchment did not influence the long-term trend in total phosphorus load discharged, which significantly decreased (82%) in the last 25 years.

Step trend analysis for the two separate periods revealed that total nitrogen loads have significantly increased during both time periods ie between 1992 and 2008 (historical) the total nitrogen load increased by 109%, while between 2008 to 2017 (short-term) it increased by 369% (Figure 4-4).

Step trends in total phosphorus loads showed a decrease in two of the three stages (historical, mid-term and short-term) and an overall load increase decrease between 1992 and 2017. Between1992 and 2002, the total phosphorus load decreased by 20%, with a further 24% decrease by March 2009 by which time phosphorus upgrade works at West Camden WWTP was complete (Figure 4-4). In recent years, the total phosphorus load discharged to the Upper Nepean sub-catchment increased by 211% (short-term) which is most likely linked to the 59% increase in the population and reductions in aluminium sulphate dosing to meet the aluminium concentration limit at West Camden WWTP.



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-4 Step trends in total nitrogen (left) and total phosphorus (right) loads from the Upper Nepean WWTPs

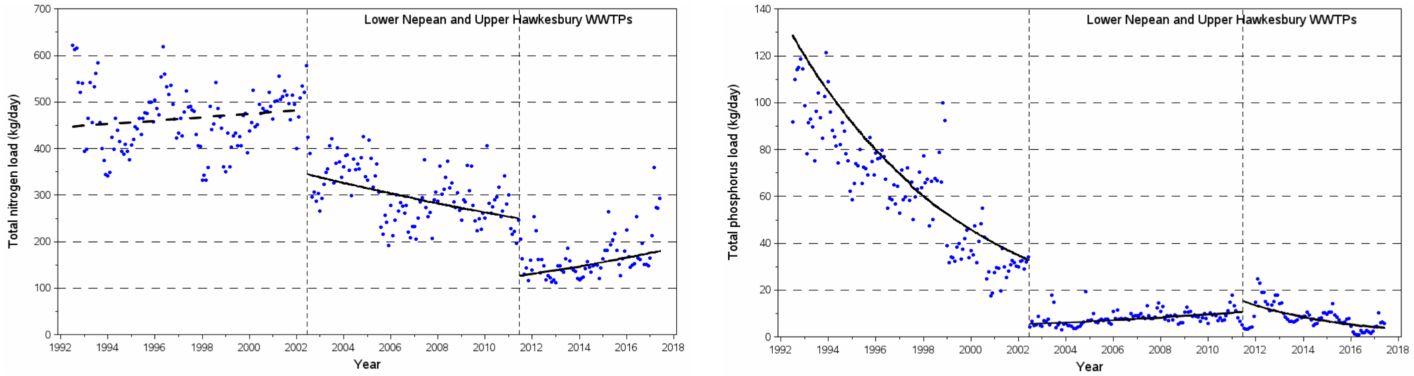
4.2.3 Nutrient loads from the Lower Nepean and Upper Hawkesbury River WWTPs

The current nutrient loads discharged from Penrith, Winmalee, North Richmond and Richmond WWTPs, and St Marys AWTP, were considered in assessing the nutrient load for this sub-catchment of the river. Historical loads from seven decommissioned Blue Mountains WWTPs were also considered. Decommissioning and flow transfer from these Blue Mountains WWTPs to the Winmalee WWTP first started in 1993, with the last one, Blackheath WWTP, transferred in 2008. The Glenbrook WWTP flow was transferred to Penrith WWTP in 2005.

The first stages of upgrade work at most of these major WWTPs was completed by June 2002. The second stages of upgrade work were completed by June 2011 soon after the commissioning of St Marys AWTP in late 2010.

In the Lower Nepean and Upper Hawkesbury River sub-catchment, both total nitrogen and phosphorus loads significantly decreased over the entire 25-year period. The total nitrogen load decreased by approximately 72% (long-term), with the step-trend analysis showing the decrease was mostly achieved between 2002 to 2011 (mid-term, Figure 4-5). However, total nitrogen loads in the last six years (short-term) have significantly increased by 41% from the historic low in 2011. Upgrade works at Winmalee WWTP are proposed to reduce nutrients discharged to this sub-catchment of the river with commissioning of new process units expected in 2021.

The total phosphorus load decreased by 96% over the entire 25-year period. The step trend analysis initially revealed a 74% reduction during the first stage of upgrades (historical) and decommissioning of WWTPs undertaken up to 2002 (Figure 4-5). Between 2002 and 2011, there was a rise in loads of 92%. This was largely due to increased phosphorus in discharges from the Winmalee WWTP. In the later years from 2011 to 2017, the total phosphorus load significantly decreased (74%) due to optimisation work at Winmalee WWTP.



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

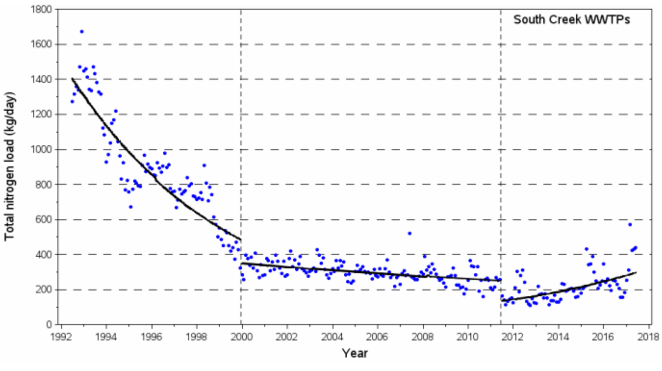
Figure 4-5 Step trends in total nitrogen (left) and total phosphorus (right) loads from the Lower Nepean and Upper Hawkesbury River WWTPs

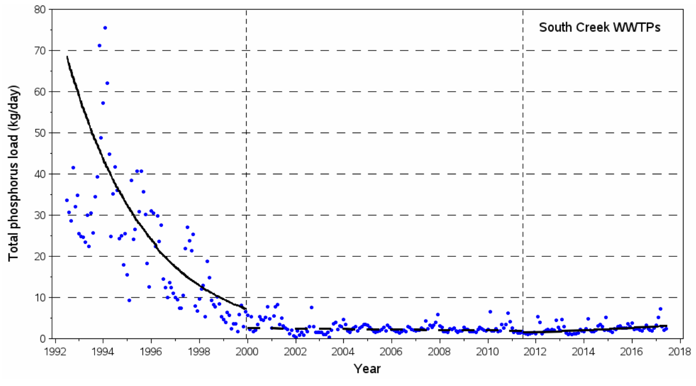
4.2.4 Nutrient loads from South Creek sub-catchment WWTPs

Three major WWTPs, Quakers Hill, Riverstone and St Marys, discharge in the South Creek sub-catchment. These WWTPs were the first group of plants to undergo major upgrades before 2000. At that time, it was believed that regular discharges of nutrient rich water via South Creek was contributing to algal blooms in the downstream Hawkesbury River. The second stage upgrade work was completed in June 2011 not long after the commissioning of the St Marys AWTP in late 2010.

The population in the South Creek catchment increased by 45% between 1992 and 2017 (1.8% per year). Despite this constant population growth, total nitrogen and phosphorus loads significantly reduced by 86% and 92% respectively, with most of the reduction achieved by 1999. The step trend analyses confirmed that total nitrogen and phosphorus loads in South Creek decreased by 65% and 89%, respectively between 1992 and 1999 (historical, Figure 4-6). By June 2011, the South Creek total nitrogen load had significantly decreased by a further 28% after the commissioning of St Marys AWTP (mid-term). However, there were no significant changes found in total phosphorus load from 2000 to 2011 (short-term).

The trends in both total nitrogen and total phosphorus loads have reversed between 2011 and 2017 due to a combination of population growth (overall 13%, 2.2% per year) and more frequent storm events. With the increasing wastewater inflows for treatment WWTP efficiency also reduces resulting in increased nutrient concentrations in discharges and ultimately in nutrient loads. The total nitrogen load from the South Creek sub-catchment WWTPs increased by 120% from the previous historic lows. Similarly, the total phosphorus load, although starting from a very low level, increased by 96%.





Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-6 Step trends in total nitrogen (left) and total phosphorus (right) loads from the South Creek WWTPs

4.2.5 Nutrient loads from Cattai Creek sub-catchment WWTPs

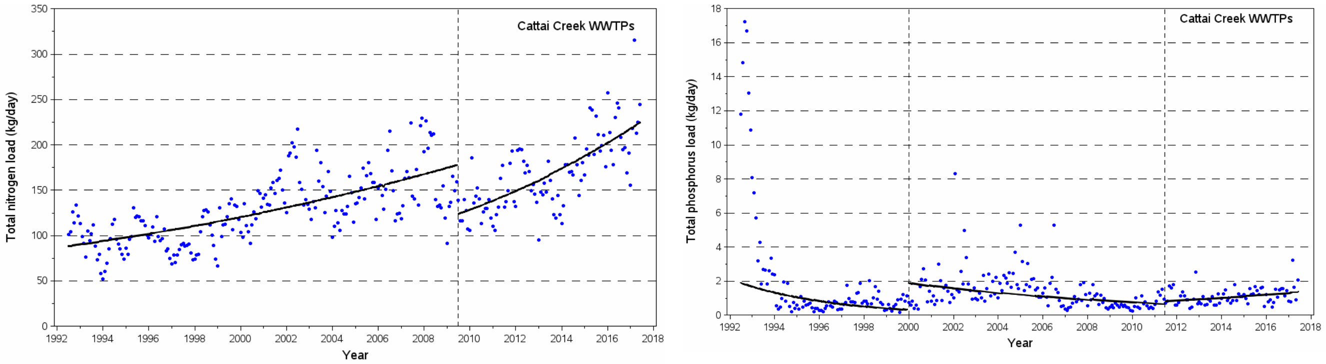
Currently Castle Hill and Rouse Hill WWTPs discharge in the Cattai Creek sub-catchment. In the past, Kellyville and Round Corner WWTPs also discharged to Cattai Creek, but were both decommissioned by 2000 with flows transferred to Rouse Hill WWTP. The first stage of upgrade works to remove more phosphorus from the Castle Hill and Rouse Hill WWTPs was completed by

December 1999. The second stage upgrade, mostly in relation to nitrogen at Rouse Hill, was completed in 2009.

The population serviced by the Cattai Creek WWTPs increased by 366% (14.6% per year) between 1992 and 2017. The benefits of WWTP upgrades and amplification works has been offset by the population increase, with the total nitrogen load to this sub-catchment increasing by 115% between 1992 and 2017. Cattai Creek is the only sub-catchment where a significantly downward trend in the total phosphorus load was not achieved despite upgrade works. This is the result of major residential development and population growth in this sub-catchment. Limited upgrade works to remove more nutrient loads were carried out at both Rouse Hill and Castle Hill WWTPs to improve discharge quality which has offset the impact of population growth. A major upgrade of the Castle Hill WWTP is planned in the early 2020's to significantly improve nutrient removal at this plant as it is currently an outlier when compared to other plants in the Hawkesbury-Nepean catchment.

The step trends demonstrated significant increases in the total nitrogen loads discharged in both stages (historical: 1992-2009 and short-term: 2009-2017, Figure 4-7). During the first stage from 1992 to 2009, the increase in the total nitrogen load was 101% while during the second stage from 2009 and 2017, the total nitrogen load increased by 82% even though starting at lower levels following the Rouse Hill WWTP upgrade.

The total phosphorus load decreased significantly during the first 2 stages up until 2011 when an upgrade to remove more nutrient loads was completed (historical and mid-term, Figure 4-7). However, in recent years between 2011 and 2017 (short-term), the total phosphorus load increased significantly (70%) from both WWTPs.



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-7 Step trends in total nitrogen (left) and total phosphorus (right) loads from the Cattai Creek WWTPs

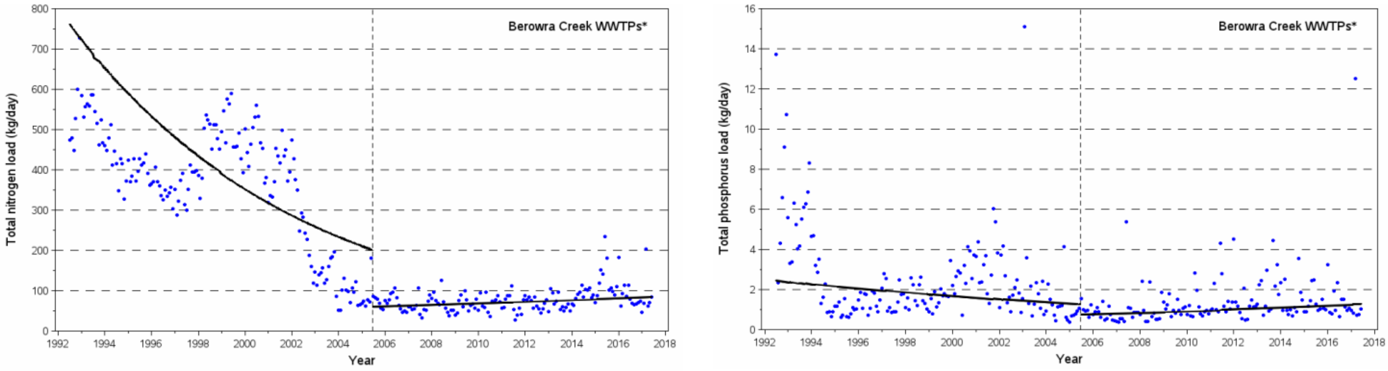
4.2.6 Nutrient loads from Berowra Creek WWTPs

Three WWTPs, Hornsby Heights, West Hornsby and Brooklyn operate in the estuarine sub-catchment of the lower Hawkesbury River with the first two discharging into Berowra Creek. Both Berowra Creek WWTPs were upgraded in 2005 to improve total nitrogen removal. The Brooklyn

WWTP commenced operations in 2007 with very minor load discharges compared to all other WWTPs operated by Sydney Water.

Both total nitrogen and phosphorus loads significantly decreased (92% and 52%, respectively) in this sub-catchment over the entire 25-year period. Nitrogen was considered the main nutrient in triggering algal blooms in this estuarine section of the river.

Step trend analysis revealed a significant decrease in total nitrogen loads between 1992 and 2005 (73%, historical). Total phosphorus loads also showed a significantly decreasing trend but to a lesser extent (47%, historical) (Figure 4-8). Post-2005 (short-term), data showed significantly increasing trends in both total nitrogen (42%) and total phosphorus (72%) loads.



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

* includes minor load from Brooklyn WWTP

Figure 4-8 Step trends in total nitrogen (left) and total phosphorus (right) loads from the Berowra Creek* WWTPs

4.3 Spatial trends in water quality (2016-17)

This section presents a generalised view of the current water quality conditions along the Hawkesbury-Nepean River and its tributaries. The water quality in the Hawkesbury-Nepean River varies widely as the river morphology and other conditions change along the 180 kilometers from Maldon Weir, downstream to Leets Vale. Several tributaries join or confluence with the river along this large distance, carrying a diverse range of inflows from different localised catchments. Among these, only four tributaries (including one lagoon) and a reference site (Colo River) are monitored where Sydney Water's WWTPs are discharging.

The water quality at the upstream reference site at Maldon Weir was good for many of the parameters monitored as it receives flows from protected drinking water catchments and environmental flow releases from upstream water storages. The water quality changes with distance downstream and the river widens and it receives nutrient rich pollutants from urbanised catchments, diffuse runoff from agriculture, plus continuous discharge from multiple WWTPs. The quality of the lower Hawkesbury River, below Windsor and downstream of the South Creek confluence is comparatively poor with very high levels of nutrients, chlorophyll-*a* and algae. In the estuary, the water quality is variable due to tidal flushing from the ocean. Typically, the Color River is of high quality water as it flows from a large mostly pristine, natural wilderness.

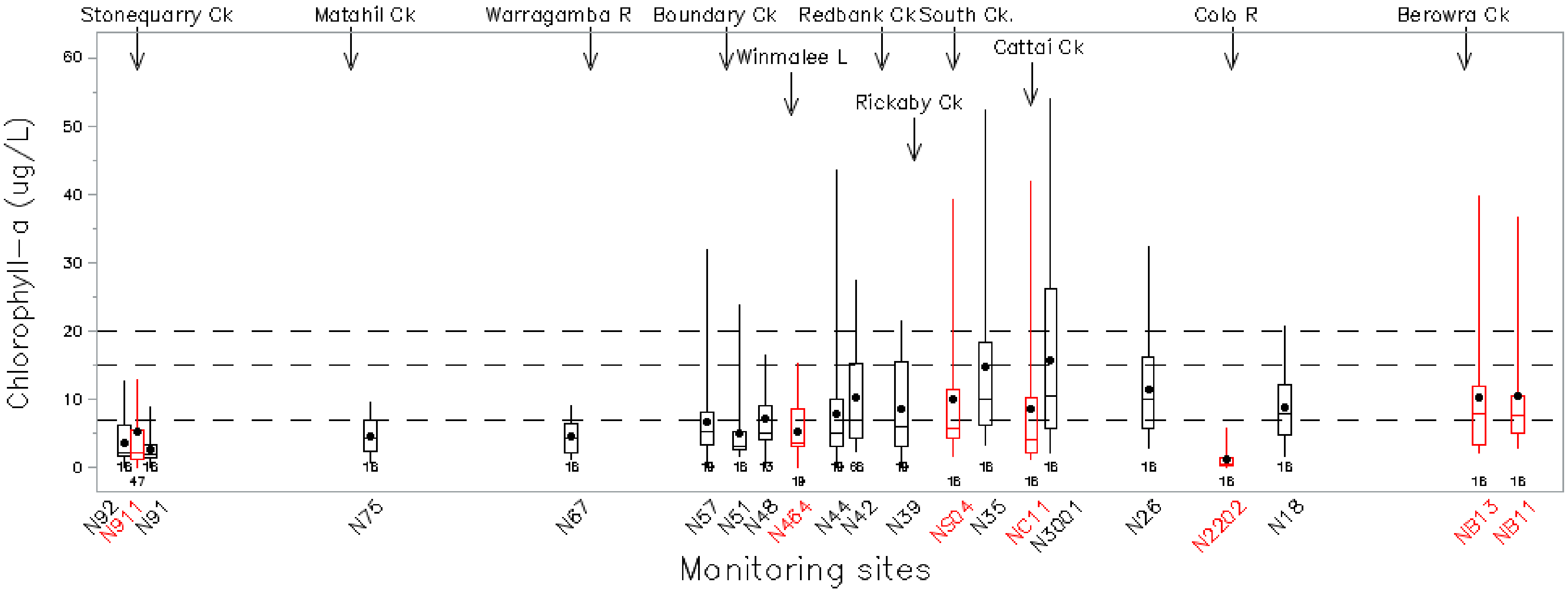
The median values for each water quality parameters for 2016-17 data for all 21 sites monitored along the Hawkesbury-Nepean River are presented in Table 4-1. Longitudinal trend plots for all water quality parameters are included in Appendix E (Figure E-1).

The longitudinal trend in chlorophyll-*a* concentrations along the river and tributaries is shown in Figure 4-9. The median chlorophyll-*a* values were lowest at the upstream Nepean River reference site at Maldon Weir (N92), Stonequarry Creek (N911) and immediately downstream of the Stonequarry Creek confluence with the Nepean River at Maldon Bridge (N91). Chlorophyll-*a* concentrations progressively increased with distance downstream, including the tributaries sites. The highest median chlorophyll-*a* concentrations (≥10 μg/L) were observed in the lower Hawkesbury River at Wilberforce (N35), the Cattai SRA (N3001) and the Sackville Ferry (N26). The second highest median chlorophyll-*a* levels were recorded further downstream at Leets Vale (N18) and the Berowra Creek sites (both NB13 and NB11). Median chlorophyll-*a* concentrations exceeded the recommended site-specific HRC (1998) objective at these six sites.

The total algal biovolume reflects a similar trend along the river to chlorophyll-*a*, with a much higher biovolume at the downstream sites. Blue-green algal abundance was evident in the lower Hawkesbury River sites, as well as limited occurrences in South and Cattai creeks. The highest median total algal biovolume (10.34 mm^3/L) recorded for the Colo River reference site (N2202) was an outlier due to a single occurrence of the large filamentous blue-green alga *Mougeotia*.

The nutrient concentrations in South Creek (NS04) were poor, with both total nitrogen and total phosphorus median concentrations exceeding the site-specific HRC (1998) objective. The median total nitrogen concentration at Cattai Creek (NC11) also exceeded the HRC objective. These sites drain large semi-urban catchments, and receive continuous discharge from WWTPs. The median total nitrogen concentration in Stonequarry Creek downstream of the Picton WWTP discharge point (N911) was high (2.07 mg/L) and exceeded the site-specific water quality objective. It should be noted that this value was derived from mostly non-routine data (n=47) collected mainly during wet weather and precautionary discharge events. The median total nitrogen concentrations also exceeded the HRC objective at two sites further downstream along the Nepean River at Sharpes Weir (N75) and Wallacia Bridge (N67). Typically, high nutrient concentrations (nitrogen and phosphorus), were evident in the Hawkesbury River downstream of the South Creek. The median total phosphorus concentrations exceeded the HRC objective at Wilberforce (N35), Cattai SRA (N3001) and Leets Vale (N18), while the median total nitrogen concentration was the only nutrient to exceed the HRC objective at Wilberforce (N35). Both total nitrogen and total phosphorus median concentrations were also above the HRC objective levels at the upstream Berowra Creek site (NB13).

Among the freshwater sites, South Creek (NS04) had the highest median conductivity followed by Stonequarry Creek (N911) and Cattai Creek (NC11). Other physico-chemical parameters indicated poor water quality in South and Cattai creeks. The highest median turbidity and lowest median dissolved oxygen saturation were also associated with these sites (NS04 and NC11).



Horizontal lines: site-specific HRC (1998) guidelines, 20 µg/L for the tributary sites (N464, NS04 and NC11), 15 µg/L for urban main stream sites (N57 and N42); 7 µg/L for all other sites

Red boxes: Tributary sites

Figure 4-9 Longitudinal variation in chlorophyll-*a* along the Hawkesbury-Nepean River (upstream to downstream) and tributaries during 2016-17

Table 4-1 Median water quality values for all sites (2016-17)

Site codes	Chlorophyll-*a* (µg/L)	Total algal biovolume** (mm^3/L)	Blue-green algal biovolume** (mm^3/L)	Total nitrogen (mg/L)	Dissolved Inorganic nitrogen (mg/L)	Total phosphorus (mg/L)	Filterable total phosphorus (mg/L)	Conduct-ivity (µS/cm)	pH	Dissolved oxygen (%)	Dissolved oxygen saturation (%)	Tempe rature (°C)	Turbidity (NTU)
N92	2.3	2.074	0.001	0.33	0.12	0.012	0.006	230.0	7.6	9.4	98.6	16.6	1.6
N911#	2.9	0.519	0.000	2.07	1.43	0.022	0.008	668.5	7.9	9.9	98.0	14.9	10.5
N91	2.1	0.509	0.000	0.36	0.15	0.013	0.006	232.5	7.6	9.4	97.7	18.3	2.3
N75	4.3	1.442	0.001	0.83	0.55	0.014	0.006	264.0	7.3	8.9	95.1	19.2	5.8
N67	4.3	1.922	0.005	0.91	0.63	0.019	0.006	339.5	7.1	8.4	90.9	18.6	9.3
N57	5.6	2.670	0.042	0.50	0.19	0.014	0.005	227.0	7.5	9.2	99.1	19.1	4.5
N51	3.2	2.661	0.010	0.52	0.22	0.015	0.006	256.0	7.6	9.2	99.9	18.6	5.0
N48	6.9	3.024	0.050	0.56	0.16	0.018	0.006	273.0	7.6	8.3	97.6	23.6	3.7
N464*	3.9	2.174	0.025	0.84	0.52	0.022	0.007	265.0	7.6	9.1	98.5	19.1	4.1
N44	5.4	3.519	0.108	0.56	0.21	0.020	0.006	244.0	7.6	9.2	95.4	19.0	6.3
N42	7.2	1.268	0.015	0.52	0.21	0.020	0.006	219.0	7.4	8.9	97.6	19.6	7.6
N39	6.1	3.528	0.069	0.53	0.22	0.019	0.006	222.0	7.3	9.3	98.3	19.6	6.3
NS04*	5.8	1.262	0.002	2.53	1.78	0.111	0.035	1040.5	7.4	7.0	72.0	19.3	53.0
N35	10.1	2.477	0.039	0.74	0.34	0.043	0.011	318.0	7.4	7.2	84.9	20.2	14.0
NC11*	4.1	5.191	0.033	1.49	1.06	0.043	0.011	509.5	7.1	6.1	61.0	18.4	21.5
N3001	10.6	3.069	0.059	0.69	0.31	0.037	0.009	314.0	7.5	8.1	88.7	20.0	14.0
N26	10.0	4.066	0.078	0.62	0.29	0.033	0.010	276.5	7.5	7.7	88.5	20.3	13.0
N2202	0.6	10.841	0.013	0.17	0.05	0.006	0.003	162.0	6.9	8.6	89.4	17.4	2.0
N18	7.9	1.692	0.018	0.65	0.25	0.044	0.011	319.0	7.3	7.3	81.5	20.2	17.5
NB13**	8.0	2.821	0.000	0.40	0.07	0.031	0.013	31300.0	7.7	7.4	95.2	21.0	2.6
NB11	7.7	3.566	0.000	0.36	0.03	0.025	0.011	36550.0	7.8	7.1	93.6	20.7	6.0

shaded cells, exceeded the site-specific guideline

* tributary sites

** may not represent actual situation as algal counts were made only on high chlorophyll-a samples

\# may not reflect the routine situation as large volume of samples (n-46) from wet weather discharge events

4.4 Site-specific water quality and algae

The detailed results of trend analysis for all 21 sites along the Hawkesbury-Nepean River from Maldon Weir in the upper reaches to Leets Vale in the lower reaches and its major tributaries (Stonequarry, South, Cattai and Berowra creeks, Colo River and Winmalee Lagoon) are included in Appendix E (Table E-1).

This section includes discussion on the trends for all water quality parameters at the 11 key sites, however only a few example plots are included. All trend plots for all water quality parameters at the 11 key sites are presented in Appendix E (Figure E-2 to Figure E-12). These 11 sites were considered important as they represented either a reference site, a site where long-term datasets were available, a site with historical water quality problems such as algal blooms, a site that could be potentially impacted by Sydney Water WWTP discharges or is strategically located in relation to volume discharged or previous modelling data being available.

The Spearman Correlation Analysis outcome is discussed/interpreted in this section to identify the factors effecting nutrients, chlorophyll-*a* and algae at each site. Further details on Spearman Correlation Analysis are included in Chapter 5 and Appendix F. The general long-term trend in algal species diversity by five key taxonomic groups is also presented in this section.

4.4.1 Nepean River at Maldon Weir (N92)

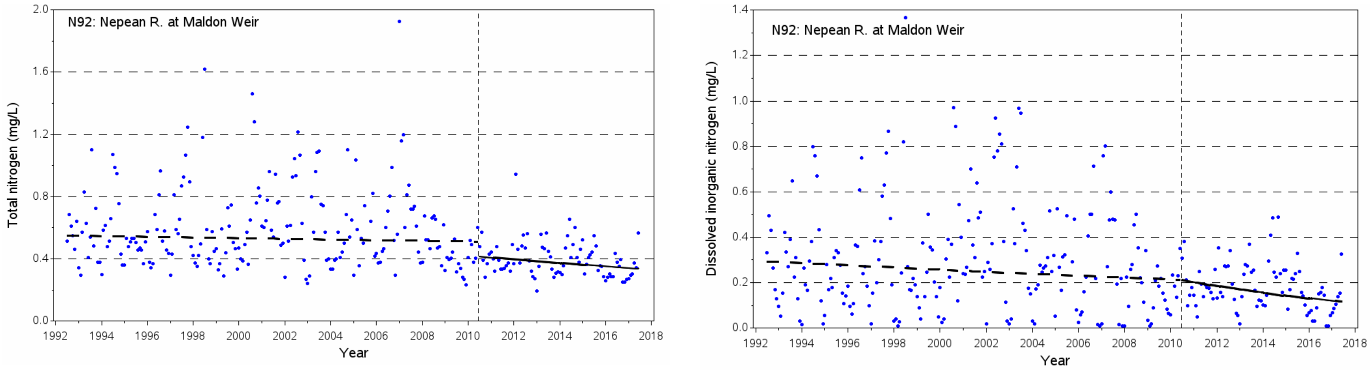
The Nepean River site at Maldon Weir (N92) is the reference site for this study, being located upstream of all Sydney Water WWTP discharge points. The water quality at this site is influenced by other upstream catchment factors as it receives inflows from the Nepean River catchment and environmental flows from the Nepean, Avon and Cordeaux dams. The upstream catchment is a protected drinking water supply catchment and consists mainly of native bushland and forest. There are also small agricultural (beef and dairy cattle) areas and rural residential development.

Trend analysis was conducted for the entire 25-year period with two distinct periods, before and after the commencement of environmental flow releases from the upstream dams in 2010. A maximum of 298 monthly observations, 214 for the pre-release (historical) and 84 for the post-release (short-term) period, were used to perform the trend analysis.

The trend analysis on the flow-adjusted data identified significantly decreasing trends ($p<0.05$) in total nitrogen (25%), dissolved inorganic nitrogen (49%) and turbidity (35%) at Maldon Weir (N92) in the last 25 years from 1992 to 2017. Using flow adjusted data removes any impact of wet weather. The analysis also revealed a significantly increasing trend in pH (3%) and dissolved oxygen (8%) over the long-term. Although the algae dataset was patchy, with only 114 observations available for analysis compared to 298 for all other parameters, significantly increasing trends in total algal biovolume and blue-green algal biovolume were also detected. These trends may not represent the actual situation given the limitation on the algal dataset where samples were not analysed for algae when the chlorophyll-*a* concentrations were low. No significant trends were detected in chlorophyll-*a*, total phosphorus, filterable total phosphorus, dissolved oxygen saturation and temperature between 1992 and 2017.

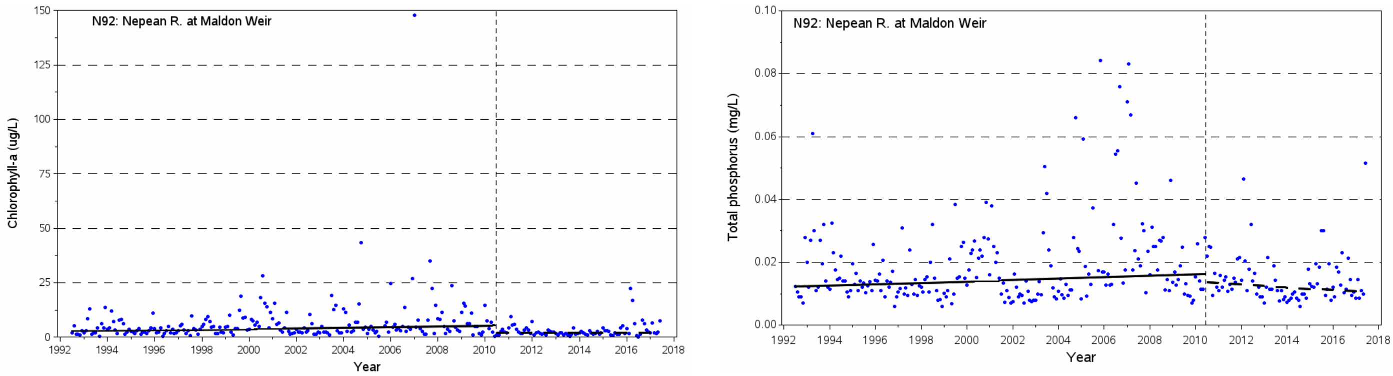
The characteristics of environmental flows are different in terms of nutrients, conductivity and pH which may have influenced the downstream Nepean River water quality at Maldon Weir. Therefore, it is appropriate to further discuss step trend analysis outcomes for the two different periods. The analyses identified a positive influence from the environmental flow releases on water quality at this site. There was a noticeable reduction in total nitrogen and dissolved inorganic nitrogen concentrations after environmental flow releases commenced in 2010, with both parameters significantly decreasing during the last six years to 2017 (Figure 4-10). Total nitrogen decreased by about 18% and dissolved inorganic nitrogen by about 44%.

During the pre-environmental release period from 1992 to 2010 (historical), significantly increasing trends were detected in chlorophyll-*a* (96%), total phosphorus (32%) and filterable total phosphorus (78%) (Figure 4-11; Appendix E: Figure E-2). This suggests that anthropogenic loads may have had some influence on the phosphorus levels at Maldon Weir. No such influence on nitrogen levels was identified, as these remained stable. There were no significant trends identified for the post-environmental flow release period (2010-2017).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-10 Step trends in total nitrogen and dissolved inorganic nitrogen concentrations at Maldon Weir, Nepean River (N92)

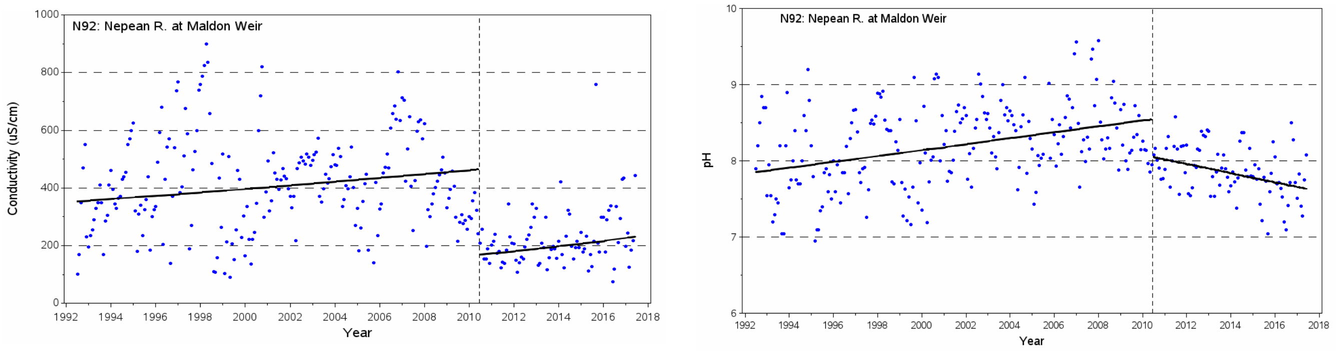


Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-11 Step trends in chlorophyll-*a* and total phosphorus concentrations at Maldon Weir, Nepean River (N92)

There was clear evidence of the environmental flows impacting conductivity and pH at this site (Figure 4-12). During the pre-release period from 1992 to 2010, conductivity significantly increased by 31%, while pH increased by 9%. However, following the commencement of environmental flows in 2010, both conductivity and pH immediately dropped. In the last six years to 2017, conductivity has again significantly increased by 37%, but pH has significantly decreased (5%).

All trend plots for the Nepean River at Maldon Weir are presented in Figure E-2 (Appendix E).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-12 Step trends in conductivity and pH at Maldon Weir, Nepean River (N92)

Spearman Correlation Analysis on the data collected between 2011 and 2017 showed that of the four nutrient parameters, only dissolved inorganic nitrogen was negatively and weakly correlated (Rho=-0.35, p=0.0003, n=104) with the chlorophyll-*a* concentrations. This indicated a possible uptake of dissolved inorganic nitrogen by the algae. Chlorophyll-*a* is positively and weakly correlated with temperature demonstrating seasonal influence in summer.

The nutrients and chlorophyll-*a* concentrations were relatively low at this reference site. Consequently, in the last six years, only seven samples exceeded the chlorophyll-*a* 7 µg/L threshold concentration and required algal counting. Therefore, the positive and negative correlation between total algal biovolume and blue-green algal biovolume with all other parameters were discarded.

Flow and turbidity were negatively and weakly correlated with chlorophyll-*a* concentrations, indicating algal wash-out due to dilution and increased turbidity in wet weather. This is demonstrated by a strong positive correlation between flow and turbidity (Rho=0.59, p=<0.0001, n=122). Similarly, flow and conductivity were strongly negatively correlated as the higher flow after rainfall contains low salt (Rho=-0.53, p=<0.0001, n=121).

The nutrient parameters were positively correlated to each other (total nitrogen vs total phosphorus, total nitrogen vs dissolved inorganic nitrogen etc) either strongly or moderately as expected. There was also a strong to moderately significant correlation found between nutrient parameters (both nitrogen and phosphorus) and turbidity indicating that the highly turbid runoff from the catchment carries high nutrient concentrations.

Total nitrogen, dissolved inorganic nitrogen and filterable total phosphorus were negatively correlated with temperature. This indicates nutrients were more available in winter when day light hours are shorter and the photosynthetic organisms have lower demand requirements.

The relationship between total nitrogen and dissolved inorganic nitrogen with flow was not significant. However, both total phosphorus and filterable total phosphorus were moderately and positively correlated to flow, demonstrating phosphorus is present in runoff from the catchment during wet weather.

The trend in algal composition for the Nepean River at Maldon Weir based on the five major taxonomic groups is shown in Figure 4-13. Generally, the trend was highly variable and the limited counts showed a dominance of monads and diatoms during recent years. No potentially toxic blue-green algae were recorded at this site in last two years.

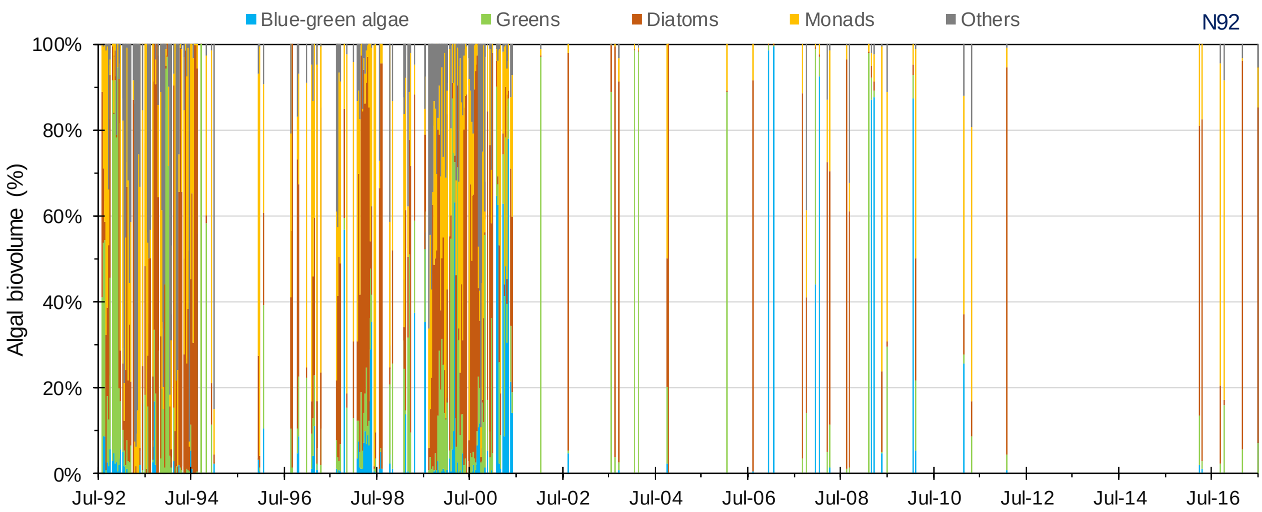


Figure 4-13 Algal composition at Maldon Weir, Nepean River (N92)

4.4.2 Stonequarry Creek at Picton Farm (N911)

The Stonequarry Creek at Picton Farm (N911) site is located immediately downstream of the precautionary discharge point from Picton WWTP. This is a key site due to the current WWTP operations, the potential impacts of proposed changes to the Picton WWTP precautionary discharge conditions and planned upgrades and amplification of the WWTP. The water quality at this site is also influenced by the inflows from Redbank Creek and the upstream Stonequarry Creek catchments. Monitoring at this site started from January 1997.

Trend analysis was conducted for the entire 20.5-year dataset with two distinct periods before and after the intensification of precautionary discharges from the Picton WWTP in 2010. Altogether a total of 239 monthly observations were recorded, with 155 for the historical and 84 for the short-term recent period used to perform the trend analysis.

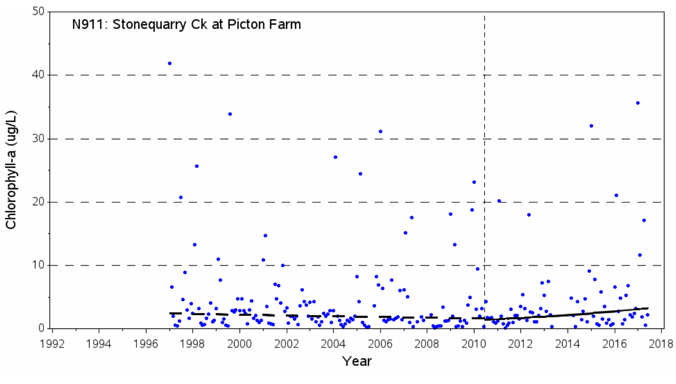
The results for the trend analysis performed on flow-adjusted long-term data (1997 to 2017) showed significant decreases ($p<0.05$) in total nitrogen (21%), total phosphorus (52%), filterable total phosphorus (46%), dissolved oxygen saturation (9%) and turbidity (33%). In contrast, a significantly increasing trend was detected for conductivity (26%). No significant trends were found for chlorophyll-*a*, dissolved inorganic nitrogen, pH, dissolved oxygen and temperature. The algal biovolume data was insufficient to perform any trend analysis.

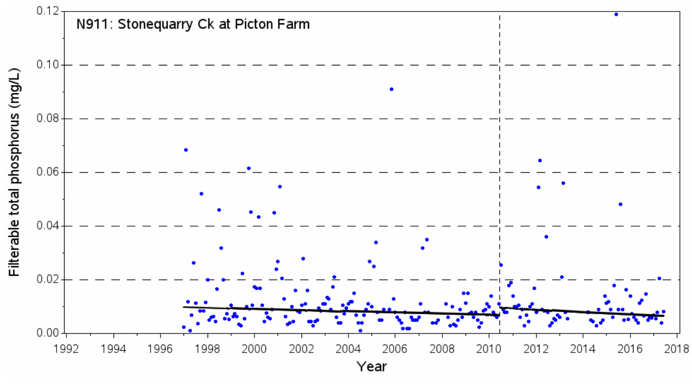
Step trend analysis found that all nutrient parameters significantly decreased in the historical period between 1997 and 2010. Total nitrogen decreased by 32%, dissolved inorganic nitrogen by 50%, total phosphorus by 35% and filterable total phosphorus by 28%. This trend reflects the benefits of Sydney Water's amplification of its wastewater network and the establishment of the Picton WWTP and on-site recycling scheme servicing this catchment. From 2010, there were no significant short-term trends identified in total nitrogen, dissolved inorganic nitrogen and total phosphorus concentrations in Stonequarry Creek.

Very high chlorophyll-*a* concentrations have historically been observed at the Stonequarry Creek site (N911), as well as in recent years (Figure 4-14). Step trend analysis identified a significant increase in chlorophyll-*a* concentrations (125%) and a significant decrease in filterable total phosphorus concentrations (32%) between 2010 and 2017 (Figure 4-14). There were no significant trends identified in other nutrient parameters for this period. There was insufficient algal data for the step trend analysis.

Conductivity significantly increased (14%) and pH significantly decreased (4%) at this site in the short-term between 2010 and 2017 (Figure 4-15). This may be linked with the increasing level of discharges from Picton WWTP in recent years. In the historic period between 1997 and 2010, pH showed a significant upward trend (4%).

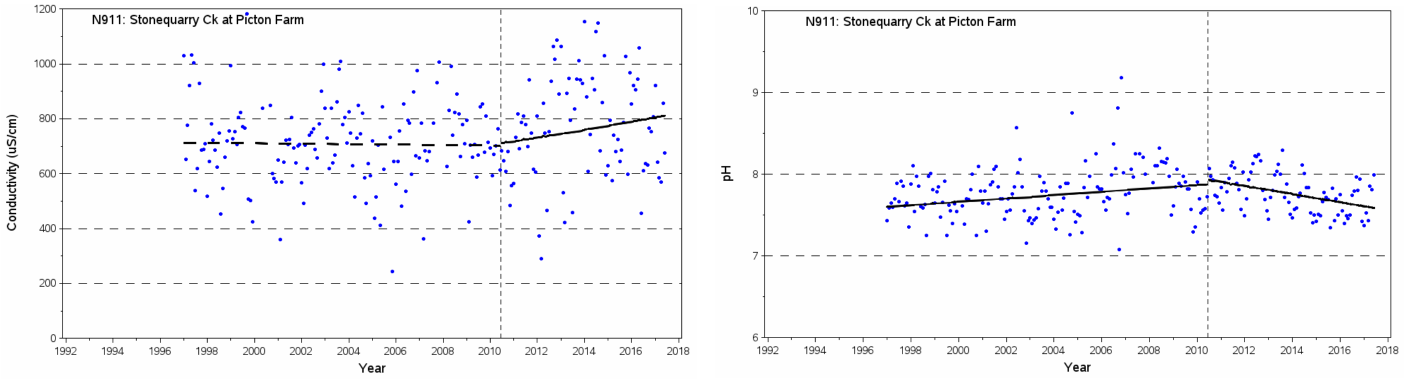
All trend plots for Stonequarry Creek are presented in Figure E-3 (Appendix E).





Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-14 Step trends in chlorophyll-*a* and filterable total phosphorus concentrations at Stonequarry Creek (N911), downstream of precautionary discharge point



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-15 Step trends in conductivity and pH at Stonequarry Creek (N911), downstream of precautionary discharge point

Spearman Correlation Analysis on the data collected between 2011 and 2017 indicated that the chlorophyll-*a* concentration is moderately/weakly correlated with Picton WWTP's total phosphorus load (Rho=0.31, p=0.0177, n=57) along with the total phosphorus (Rho=0.49, p=<0.0001, n=128) and filterable total phosphorus (Rho=0.37, p=0.0001, n=104) concentrations. The limited total algal biovolume data also demonstrated a significant positive correlation with the total phosphorus loads and total phosphorus concentrations. That is, when the total phosphorus load and the total phosphorus concentrations increased, chlorophyll-*a* and total algal biovolume also increased at this site.

The total algal biovolume at this site was also weakly and positively correlated with Picton WWTP's total nitrogen load, but negatively correlated with the total nitrogen and dissolved inorganic nitrogen concentration. This indicates a possible uptake of nitrogen by the algae. Chlorophyll-*a* is moderately correlated with temperature demonstrating seasonal influence during summer.

The Spearman Correlation Analysis also revealed that, total nitrogen and dissolved inorganic nitrogen concentrations were not significantly correlated with the total nitrogen load from the Picton WWTP. However, the total phosphorus load from Picton WWTP was strongly correlated with the total phosphorus (Rho=0.71, p=<0.0001, n=72) and filterable total phosphorus (Rho=0.68, p=<0.0001, n=34) concentrations. That is, the total nitrogen loads from Picton WWTP are not significantly contributing to the total nitrogen concentrations in Stonequarry Creek, while the phosphorus loads are contributing to the phosphorus concentrations in Stonequarry Creek.

Flow was strongly and positively correlated with the total nitrogen and total phosphorus loads and nutrient concentrations (all four parameters). This is expected as the precautionary discharges only occur during wet weather. Turbidity also demonstrated the same strong positive correlation with the nutrient concentrations and moderate correlation with the total nitrogen and total phosphorus loads. This indicates that the turbid water contains more nutrients and some contribution from nutrient loads from Picton WWTP.

The limited algal biovolume data for Stonequarry Creek is displayed based on the five major taxonomic groups in Figure 4-16. The recent algal counts were mostly performed for a special investigation on precautionary discharges and were irrespective of chlorophyll-*a* concentrations thresholds. Generally, the trend was highly variable, with monads and diatoms being the most dominant groups in 2016-17. One blue-green algal bloom was identified in April 2017 when the potentially toxic *Microcystis* was present in high densities (60,800 cells/mL).

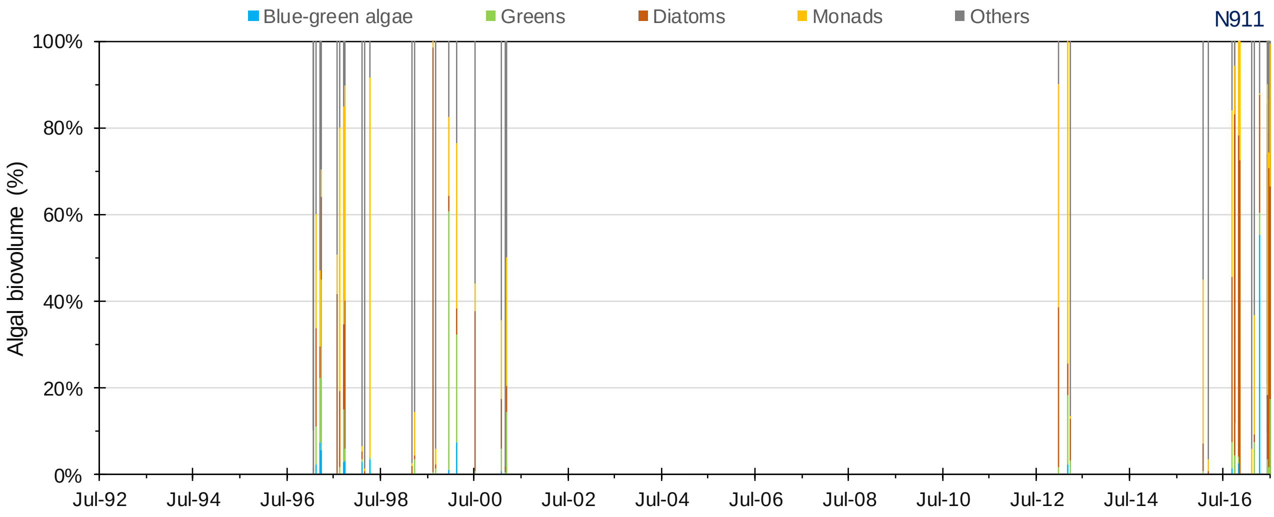


Figure 4-16 Algal composition at Stonequarry Creek (N911), downstream of discharge point

4.4.3 Nepean River at Maldon Bridge (N91)

The Nepean River at Maldon Bridge (N91) is located immediately downstream of the confluence with Stonequarry Creek. The water quality at this site is influenced by the water quality from the upstream Stonequarry Creek and precautionary discharges from Picton WWTP during wet weather, as well as from the upstream Nepean River catchment and environmental flow releases. This site was not considered a key site for detailed analysis and interpretation.

Trend analysis was conducted for the entire 25-year period and for the two distinct periods before and after the commencement of environmental flow releases from the upstream water storages in 2010. A maximum of 285 monthly observations including 201 for the pre-release (historical) and 84 for the post-release (short-term) period were used to perform the trend analysis.

The analysis on the short-term data (2010 to 2017) revealed decreasing trends in dissolved inorganic nitrogen (36%), total phosphorus (26%) and pH (4%). A significant increasing trend was identified for conductivity (28%). No significant trends were identified for any other water quality parameters between 2010 and 2017.

Further detailed results of the long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.4 Nepean River at Sharpes Weir (N75)

The Nepean River at Sharpes Weir (N75) is located immediately downstream of Matahil Creek which transports continuous discharges from the West Camden WWTP. This site is classified as a key site for this study. The West Camden WWTP is a tertiary treatment plant with an efficient phosphorus removal process but had limited nitrogen removal capacity prior to 2009. Following the completion of upgrade works in 2008-09, nutrient concentrations in the wastewater discharges was much lower than past concentrations. However, in recent years, the nitrogen concentrations in discharge from the West Camden WWTP has increased again. The level of precautionary discharges has increased in recent years as the plant reaches its design capacity. Beyond this, agricultural farms and other rural developments in Matahil and upstream catchments of the Nepean River are likely to influence the water quality at this site. Historically, the nutrients and algae levels at this site were poor compared to the upstream reference site.

Trend analysis was conducted for the entire 25-year period as well as for two distinct periods before and after the major upgrade works at West Camden WWTP in 2008-09. A maximum of 295 monthly observations, with 190 for the historical period and 105 for the short-term periods were used to perform the trend analysis.

Results of the trend analysis performed on the flow-adjusted data show that there have been significant decreases ($p<0.05$) in total nitrogen (22%), total phosphorus (22%) and turbidity (36%) in the last 25 years from 1992 to 2017. There has also been a significant increase in the water temperature at this site over the long-term. No significant trends were detected in chlorophyll-*a*, total algal biovolume, blue-green algal biovolume, dissolved inorganic nitrogen, filterable total phosphorus, conductivity, pH, dissolved oxygen and dissolved oxygen saturation between 1992 and 2017.

Step trend analysis revealed a positive influence from the West Camden WWTP upgrade and amplification. Total nitrogen and dissolved inorganic nitrogen concentrations decreased at Sharpes Weir (N75) after the completion of upgrade works to remove nitrogen in September 2008. Total phosphorus and filterable total phosphorus also decreased after the completion of phosphorus upgrade works in March 2009.

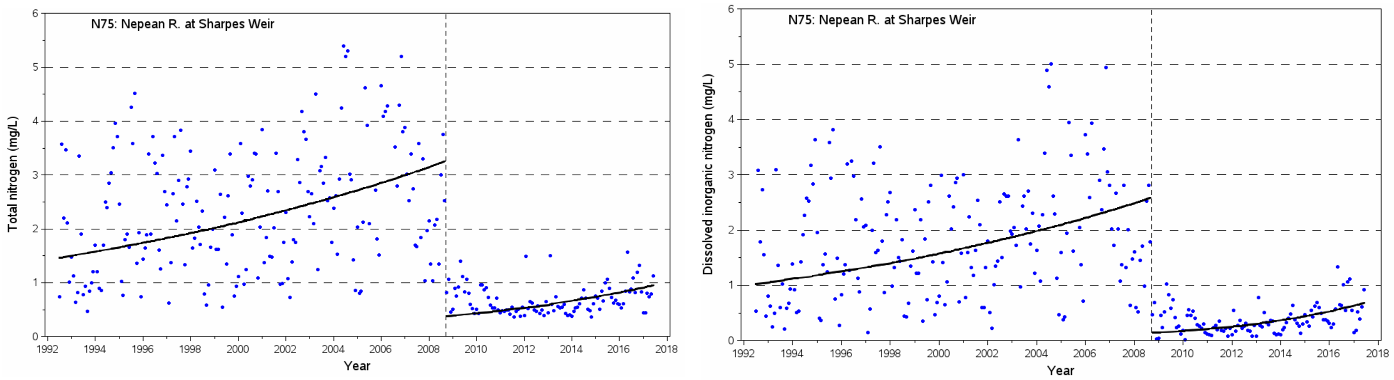
Step trend analysis did not identify a trend in either chlorophyll-*a* or total algal biovolume during the historical period from 1992 to 2008, but during the short-term period (2008-2017), the chlorophyll-*a* concentration significantly decreased (39%) at this site. Although limited algal data was available, it showed a significant increasing trend in total algal biomass in the more recent short-term period from 2008 to 2017.

Total nitrogen and dissolved inorganic nitrogen concentrations at Sharpes Weir (N75) significantly increased during the historical period by 122% and 152%, respectively (Figure 4-17). From the low concentrations after the upgrade works, both total nitrogen and dissolved inorganic nitrogen concentrations significantly increased again between 2008 and 2017. Total nitrogen has increased by about 151% and dissolved inorganic nitrogen by about 386% during the last nine years. This increasing concentration of nitrogen at Sharpes Weir (N75) reflects the increasing trend in nitrogen loads from West Camden and Picton WWTPs located in the upper Nepean River sub-catchment. Population growth in Sydney's south west corridor has resulted in increased servicing needs in this area in recent years.

Consistent with nitrogen, total phosphorus and filterable total phosphorus also showed a significantly increasing trend during the historical period, but to a much lesser magnitude (48% and 131% increase, respectively) (Figure 4-18). However, during the short-term recent period, total phosphorus significantly decreased by 18% (from 2009 to 2017).

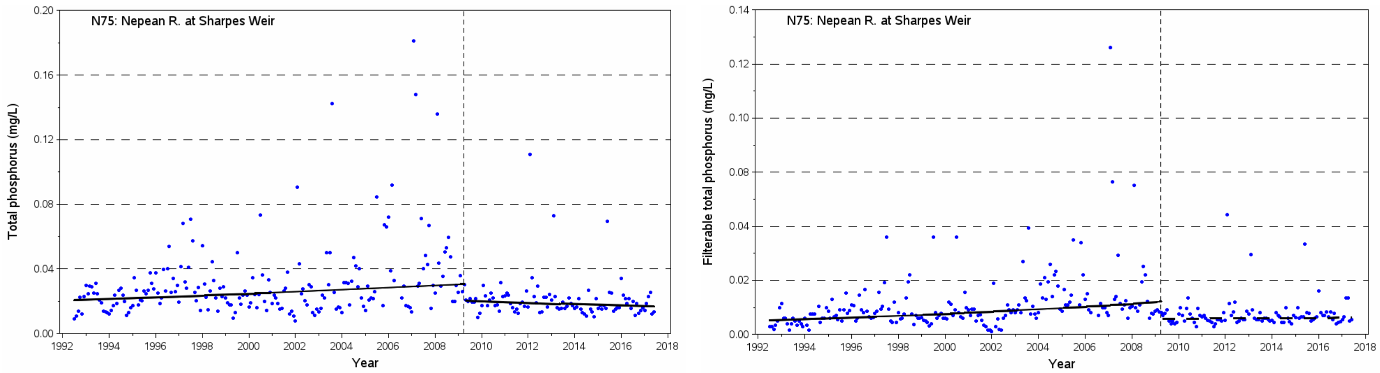
There was clear evidence of the West Camden WWTP upgrade on conductivity and pH (Figure 4-19). Both parameters significantly increased in the historical period between 1992 and 2008 (65% and 6% increase, respectively), however the upgrade works contributed an immediate drop in conductivity. During the short-term period (2008 to 2017) both conductivity and pH continued to significantly decrease (16% and 5%, respectively).

All trend plots for the Nepean River at Sharpes Weir are presented in Figure E-4 (Appendix E).



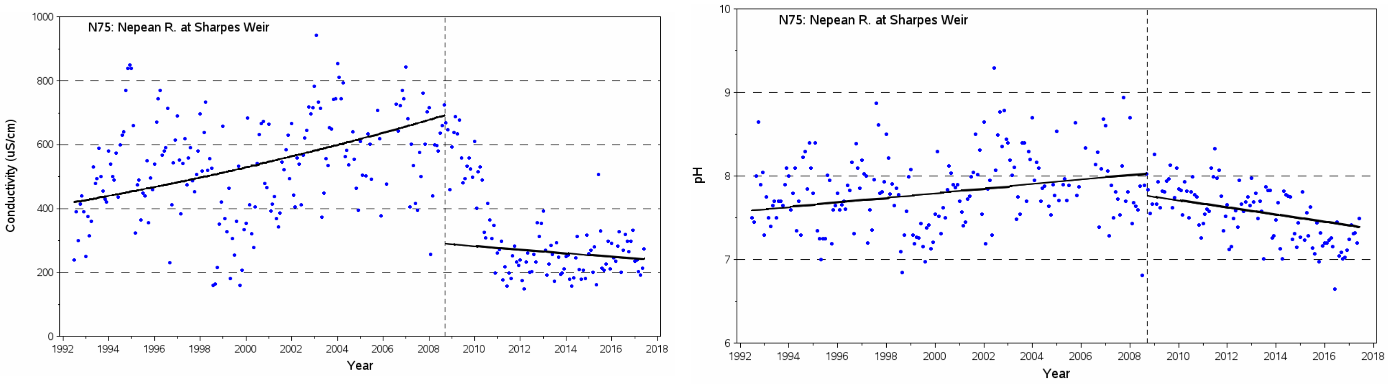
Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-17 Step trends in total nitrogen and dissolved inorganic nitrogen concentrations at Sharpes Weir, Nepean River (N75)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-18 Step trends in total phosphorus and filterable total phosphorus concentrations at Sharpes Weir, Nepean River (N75)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-19 Step trends in conductivity and pH at Sharpes Weir, Nepean River (N75)

Spearman Correlation Analysis results identified that the chlorophyll-*a* concentration in the Nepean River at Sharpes Weir (N75) was not significantly correlated with the total phosphorus and filterable total phosphorus concentrations and total phosphorus loads from Sydney Water's WWTPs. However, chlorophyll-*a* showed strong negative correlation with the total nitrogen load from Picton and West Camden WWTPs (Rho=-0.58, p=<0.0001, n=103) and a significant weak negative correlation with total nitrogen (Rho=-0.31, p=0.0014, n=104) and dissolved inorganic nitrogen (Rho=-0.36, p=0.0002, n=104) possibly indicating nitrogen utilisation by algae when they are in high numbers. As expected, chlorophyll-*a* and blue-green algal biovolume were significantly and negatively correlated with flow because of the wash-out effect and positively correlated with temperature, which supports more algal growth in the warmer summer months.

Total nitrogen and dissolved inorganic nitrogen concentrations were strongly and positively correlated with the total nitrogen loads from Picton and West Camden WWTPs. Similarly, total phosphorus and filterable phosphorus concentrations were also strongly correlated with the total phosphorus load. This confirms that the wastewater discharges influence nutrient concentrations in the Nepean River at Sharpes Weir (N75).

The relationship between total nitrogen/dissolved inorganic nitrogen with the site-specific flow and turbidity was insignificant. However, total/filterable total phosphorus was strongly correlated with the turbidity and moderately and weakly correlated with the flow. This reinforces the influence of high flow and turbid water on phosphorus concentrations at this site.

The trend in algal composition data for the Nepean River at Sharpes Weir (N75) based on the five major taxonomic groups is shown in Figure 4-20. Generally, the trend was highly variable and showed a dominance of monads and other types of algae during recent years. In the past, blue-green algae were periodically dominant but more recently there has been no blue-green algal blooms evident. The most common potentially toxic alga *Microcystis* was not found at this site in the last two years.

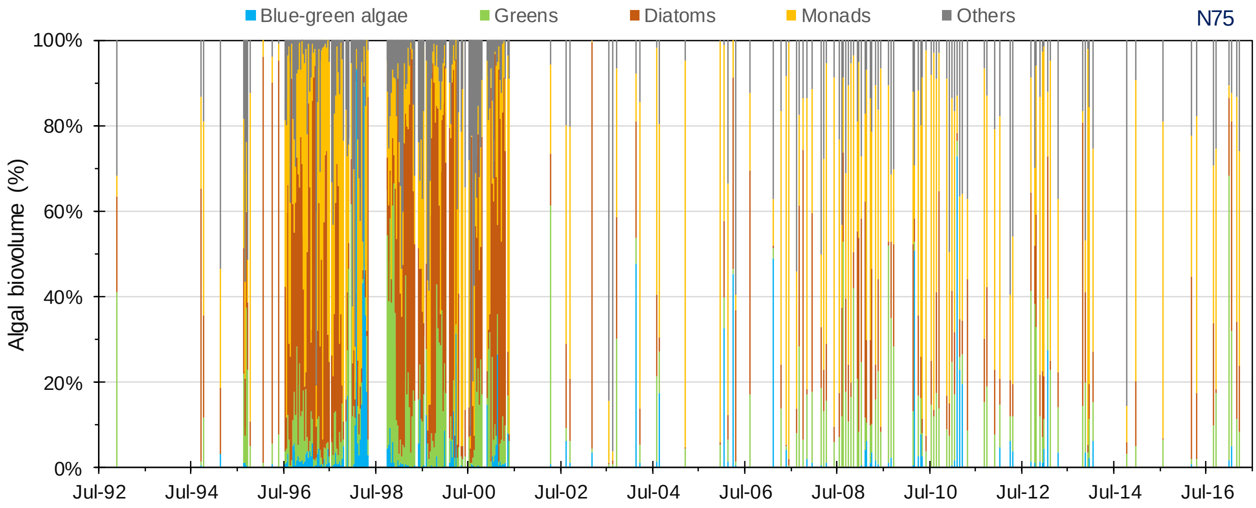


Figure 4-20 Algal composition at Sharpes Weir (N75)

4.4.5 Nepean River at Wallacia Bridge (N67)

The Nepean River at Wallacia Bridge (N67) is located approximately 30 km downstream of the Sharpes Weir (N75) site and 4 km upstream of the Warragamba River confluence. The area between these sites is primarily natural undeveloped catchment. The water quality and algal densities improved at this site compared to the upstream sites due to nutrient assimilation and loss processes such as sedimentation with minimal influx of nutrients. This site was not considered a key site for detailed analysis and interpretation due to large data gaps.

There was a large data gap at this site as water quality monitoring was suspended from 2000 to June 2008, and only re-commenced under the current monitoring program. Trend analysis was conducted for the entire 25-year period and for the two distinct periods before and after 2011. A maximum of 224 monthly observations, 152 for the historical period and 72 for the short-term recent period was used to perform the trend analysis.

The analysis of last six years data (2011-2017) revealed a decreasing trend in chlorophyll-*a* (52%) and pH (8%). Significant increasing trends were identified for total nitrogen (73%) and dissolved inorganic nitrogen (166%) between 2011 and 2017. No significant trend was identified for any other parameter for the recent period.

Detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.6 Nepean River at Penrith Weir (N57)

The Nepean River at Penrith Weir (N57) is located 21 km downstream of the Wallacia Bridge (N67) site with the immediate upstream catchment largely undeveloped. The Warragamba River joins the Nepean River upstream of the Penrith Weir, carrying discharge from the Wallacia WWTP and environmental flow releases from Warragamba Dam. Nutrients that entered via Matahil Creek from the West Camden WWTP and via the Warragamba River from Wallacia

WWTP experience long residence time and distance for assimilation, as well as dilution by low nutrient water from Warragamba Dam before reaching this site. Consequently, the nutrient levels (both nitrogen and phosphorus) decreased compared to the upstream sites. Due to the long residence time for WWTP derived nutrients, upstream catchment influences and a complete dataset, this site was classified as a key site.

Trend analysis was conducted for the entire 25-year period along with the two distinct periods before and after 2011 when major upgrade work on the upstream WWTPs were completed. A maximum of 298 monthly observations including 226 for the historical period and 72 for the short-term recent period was used to perform the trend analysis.

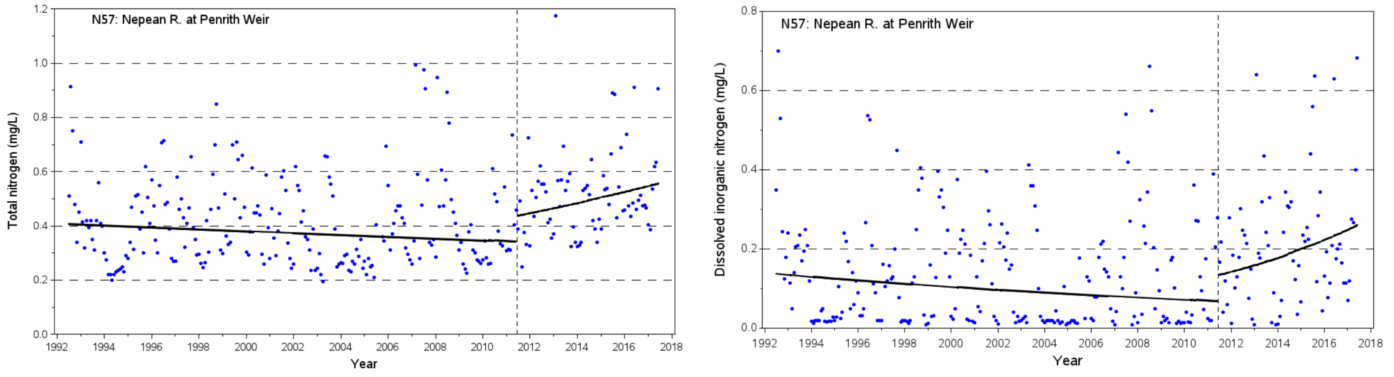
Results of the trend analysis on the flow-adjusted data showed that there was an overall deterioration in phosphorus, chlorophyll-*a* and algal condition at this site over the 25 years from 1992 to 2017. There were significant increases ($p<0.05$) in chlorophyll-*a* (76%), total algal biovolume (307%), total phosphorus (16%) and filterable total phosphorus (21%) during this period. No significant long-term trends were detected in the other water quality parameters (blue-green algal biovolume, total nitrogen, dissolved inorganic nitrogen, conductivity, pH, dissolved oxygen, dissolved oxygen saturation, temperature and turbidity).

The transfer of flow from Warragamba WWTP to the new Wallacia WWTP and the Glenbrook WWTP to Penrith WWTP, along with the commencement of increased environmental flows from Warragamba Dam are most likely responsible for improving the Nepean River water quality at Penrith Weir (N57) in the earlier years. Step trend analysis revealed significantly decreasing trends in total nitrogen (15%) and dissolved inorganic nitrogen (50%) during the historical period from 1992 to 2011. However, the trend is reversed in the short-term recent years, with both total nitrogen and filterable total nitrogen concentrations showing increases (27% and 93%, respectively) between 2011 and 2017 (Figure 4-21).

There was no significant trend identified in total phosphorus or filterable total phosphorus during the historical period, but concentrations of both parameters decreased significantly (26% and 24%, respectively) in the short-term from 2011 to 2017 (Figure 4-22).

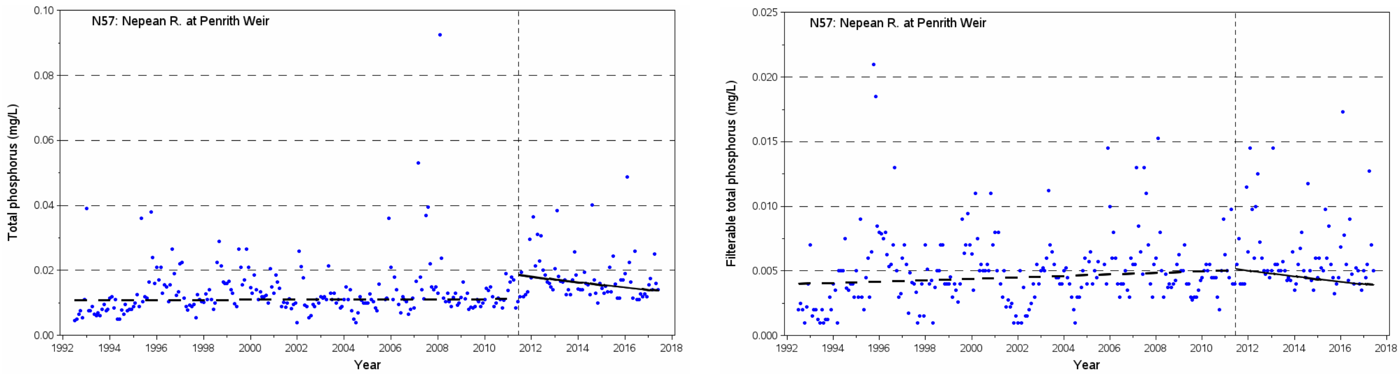
During 1992 to 2011, pH at Penrith Weir (N57) increased significantly (6%), but as with the upstream Nepean River sites, the pH at this site decreased significantly (6%) during the short-term from 2011 to 2017. No trend in conductivity was found either in historical or short-term periods.

All trend plots for the Nepean River at Penrith Weir are presented in Figure E-5 (Appendix E).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-21 Step trends in total nitrogen and dissolved inorganic nitrogen concentrations at Penrith Weir, Nepean River (N57)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-22 Step trends in total phosphorus and filterable total phosphorus at Penrith Weir, Nepean River (N57)

The results from the Spearman Correlation Analysis indicated that total nitrogen, dissolved inorganic nitrogen, total phosphorus and filterable total phosphorus in the Nepean River at Penrith Weir (N57) were not significantly correlated to the site-specific total nitrogen and phosphorus loads, respectively. This confirms that the upstream Sydney Water WWTPs had no noticeable contribution to nutrient concentrations at Penrith Weir (N57).

Spearman Correlation Analysis also confirmed that site-specific nutrient loads (both total nitrogen and total phosphorus) and chlorophyll-*a* were not significantly correlated. The dissolved inorganic nitrogen concentration was significantly and negatively correlated with the chlorophyll-*a* (Rho=- 0.41, p=<0.0001, n=104), total algal biovolume (Rho=0.-0.34, p=0.0118, n=55) and blue-green algal biovolume (Rho=-0.49, p=0.0001, n=55). This explains the dynamic nature within the water column where algae and macrophyte use up the readily available form of nitrogen.

As expected, chlorophyll-*a* was strongly/moderately and positively correlated to the total algal biovolume, temperature and negatively correlated to site-specific flow. Blue-green algal biovolume was strongly and positively correlated with the temperature confirming the dominance in summer.

The relationships of total nitrogen/dissolved inorganic nitrogen and total/filterable total phosphorus with the site-specific flow and turbidity were all significant. This again confirms the influence of high flow in wet weather and turbid water on nitrogen and phosphorus concentrations.

The trend in algal composition in the Nepean River at Penrith Weir (N57) based on the five major taxonomic groups is shown in Figure 4-23. No specific trend in algal composition could be determined because of the limited algal biovolume data. In general, monads, diatoms and other types of algae were dominant. Blue-green algae have not usually been dominant at this site historically or in more recent years. The most common potentially toxic blue-green algae, *Microcystis* was not found at this site in the last two years.

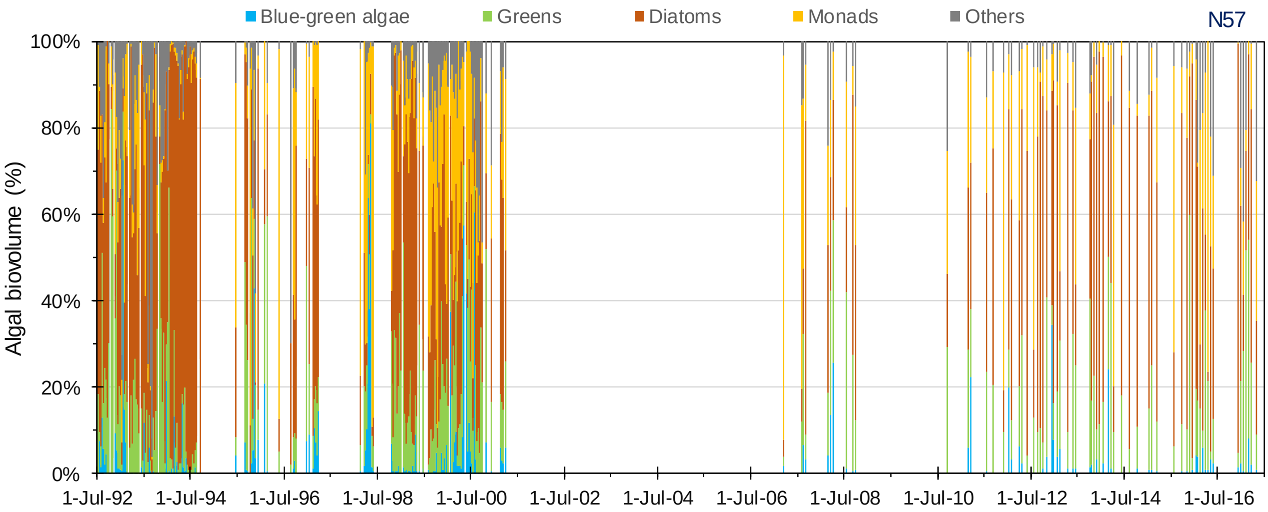


Figure 4-23 Algal composition at Penrith Weir, Nepean River (N57)

4.4.7 Nepean River opposite Fitzgeralds Creek (N51)

The Nepean River site opposite Fitzgeralds Creek (N51) is located approximately 5 km downstream from Penrith Weir. Penrith WWTP discharges treated wastewater to Boundary Creek, a small tributary entering the Nepean River below Penrith Weir. The Penrith WWTP was upgraded in 2001-02 to improve phosphorus and nitrogen removal capacity from the wastewater. Additionally, advanced treatment recycled water from the St Marys AWTP began discharging into Boundary Creek from late 2010, with approx. 75% of Penrith WWTPs tertiary treated wastewater diverted to the St Marys AWTP for treatment. There are also mining and agricultural activities in this region that may impact the water quality at this site. The site often contains submerged macrophyte beds and the occasional floating macrophyte species. This site was not considered a key site, therefore minimal commentary on water quality trends is provided.

The historical water quality monitoring site at BMG causeway (N53), located immediately downstream of Boundary Creek, was discontinued as a routine monitoring site in July 2008. At that time, this new monitoring site further downstream at Fitzgeralds Creek (N51) was established.

Trend analysis was conducted for the entire dataset (9 years) and for the two distinct periods for before and after the major WWTP upgrade works and the commissioning of the St Marys AWTP in September 2010. A maximum of 106 monthly observations, 36 for the historical and 70 for the short-term period were used to perform the trend analysis.

The analysis on the data for the last six years from 2011 to 2017 revealed decreasing trends in chlorophyll-*a* (55%) and total phosphorus (34%). In the short-term, significantly increasing trends were identified in total nitrogen (55%), dissolved inorganic nitrogen (153%) and conductivity (40%). No significant trend was identified in any of the other parameters for this period between 2011 and 2017.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.8 Nepean River at Smith Road (N48)

The Nepean River site at Smith Street (N48) is a further 5 km downstream from the Fitzgeralds Creek (N51) site. There are no wastewater discharges from Sydney Water's WWTPs in the vicinity of this site other than the upstream Penrith WWTP. This site often contains submerged macrophyte beds with occasional floating macrophyte species. This site was not considered a key site therefore minimal commentary on water quality trends is provided.

Trend analysis was conducted for the entire 25-year period and for the two distinct periods for before and after the major WWTP upgrade works in 2011 to improve nutrient removal. A maximum of 289 monthly observations, 221 for the historical and 68 for the short-term recent period were used to perform the trend analysis.

Analysis of the data for the last six years from 2011 to 2017 identified a decreasing trend in total phosphorus (20%). Significant increasing trends were identified for total nitrogen (55%), dissolved inorganic nitrogen (158%) and conductivity (26%) in this period. No significant trend was identified in any other parameters for the short-term.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.9 Winmalee Lagoon outflow at Springwood Road (N464)

The Nepean River divides into two separate branches immediately downstream of the Smith Road site (N48). The eastern branch bypasses the Winmalee Lagoon and rejoins the mainstream river approximately two kilometres downstream. The western branch flows via the Winmalee Lagoon rejoining the mainstream of the river just prior to the unnamed creek which transports continuous discharge from Winmalee WWTP. After diverting the wastewater from all Blue-Mountains WWTPs to Winmalee, the overall volume of wastewater discharge increased. The Winmalee Lagoon (N464) sampling site is located at the lagoon outflow, about half way through on the left branch of the Nepean River. This site is considered as a key site because of the impact from Winmalee WWTP, an ongoing Pollution Reduction Program and a future planned upgrade.

Submerged macrophyte beds are abundant in the Winmalee Lagoon, with the occasional floating macrophytes from time to time. Since macrophytes assimilate nutrients and release them back to the water column (depending on their growth and removal by floodwaters) it is not appropriate to only use chlorophyll-*a,* (an indicator of planktonic algae only) to assess nutrient enrichment or reduction.

This site is not a regular compliance monitoring site for the Winmalee WWTP under the STSIMP. As such, there was no monitoring between 2011 and 2014. Despite this data gap, trend analysis was conducted for the entire period and for the period prior to major nutrient removal works completed by 2011.

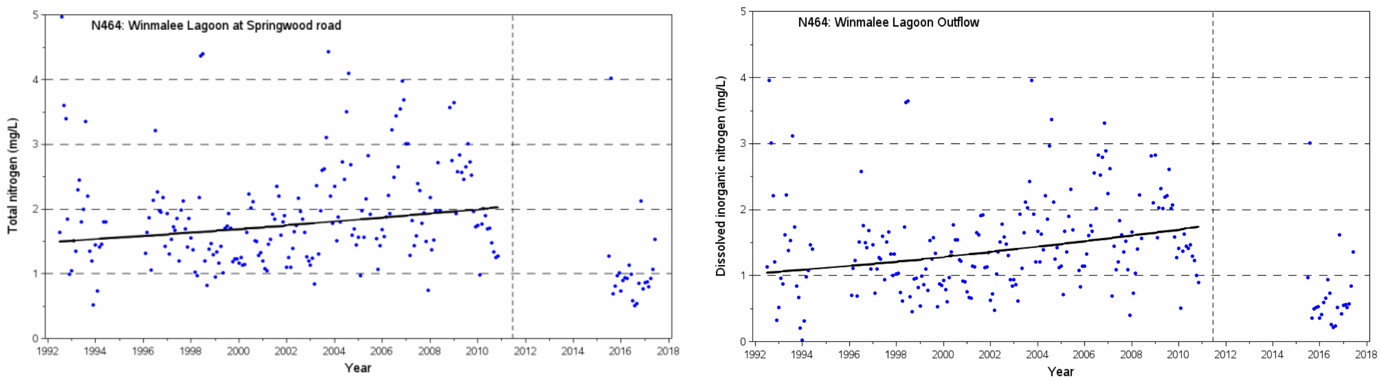
Trend analysis was conducted on a maximum of 220 monthly observations, with 196 observations used for the historical pre-upgrade period. The short-term recent data was insufficient to perform any trend analysis as only 24 monthly observations were recorded.

Results of the trend analysis performed on the flow-adjusted data identified significant decreases ($p<0.05$) in chlorophyll-*a* (64%), total phosphorus (47%), filterable total phosphorus (72%) and turbidity (36%) in the last 25 years from 1992 to 2017. In contrast, the limited total algal biovolume data indicated a significantly increasing trend over the long-term. Water temperature also significantly increased over the last 25 years from 1992 to 2017 at this site.

No significant long-term trends were detected in any other water quality parameters (blue-green algal biovolume, total nitrogen, dissolved inorganic nitrogen, conductivity, pH, dissolved oxygen and dissolved oxygen saturation).

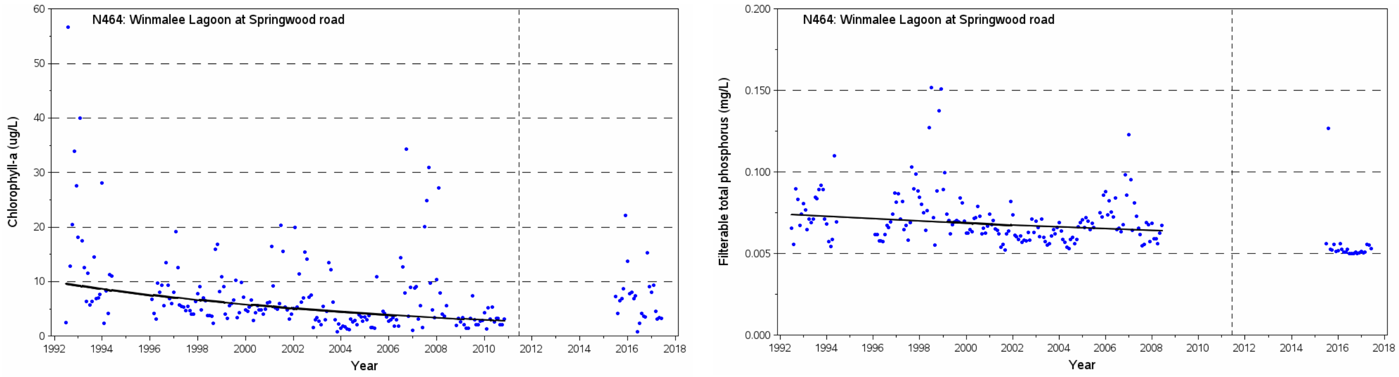
Trend analysis on the historical data et found significantly increasing trends for total nitrogen, dissolved inorganic nitrogen and conductivity (35%, 66% and 17% respectively) between 1992 and 2011 (Figure 4-24). This was prior to the completion of the nitrogen removal upgrade works at Winmalee WWTP in 2011. However, chlorophyll-*a* and filterable total phosphorus significantly decreased (70% and 41%) between 1992 and 2011 (Figure 4-25). The data for the short-term recent period was insufficient to perform a trend analysis.

All trend plots for the Winmalee Lagoon outflow are presented in Figure E-6 (Appendix E).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-24 Step trends in total nitrogen and dissolved inorganic nitrogen concentrations at Winmalee Lagoon outflow (N464)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-25 Step trends in chlorophyll-*a* and filterable total phosphorus concentrations at Winmalee Lagoon outflow (N464)

The results from the Spearman Correlation Analysis on the very limited short-term data (2015-2017) indicated that total nitrogen and dissolved inorganic nitrogen at Winmalee Lagoon outflow were not significantly correlated to the site-specific total nitrogen load. However, the total phosphorus load from Winmalee WWTP was weakly correlated with the total phosphorus (Rho=0.48, p=0.0007, n=47) and filterable total phosphorus (Rho=0.42, p=0.0037, n=46) concentrations. This indicates the utilisation of nitrogen through the lagoon, while phosphorus remains in the water column and is transported downstream to the main river stream.

Chlorophyll-*a* was not significantly correlated with any nutrient parameters. However, limited algal data collected during 2015-2017 demonstrated that blue-green algal biovolume was significantly and negatively correlated with the total nitrogen (Rho=-0.39, p=0.0322, n=31) and dissolved inorganic nitrogen (Rho=-0.50, p=0.0046, n=31) concentrations. Total algal biovolume was also negatively correlated with filterable total phosphorus. This emphasises the dynamic nature of the water column where algae use up the readily available forms of nutrients.

As expected and in line with upstream sites, chlorophyll-*a* was significantly and positively correlated to total algal biovolume, blue-green algal biovolume, conductivity and temperature, and negatively correlated to site-specific flow.

Unlike other monitoring sites, the relationships between the site-specific total nitrogen/dissolved inorganic nitrogen concentrations and flow was significantly negative. This indicated the possibility of dry weather nitrogen enrichment at this site. No significant relationship was found between total phosphorus/filterable total phosphorus and flow.

The relationship between turbidity and total/filterable total phosphorus was significantly positive indicating particulate matter is the source of phosphorus at this site.

The trend in algal composition for the Winmalee Lagoon based on the five major taxonomic groups is shown in Figure 4-26. No specific trend in algal composition could be determined because of limited algal biovolume data. The combination of algal species was mixed with green, monads, diatoms and other types of algae being dominant at any point of time. Blue-green algae was not dominant during the last two years with the most common potentially toxic blue-green algae *Microcystis* was found at a maximum density of 1,180 cells/ML.

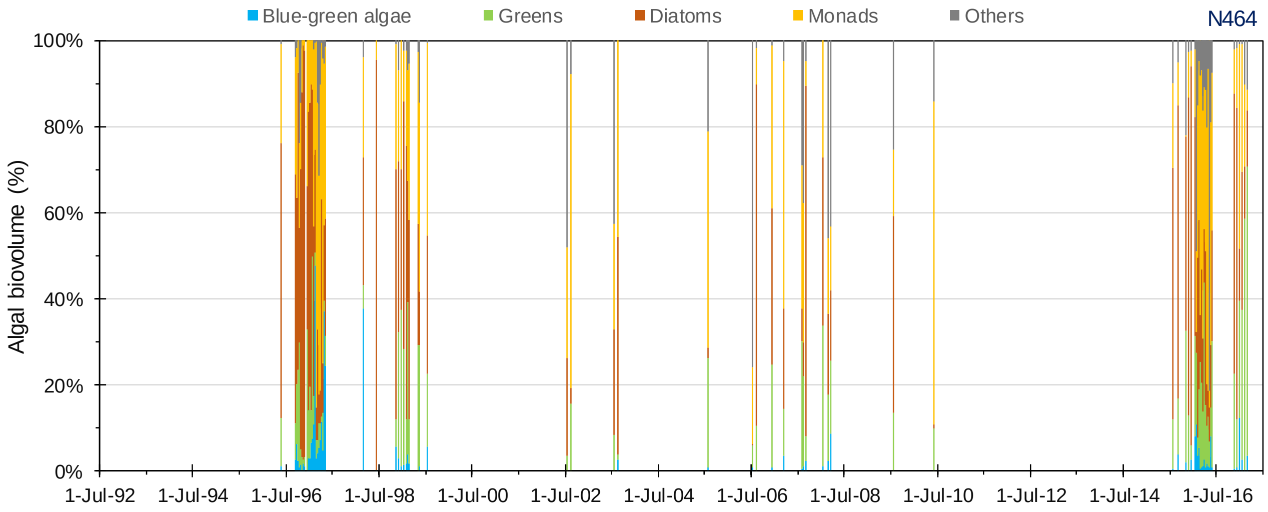


Figure 4-26 Algal composition at Winmalee Lagoon outflow (N464)

4.4.10 Nepean River at Yarramundi Bridge (N44)

The Nepean River at Yarramundi Bridge (N44) is located approximately 20 km downstream of Penrith Weir, just before the confluence with the Grose River. The site is situated downstream of Winmalee Lagoon where Winmalee WWTP discharges. Monitoring of this site was discontinued between 2000 to 2008. This site was not considered a key site for detailed analysis and interpretation.

Trend analysis was conducted for the entire 25-year period with two distinct periods identified before and after the Winmalee WWTP upgrade works to improve nutrient removal by 2011. A maximum of 222 monthly observations, including150 for the historical and 72 for the short-term recent period were used to perform the trend analysis.

The analysis of the last six years data from 2011 to 2017 identified decreasing trends in chlorophyll-*a* (59%), total phosphorus (38%) and filterable total phosphorus (36%). Significant increasing trends were identified for total nitrogen (26%), dissolved inorganic nitrogen (58%) and conductivity (19%) in the short-term between 2011 and 2017. No significant trend was identified in any other parameters over the short-term.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.11 Hawkesbury River at North Richmond (N42)

The uppermost site of the Hawkesbury River is located at North Richmond (N42), downstream of the confluence with the Grose River. The river widens and deepens from this point. The chlorophyll-*a* and algae are monitored at weekly intervals at this site as it represents the raw water supply point for the North Richmond Water Filtration Plant. Algal measurements were made on all samples irrespective of the chlorophyll-*a* concentration and therefore the trend analysis on the algal variable was considered most valuable for this study. There are also established beds of submerged macrophytes in the vicinity that influence water quality at this location. This site was classed as a key site due to its complete dataset, importance as a raw water supply point for drinking water, and being the uppermost site of the Hawkesbury River before the South Creek inflow.

Trend analysis was conducted for the entire 25-year period from 1992 to 2017, along with two distinct periods, before and after the major WWTP upgrade to improve nutrient removal from Winmalee WWTP was completed in 2011. A maximum of 300 monthly observations, with 228 for the historical and 72 for the short-term recent period, was used to perform the trend analysis.

Results of the trend analysis performed on the flow-adjusted data showed that there have been significant decreases ($p<0.05$) in total nitrogen (19%), dissolved inorganic nitrogen (27%), total phosphorus (35%) and filterable total phosphorus (37%) in the 25 years from 1992 to 2017. During this long-term, no significantly increasing or decreasing trends were detected in any of the other parameters (chlorophyll-*a*, total algal biovolume, blue-green algal biovolume, conductivity, pH, dissolved oxygen, dissolved oxygen saturation, temperature and turbidity).

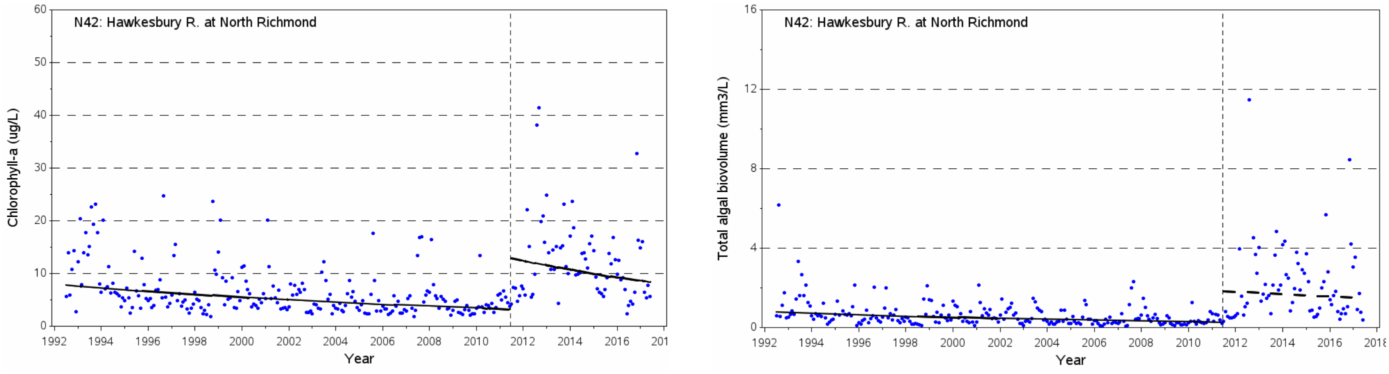
Step trend analysis identified that chlorophyll-*a*, total algal biovolume and blue-green algal biovolume decreased significantly (58%, 65% and 80%, respectively) in the Hawkesbury River at North Richmond (N42) in the historical period from 1992 to 2011 (Figure 4-27). Chlorophyll-*a* continued to significantly decrease during the short-term recent period (35%). No significant trends were identified in algal parameters during this period. Although, trend analysis showed decreases in chlorophyll-*a* in the two steps stages, there were more high chlorophyll-*a* peaks in the more recent years than the historical years. As macrophytes also compete with algae for nutrients, the extensive wash-out of macrophytes in this area of the river during the 2012 flood may have played a significant role in the chlorophyll-*a* trend for this site.

Total nitrogen concentrations significantly decreased (26%) during the historical period from 1992 to 2011. Both total nitrogen and dissolved inorganic nitrogen concentrations showed an increasing trend during the short-term recent period from 2011 to 2017 (Figure 4-28). During the short-term, total nitrogen increased by 19% and dissolved inorganic nitrogen by 55%. This indicates nitrogen enrichment at this site in recent years.

In contrast to total nitrogen, total phosphorus and filterable total phosphorus decreased significantly in both the historical and short-term recent periods (Figure 4-29). In the short-term between 2011 and 2017, total phosphorus and filterable total phosphorus decreased by 33% and 24%, respectively. However, an increase in both total phosphorus and filterable total phosphorus concentration was evident at the start of the short-term period (Figure 4-29).

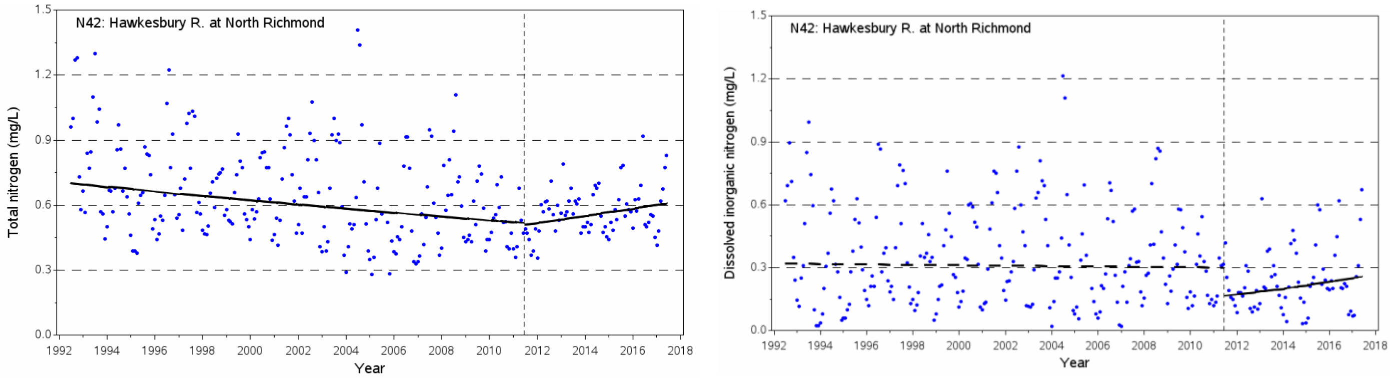
Step trend analysis on conductivity data for North Richmond (N42) found significant increases in the historical and short-term periods (10% and 28% respectively). For pH, the trend was insignificant during the historical period but showed a significantly decreasing trend (5%) during the short-term recent period.

All trend plots for the Hawkesbury River at North Richmond are presented in Figure E-7 (Appendix E).



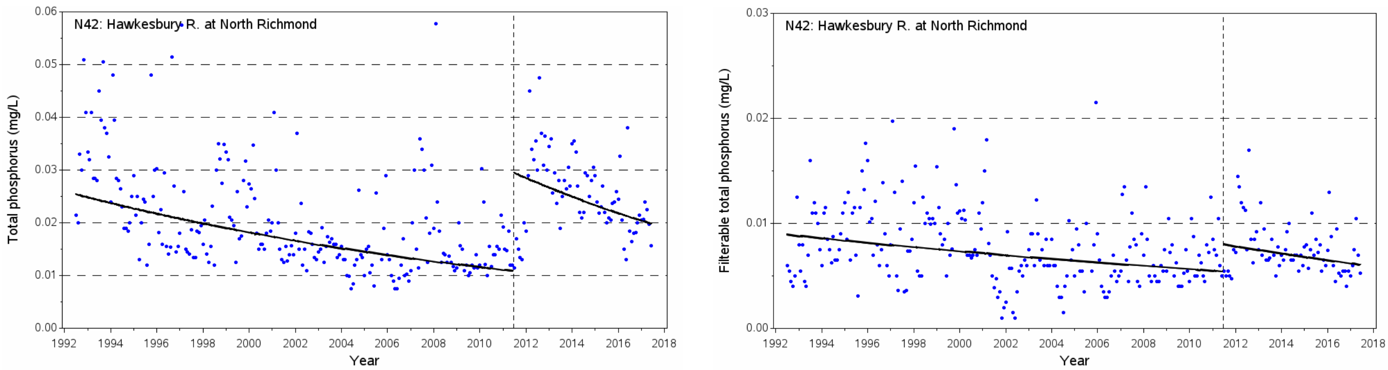
Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-27 Step trends in chlorophyll-*a* and total algal biovolume at North Richmond, Hawkesbury River (N42)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-28 Step trends in total nitrogen and dissolved inorganic nitrogen at North Richmond, Hawkesbury River (N42)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-29 Step trends in total phosphorus and filterable total phosphorus at North Richmond, Hawkesbury River (N42)

The results from the Spearman Correlation Analysis indicated chlorophyll-*a* in the Hawkesbury River at North Richmond (N42) is negatively and moderately correlated with the dissolved inorganic nitrogen (Rho=-0.41, p=<0.0001, n=104). Dissolved inorganic nitrogen was strongly and negatively correlated with the total algal biovolume (Rho=-0.52, p=<0.0001, n=78) and blue-green algal biovolume (Rho=-0.57, p=<0.0001, n=78). It shows that algae utilise nitrogen to a great extent, especially when blue-green are dominant. Total phosphorus concentration was moderately and positively correlated with the chlorophyll-*a* (Rho=0.48, p=<0.0001, n=396), total algal biovolume (Rho=0.42, p=<0.0001, n=370) and blue-green algal biovolume (Rho=0.38, p=<0.0001, n=370), indicating phosphorus is a key contributor to algal abundance at this site.

Both total nitrogen and dissolved inorganic nitrogen were not significantly correlated with the site-specific total nitrogen loads. However, both total phosphorus and filterable total phosphorus were strongly correlated with the total phosphorus load from the upstream Winmalee WWTP. This indicates that the phosphorus discharged from Winmalee WWTP, has extended downstream to North Richmond (N42).

Flow is not correlated with total nitrogen, dissolved inorganic nitrogen and total phosphorus at this site which confirms dry weather nutrient enrichment. Consistent with other sites, total phosphorus was strongly correlated with turbidity which indicates that particulate matter is a key source of phosphorus in the river.

As expected, chlorophyll-*a* was significantly and strongly correlated with the total algal biovolume and blue-green algal biovolume. Chlorophyll-*a* and total algal biovolume were moderately correlated with the temperature and blue-green algae was strongly correlated the temperature indicating strong seasonal influences.

The long-term algal dataset was mostly complete for the Hawkesbury River at North Richmond (N42), with the variation in algal composition based on the five major taxonomic groups shown in Figure 4-30. Historically, the algal composition at this site has been characteristically dominated by flagellated monad algae which are commonly found after rainfall events. In recent years, diatoms and blue-green algae also comprised a significant proportion of the biomass. Blue-green algae have been present from time to time throughout the 25-year period. The blue-green algal bloom in 2012 was the largest incidence of potentially toxic algae being present in recent years. In that year, *Microcystis* and *Cylindrospermopsis raciborskii* were present at maximum densities of 10,180 cells/mL and 4,910 cells/mL respectively.

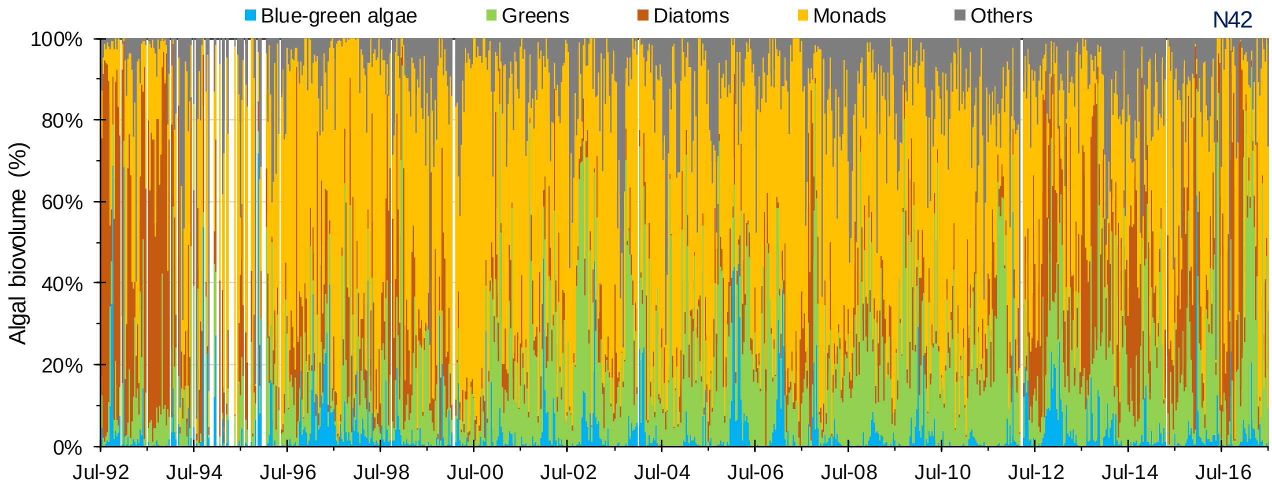


Figure 4-30 Algal composition at North Richmond, Hawkesbury River (N42)

4.4.12 Hawkesbury River at Freemans Reach (N39)

The Hawkesbury River at Freemans Reach (N39) is located approximately 7 km downstream from the North Richmond (N42) site. In addition to the influence from the upstream Winmalee WWTP, the water quality at this site may also be influenced by small volumes of treated wastewater discharge from the North Richmond WWTP via a small tributary called Redbank Creek. Monitoring at this site commenced from January 1996. This site was not considered a key site, therefore minimal commentary on water quality trends is provided.

Trend analysis was conducted for the entire 21.5-year period with two distinct periods identified before and after the major upgrade at Winmalee WWTP to improve nutrient removal in 2011. A maximum of 249 monthly observations, 177 for the historical and 72 for the short-term recent period was used to perform the trend analysis.

The analysis on the last six years data from 2011 to 2017 identified increasing trends in total nitrogen (23%) and conductivity (28%). No significant trend was identified in any other parameters over the short-term.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.13 South Creek at Fitzroy Bridge (NS04)

South Creek is one of the major tributaries of the Hawkesbury River. It originates at Narellan in the south west and travels 64 km north before joining the Hawkesbury River at Windsor. The land uses in the South Creek sub-catchment are diverse and include rural activities such as cattle and sheep grazing, market gardening, intensive agriculture such as poultry farming as well as both urban and industrial land uses. Currently the South Creek catchment is experiencing rapid urban growth in the Narellan area, Ropes Crossing and Marsden Park. South Creek and its tributaries receive tertiary treated wastewater discharges from three major WWTPs operated by Sydney Water (St Marys, Riverstone, and Quakers Hill) and two council operated WWTPs (McGraths Hill and South Windsor). The South Creek (NS04) water quality monitoring site is located at the Fitzroy Pedestrian Bridge, about 2 km upstream of the confluence with the Hawkesbury River. Although, the lower part of the creek is tidal, the water quality at this site is expected to represent the overall quality of the South Creek before meeting the main stream of the Hawkesbury River. This site was considered a key site due to the potential impact posed by the three Sydney Water WWTP discharges.

Although this site was only added as a regular monitoring site from 2008, some historical data is available from 1992 even though there are some data gaps from 1993 to 1994 and 2008 to 2011. Despite this, trend analysis was conducted for the entire 25-year period and two distinct periods before and after the completion of major WWTP upgrade works (Quakers Hill, Riverstone and St Marys) to improve nutrient removal in 2011. A maximum of 197 monthly observations, with 125 for the historical period and 72 for the short-term recent period was used to perform the trend analysis.

The results from the trend analysis performed on the flow-adjusted data showed that there have been significant decreases ($p<0.05$) in total nitrogen (73%), dissolved inorganic nitrogen (79%), total phosphorus (59%), filterable total phosphorus (75%) and turbidity (29%) in the last 25 years from 1992 to 2017. The limited algal data showed a significantly increasing trend in the total algal biovolume (254%) over the long-term from 1996 to 2017. Significantly increasing trends were also revealed for conductivity (26%) and dissolved oxygen (18%). No significant trends were detected in chlorophyll-*a*, blue-green algal biovolume, dissolved oxygen saturation and temperature between 1992 and 2017.

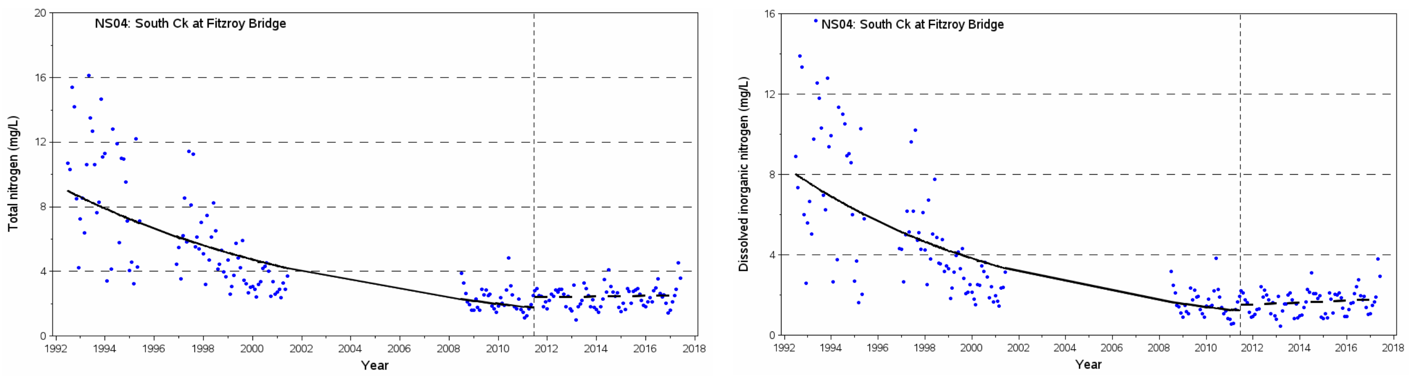
It was expected that river water quality would improve from 2011 after the completion of the WWTP upgrades at Quakers Hill, St Marys and Riverstone to improve nutrient removal and after the commissioning of the St Marys AWTP. Therefore, step trend analysis outcomes for the two different periods before and after the upgrade was considered important for further detailed discussion.

Step trend analysis identified that chlorophyll-*a* significantly decreased (36%) at South Creek (NS04) during the historical period from 1992 to 2011. Analysis on the limited algal data revealed a significantly increasing trend in total algal biovolume and a significantly decreasing trend in blue-green algal biovolume during this period. These trends on algal biovolume may not represent the actual situation given the limitation on algal dataset with selective missing data for the low chlorophyll-*a* samples. During the short-term recent period from 2011 to 2017, no significant trends were identified for chlorophyll-*a* and algae.

Nutrient concentrations decreased across the board at South Creek (NS04) in the historical period from 1992 to 2011. All four parameters (total nitrogen: 80%, dissolved inorganic nitrogen: 85%, total phosphorus: 73% and filterable total phosphorus: 83%) exhibited significantly decreasing trends during this period between 1992 to 2011 (Figure 4-31 and Figure 4-32). However, no significant trends were found in these parameters for the short-term recent period after completion of upgrade works in 2011. This confirms that although significant nutrient reduction was achieved at South Creek by 2011, the nutrient level stabilised after that point.

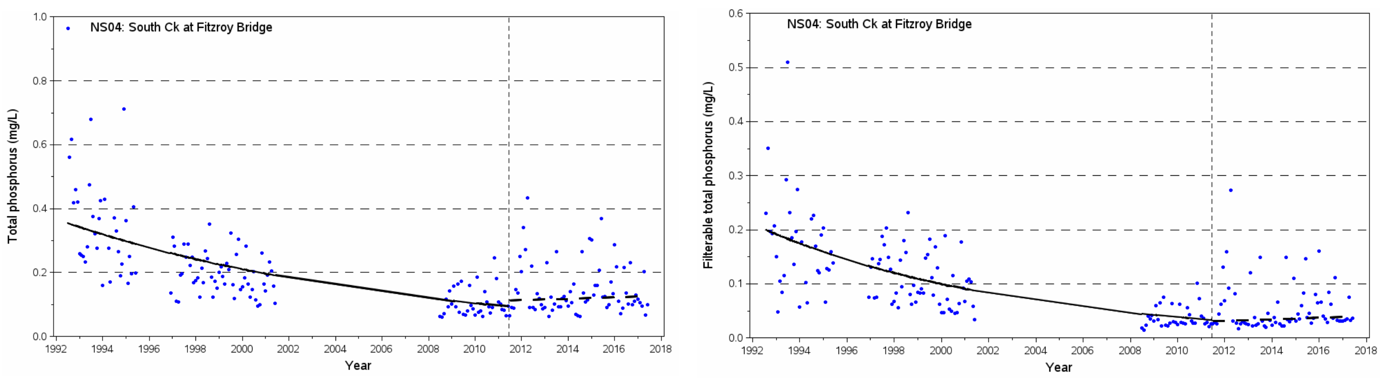
Step trend analysis on conductivity data from South Creek (NS04) showed a significant increase during the historical period (14%), with no trend during the short-term recent period. For pH, the trend was significantly upwards (4%) during the historical period and significantly downwards (3%) during the short-term recent period.

All trend plots for South Creek are presented in Figure E-8 (Appendix E).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-31 Step trends in total nitrogen and dissolved inorganic nitrogen at South Creek (NS04)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-32 Step trends in total phosphorus and filterable total phosphorus at South Creek (NS04)

The results from the Spearman Correlation Analysis on the data from the last six years (2011-2017) indicated that total nitrogen and dissolved inorganic nitrogen in South Creek was not significantly correlated with the site-specific total nitrogen loads from the upstream WWTPs. However, the total phosphorus loads from the WWTPs were moderately and positively correlated with the total phosphorus (Rho=0.45, p=<0.0001, n=104) and strongly correlated with the filterable total phosphorus (Rho=0.51, p=<0.0001, n=104). This suggests the WWTPs that discharge to the upper South Creek catchment have a reasonable influence on phosphorus levels downstream.

The relationship between chlorophyll-*a* and nitrogen parameters was insignificant. However, chlorophyll-*a* was strongly and negatively correlated with the filterable total phosphorus (Rho=- 0.54, p=<0.0001, n=104) and moderately and negatively correlated with the total phosphorus (Rho=-0.36, p=0.0002, n=104). It indicates that nitrogen parameters have no direct relationship to the chlorophyll-*a* concentrations in South Creek and that phosphorus is less abundant when chlorophyll-*a* is high.

Dissolved inorganic nitrogen was weakly negatively correlated with the limited total algal biovolume data. Blue-green algal biovolume showed a weak negative correlation with both total nitrogen and dissolved inorganic nitrogen. This suggests that algae are deriving nitrogen from other sources or are continuously consuming available nitrogen in the water column.

As expected, chlorophyll-*a* was strongly and positively correlated with the total algal biovolume and weakly correlated with the temperature. Moderate negative correlations were found among chlorophyll-*a* with flow and turbidity indicating algal wash-out during high flow and turbid water contains low algae because of low light availability.

Both total phosphorus and filterable total phosphorus were strongly correlated with the flow and turbidity indicating phosphorus enrichment during wet weather. However, for total nitrogen, no significant relationship was found with the flow or turbidity. Dissolved inorganic nitrogen was moderately and negatively correlated with the turbidity demonstrating turbid water contains low available nitrogen.

Total nitrogen and dissolved inorganic nitrogen concentrations at South Creek were strongly and negatively correlated with temperature, demonstrating nitrogen enrichment at this site during winter months. As expected nitrogen was probably more utilized in summer months by algae and macrophytes because of long day light hours and warm weather. Similarly, pH was strongly and negatively correlated with the temperature indicating less photosynthetic activity during winter.

Turbidity was strongly and positively correlated with the conductivity, that is, turbid water contains more salt at South Creek.

The trend in algal composition data for South Creek based on the five major taxonomic groups is shown in Figure 4-33. The combination of algal species was mixed, with green, monads, diatoms and other types of algae all being dominant at any one time. Although blue-green algae have been detected at this site, they have not been in dominant numbers in recent years. However, in the last two years the most common potentially toxic alga *Microcystis* was found at a maximum density of 11,060 cells/mL.

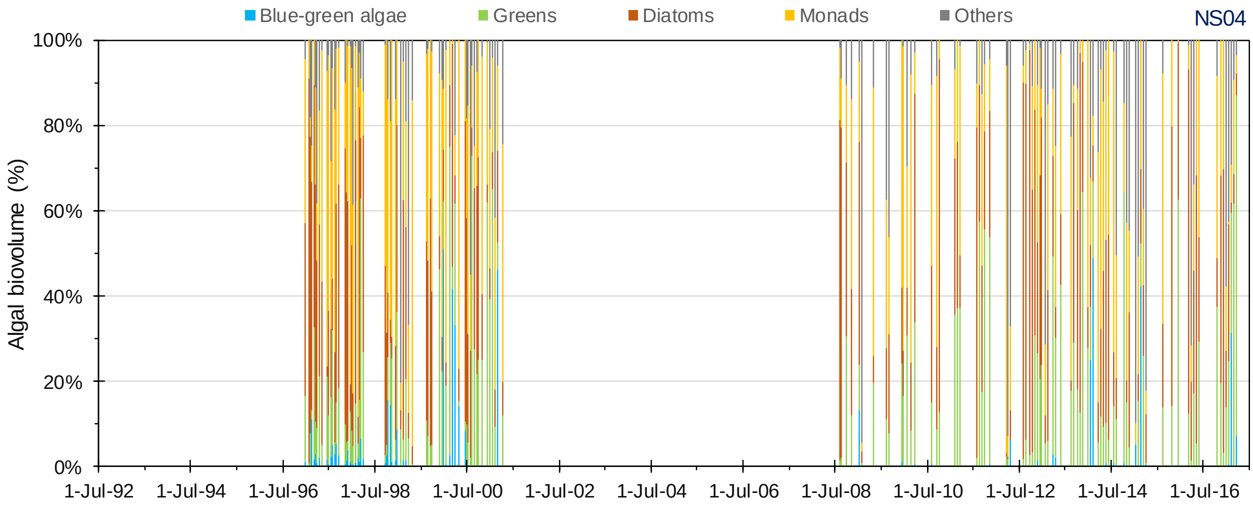


Figure 4-33 Algal composition at South Creek (NS04)

4.4.14 Hawkesbury River at Wilberforce (N35)

The Hawkesbury River site at Wilberforce (N35) is located approximately 5 km downstream of the confluence with South Creek. Water quality at this site is affected by the quality and magnitude of flows coming from South Creek. Historically, there have been water quality concerns at this site due to high nutrient concentrations, high chlorophyll-*a* levels and algal blooms, especially blooms of potentially toxic blue-green algae. The width and depth of the river, combined with the high nutrients, tidal influence and high residence time makes this site an ideal location for algal growth and proliferation. This site was classified as a key site as it measures the impact of South Creek on the water quality of the mainstream river, plus it has a history of water quality problems.

Trend analysis was conducted for the entire 25-year period plus two distinct time periods, before and after the completion of major upgrade works to WWTPs (North Richmond, Quakers Hill, Riverstone and St Marys) in 2011 to improve nutrient removal. A maximum of 292 monthly observations, with 221 for the historical period and 71 for the short-term recent period was used to perform the trend analysis.

The results of the trend analysis performed on the flow-adjusted data show that there have been significant decreases ($p<0.05$) in total nitrogen (66%), dissolved inorganic nitrogen (83%), total phosphorus (48%), filterable total phosphorus (57%) and dissolved oxygen saturation (8%) in the last 25 years from 1992 to 2017. The limited algal data demonstrated a significantly increasing trend in total algal biovolume over the long-term. No other significant trends were detected in chlorophyll-*a*, blue-green algal biovolume, conductivity, pH, dissolved oxygen, temperature and turbidity between 1992 and 2017.

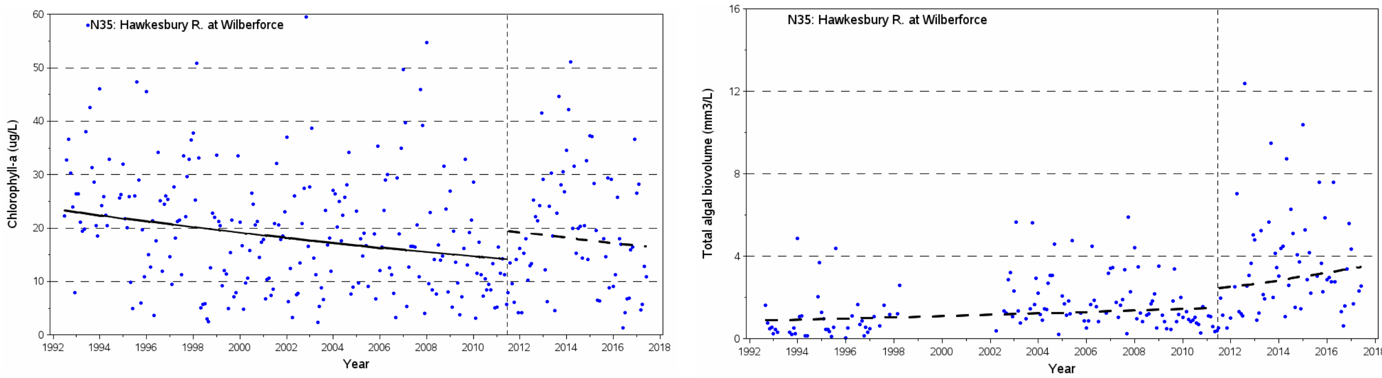
It was expected that river water quality would improve after the completion of all WWTP upgrade works to improve nutrient removal in 2011. Therefore, step trend analysis outcomes for the two different periods before and after this upgrade was considered important for further analysis.

Step trend analysis demonstrated improvement in chlorophyll-*a* and nutrient parameters in the Hawkesbury River at Wilberforce (N35) during the historical period between 1992 and 2011.

During this period, there were significant decreases in the concentrations of chlorophyll-*a* (39%), total nitrogen (68%), dissolved inorganic nitrogen (80%), total phosphorus (55%) and filterable total phosphorus (59%). This improving trend plateaued or reversed during the short-term recent period from 2011 to 2017 (Figure 4-34, Figure 4-35 and Figure 4-36). While the trend in chlorophyll-*a*, dissolved inorganic nitrogen, total phosphorus and filterable total phosphorus was insignificant during the short-term, total nitrogen significantly increased (25%). Step trend analysis on limited total algal biovolume and blue-green algal biovolume found no significant trends in any period (Figure 4-34).

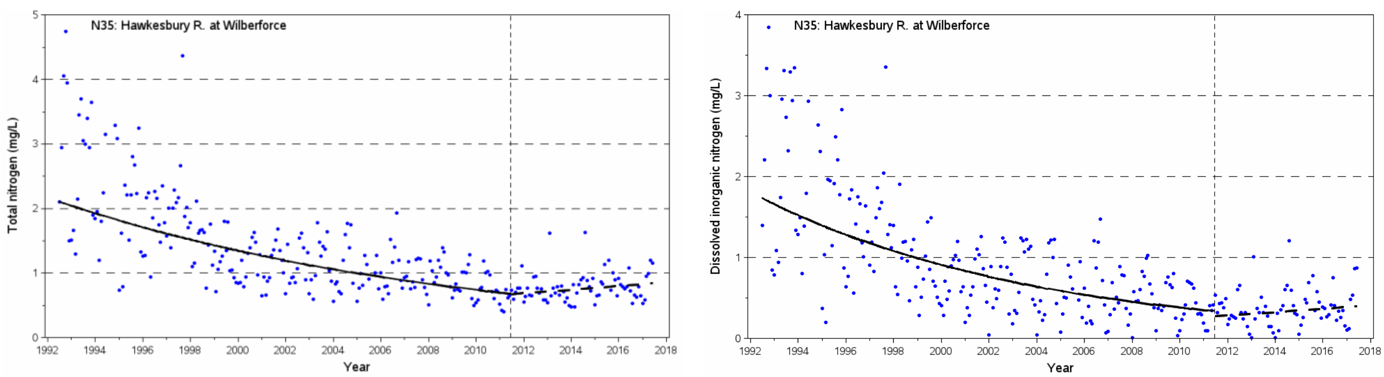
Step trend analysis on the conductivity data from the Hawkesbury River at Wilberforce (N35) found no significant trend in either period. There were significant increases in pH during the historical period (2%) but no significant trend during the short-term recent period.

All trend plots for the Hawkesbury River at Wilberforce are presented in Figure E-9 (Appendix E).



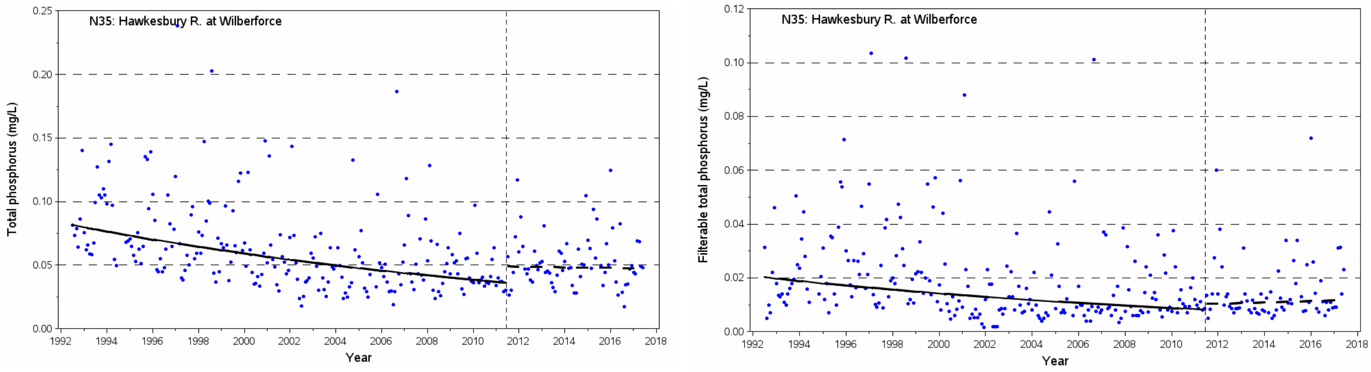
Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-34 Step trends in chlorophyll-*a* and total algal biovolume at Wilberforce, Hawkesbury River (N35)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-35 Step trends in total nitrogen and dissolved inorganic nitrogen at Wilberforce, Hawkesbury River (N35)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-36 Step trends in total phosphorus and filterable total phosphorus at Wilberforce, Hawkesbury River (N35)

The results from the Spearman Correlation Analysis indicated that total nitrogen and phosphorus concentrations in the Hawkesbury River at Wilberforce (N35) were significantly related with the site-specific total nitrogen and phosphorus loads. The total nitrogen concentration was strongly and positively correlated with the total nitrogen load (Rho=0.54, p=<0.0001, n=102) while the dissolved inorganic nitrogen was moderately correlated with total nitrogen load (Rho=0.47, p=<0.0001, n=102). The total phosphorus load was moderately correlated with the total phosphorus (Rho=0.39, p=<0.0001, n=102) and filterable total phosphorus (Rho=0.39, p=<0.0001, n=102) concentrations. The correlation analysis suggests that the upstream WWTPs discharging via South Creek are influencing (39 to 54% variation) nutrient concentrations in the Hawkesbury River at Wilberforce (N35).

Although the nutrient levels at Wilberforce were directly related with the nutrient loads from upstream Sydney Water WWTPs, chlorophyll-*a* did not show a significant positive relationship with the total phosphorus loads and showed a moderate negative relationship with the total nitrogen load. Similarly, the relationship between chlorophyll-*a* and concentrations of total nitrogen (weak), dissolved inorganic nitrogen (moderate) and filterable total phosphorus (strong) was negative. Analysis of the limited algal biovolume data showed that the total algal biovolume was negatively correlated with the filterable total phosphorus. Similarly, blue green algal biovolume was strongly and negatively correlated with the dissolved inorganic nitrogen and moderately and negatively correlated with the total nitrogen concentration. This suggests that when total or blue-green algal biovolume levels are high and dissolved inorganic nitrogen concentrations are low, the algae at this site may be sourcing nitrogen from other non-available form (dissolved organic nitrogen) or nitrogen fixing algae may be also present.

As expected, chlorophyll-*a* was strongly and positively correlated with both total algal biovolume and blue-green algal biovolume. Flow was negatively correlated with the chlorophyll-*a* (strong), total algal biovolume (moderate) and blue-green algal biovolume (weak) due to algal wash-out during high flows.

As usual, chlorophyll-*a* and blue-green algal biovolume were moderately and positively correlated with the temperature showing seasonal influence. The relationship between temperature and total nitrogen (moderate) and dissolved inorganic nitrogen (strong) was negative, possibly suggesting that during summer, these nutrients are being utilised by the algae. There was a moderate positive relationship between temperature and total phosphorus.

Flow was positively correlated with the dissolved inorganic nitrogen (weak), total phosphorus (weak) and filterable total phosphorus (strong) indicating phosphorus enrichment during wet weather. No significant relationship was detected with turbidity and total nitrogen or dissolved inorganic nitrogen, however, there was a strong positive correlation between total phosphorus and filterable total phosphorus with the turbidity, indicating particulate matter is a key source of phosphorus in the Hawkesbury River at Wilberforce (N35).

The trend in algal composition data for the Hawkesbury River at Wilberforce (N35) based on the five major groups is shown in Figure 4-37. Generally, the trend was highly variable and showed more blue-green algal dominance in the past rather than in more recent years where blue-green levels have been proportionately less. From time to time the toxic blue-green algae have also been present. In the last two years, the most common potentially toxic alga *Microcystis* was found at a maximum density of 1,710 cell/mL. Another, potentially toxic benthic filamentous alga *Phormidium* was also recorded at this site in the last two years at a maximum density of 8,270 cells/mL.

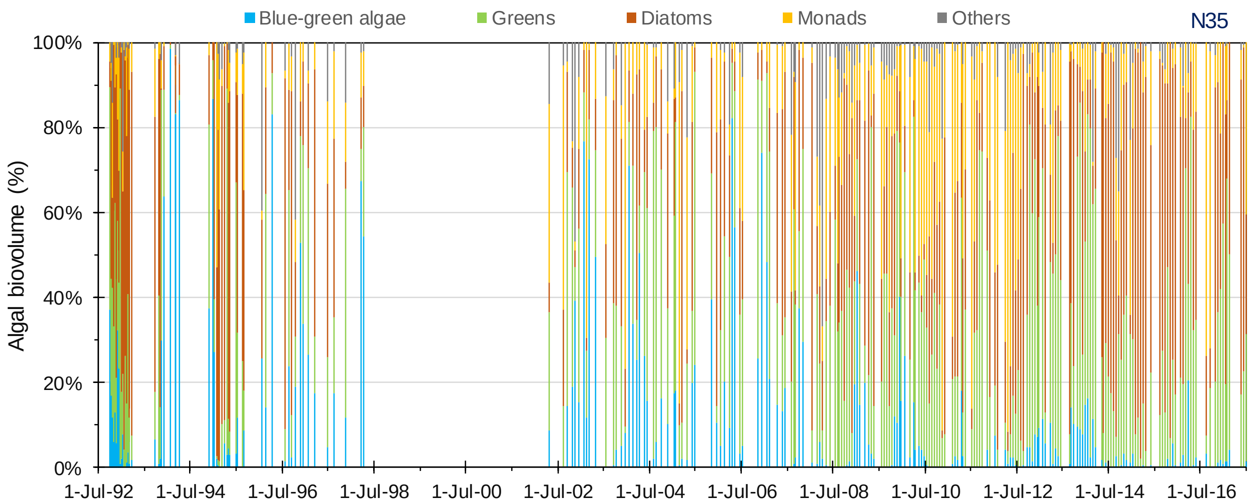


Figure 4-37 Algal composition at Wilberforce, Hawkesbury River (N35)

4.4.15 Cattai Creek at Cattai Road (NC11)

The Cattai Creek at Cattai Ridge Road (NC11) site is a major tributary to the Hawkesbury River draining part of the Sydney's north-west corridor, a growing population and urban development catchment in Sydney. The land uses in this sub-catchment include rural or farming activities, intensive agricultural, urban development and commercial and industrial uses. Two of Sydney Water's WWTPs, Castle Hill and Rouse Hill, operate in the Cattai Creek catchment. Rouse Hill WWTP discharges to a constructed wetland and the Seconds Ponds Creek, a tributary of Cattai Creek. Castle Hill WWTP discharges directly to Cattai Creek. The Cattai Creek (NC11) water quality monitoring site is located at Cattai Ridge Road, approximately 7 km upstream from the confluence with the Hawkesbury River. This site was classified as a key site due to urban development in the catchment and treated wastewater discharges from the Castle Hill and Rouse Hill WWTPs.

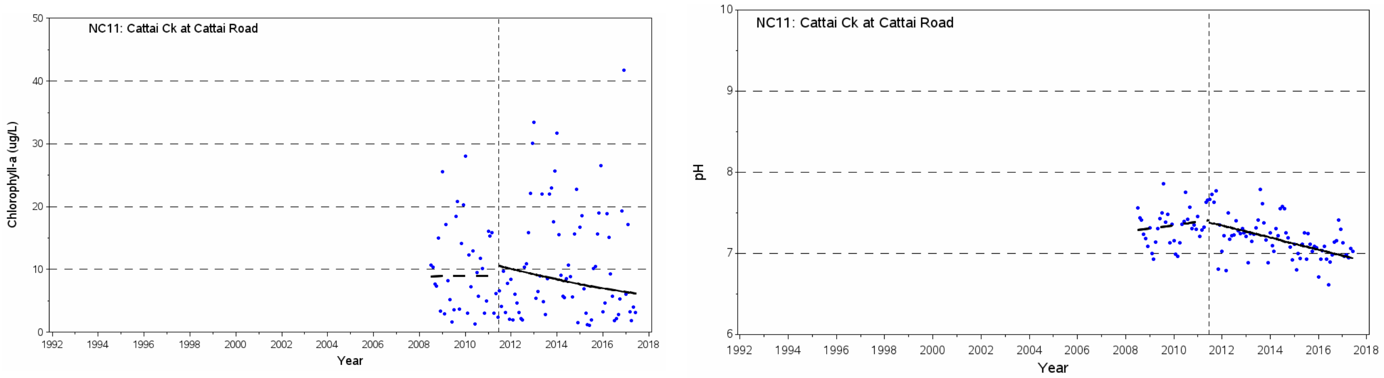
This site was only added to the regular monitoring program from 2008, consequently there is no historical data available for analysis. Trend analysis was performed for the entire 9-year period as well as for the two stage periods: historical leading to major WWTP upgrade works in 2011 and short-term after the upgrade works from 2011 to 2017. A maximum of 108 monthly observations, with 36 for the historical and 72 for the short-term period was used to perform the trend analysis.

The results of the trend analysis performed on the flow-adjusted data identified significant decreases ($p<0.05$) in pH (5%) in the last nine years from 2008 to 2017. The limited algal data exhibits a significantly increasing trend in total algal biovolume, while water temperature and turbidity (38%) also significantly increased. No other significant trends were detected for chlorophyll-*a*, blue-green algal biovolume, total nitrogen, dissolved inorganic nitrogen, total phosphorus, filterable total phosphorus, conductivity, dissolved oxygen and dissolved oxygen saturation between 2008 and 2017.

Step trend analysis on the Cattai Creek (NC11) data between 2011 and 2017 demonstrated a significant decrease in chlorophyll-*a* (41%) (Figure 4-38). There were also significant decreases in total nitrogen (42%) and dissolved inorganic nitrogen (51%) in the first three years from 2008 to 2011 before the trends stabilised in the short-term recent period (Figure 4-39). No significant trends were detected during the short-term period from 2011 to 2017. The trends in total phosphorus and filterable total phosphorus were insignificant for both historical and short-term recent periods.

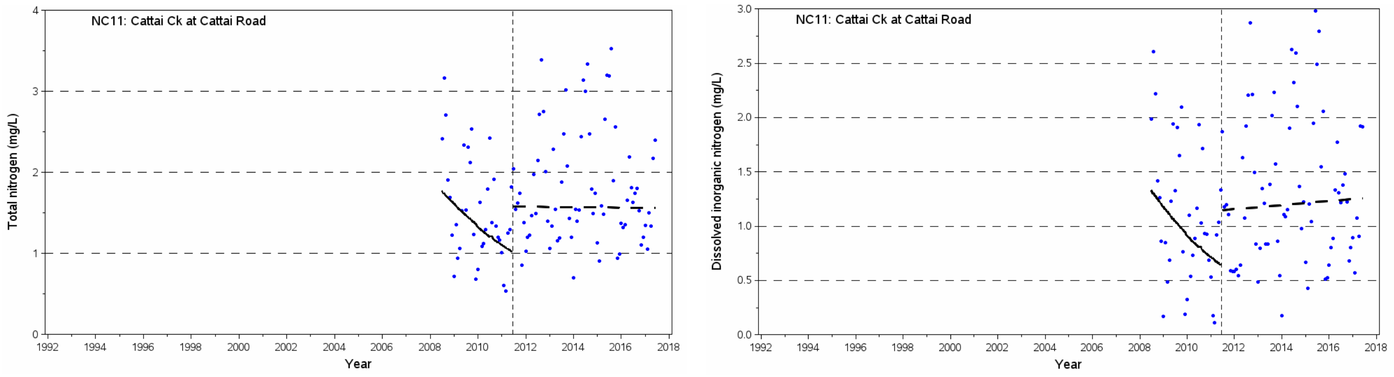
Step trend analysis on the Cattai Creek (NC11) water quality data found that the decreasing trend in pH was mostly achieved in the short-term recent period (Figure 4-38). This is in line with decreasing chlorophyll-*a* concentrations meaning less photosynthetic activity to influence daytime pH.

All trend plots for Cattai Creek are presented in Figure E-10 (Appendix E).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-38 Step trends in chlorophyll-*a* and pH at Cattai Creek (NC11)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-39 Step trends in total nitrogen and dissolved inorganic nitrogen at Cattai Creek (NC11)

The results from the Spearman Correlation Analysis indicated that nutrient concentrations were not significantly correlated with the site-specific total nitrogen or total phosphorus load from WWTPs in the Cattai Creek catchment. This suggests that nutrient discharged from the upstream Cattai Creek WWTPs has minimal influence on nutrient levels in Cattai Creek.

The relationships between chlorophyll-*a* and nitrogen parameters were insignificant. Filterable total phosphorus showed a strong negative correlation with chlorophyll-*a* (Rho=-0.58, p=<0.0001, n=103). This indicates that nitrogen parameters have no direct relationship with chlorophyll-*a* concentrations in Cattai Creek and for phosphorus, it is apparent that with increasing chlorophyll-*a* concentration filterable phosphorus concentration decreases.

The limited algal biovolume data showed that dissolved inorganic nitrogen was negatively correlated with the total algal biovolume (Rho=-0.32, p=0.0149, n=59). Blue-green algal biovolume showed a negative correlation with both total nitrogen (Rho=-0.47, p=0.0002, n=59) and dissolved inorganic nitrogen (Rho=-0.52, p=<0.0001, n=59). This suggests that algae may be deriving nitrogen from other sources or continuously utilize the available nitrogen in the water column. Total phosphorus was positively correlated (weak) with the blue-green algal biovolume.

As expected, chlorophyll-*a*, total algal biovolume and blue-green algal biovolume were strongly and positively correlated with the temperature showing seasonal variation. Negative correlations were found for chlorophyll-*a* with flow (strong) and chlorophyll-*a* with turbidity (moderate) indicating algal wash-out during high flow and turbid water containing low algae numbers because of low light availability.

Total phosphorus and filterable total phosphorus were strongly or moderately correlated with the flow and turbidity indicating phosphorus enrichment during wet weather. However, for total nitrogen/dissolved inorganic nitrogen no significant correlation was found with flow. Turbidity was negatively correlated with the total nitrogen (weak) and dissolved inorganic nitrogen (moderate) which suggests turbid water at this site contains low nitrogen levels.

Total nitrogen and dissolved inorganic nitrogen concentrations at Cattai Creek were strongly and negatively correlated with the temperature which demonstrates nitrogen enrichment occurs at this site in winter months. In other words, nitrogen was more utilized in summer months by algae and macrophytes because of long day light hours and warm weather. Total phosphorus was weakly and positively correlated with the temperature indicating more phosphorus during summer months.

The algal composition trend for the last nine years for Cattai Creek based on the five major taxonomic groups is shown in Figure 4-40. Algal composition was varied and the dominance of blue-green algae less in more recent years than in 2008 to 2010. Toxic blue-green algal blooms were also evident at times in Cattai Creek. In the last two years, the most common potentially toxic alga *Microcystis* was found at this site at a maximum density of 23,110 cells/mL.

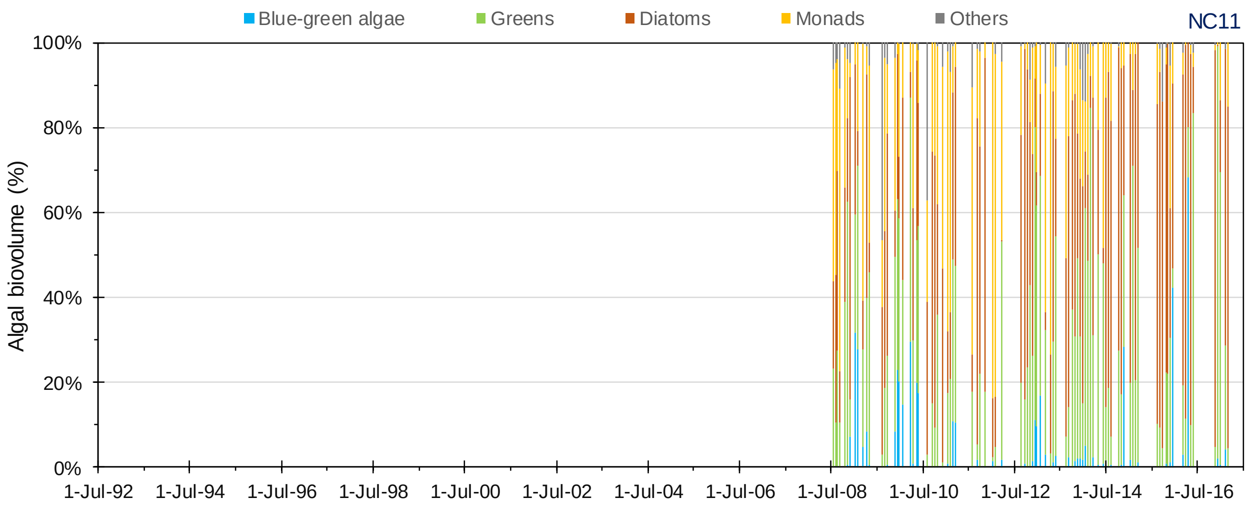


Figure 4-40 Algal composition at Cattai Creek (NC11)

4.4.16 Hawkesbury River at Cattai SRA (N3001)

The Hawkesbury River off Cattai SRA (N3001) is located approximately 2 km downstream of the confluence with the Cattai Creek. The water quality at this site is influenced by flows coming from both South and Cattai creeks. Historically, this site has experienced problems with high nutrients, chlorophyll-*a* and algal blooms. This site is not classified as a key site because of inconsistent monitoring data.

Consistent data for this Hawkesbury River site was available from July 1994 to 2000, although monitoring ceased from 2000 till June 2008 when the current STSIMP commenced. Trend analysis was conducted for the entire 23-year period with two distinct periods for this site before and after the major WWTP upgrade works to improve nutrient removal in 2011. A maximum of 191 monthly observations, 120 for the historical period and 71 for the short-term recent period was used to perform the trend analysis.

No significant trends were identified for the any water quality parameter for the short-term period between 2011 and 2017.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.17 Hawkesbury River at Sackville Ferry (N26)

The Hawkesbury River at Sackville Ferry (N26) site is located approximately 18 km downstream of the Cattai Creek confluence with the Hawkesbury River. It is a key site due to the high incidences of algal blooms, especially blue-green algae blooms. Algal blooms at upstream sites in close proximity to South and Cattai creeks are possibly light-limited because of turbid inflows from those creeks limiting algal growth. Water clarity generally improves due to sedimentation in the Hawkesbury River at Sackville, making it ideal for prolonged algal blooms.

Consistent data for this site was available from July 1994 onwards. Trend analysis was conducted for the entire 23-year period with two distinct periods for this site before and after the major upgrade work in 2011 to improve nutrient removal. A maximum of 271 monthly observations, with 200 for the historical period leading to the upgrade and 71 for the short-term recent period was used to perform the trend analysis.

The results for the trend analysis performed on the flow-adjusted data showed there have been significant decreases ($p<0.05$) in chlorophyll-*a* (32%), blue-green algal biovolume (55%, limited data), total nitrogen (48%), dissolved inorganic nitrogen (76%), total phosphorus (37%), filterable total phosphorus (33%), pH (6%), dissolved oxygen (8%) and dissolved oxygen saturation (9%) in the last 23 years from 1994 to 2017. The limited algal data demonstrated significantly increasing trends in total algal biovolume over the long-term. No significant trends were detected in conductivity, temperature and turbidity between 1994 and 2017.

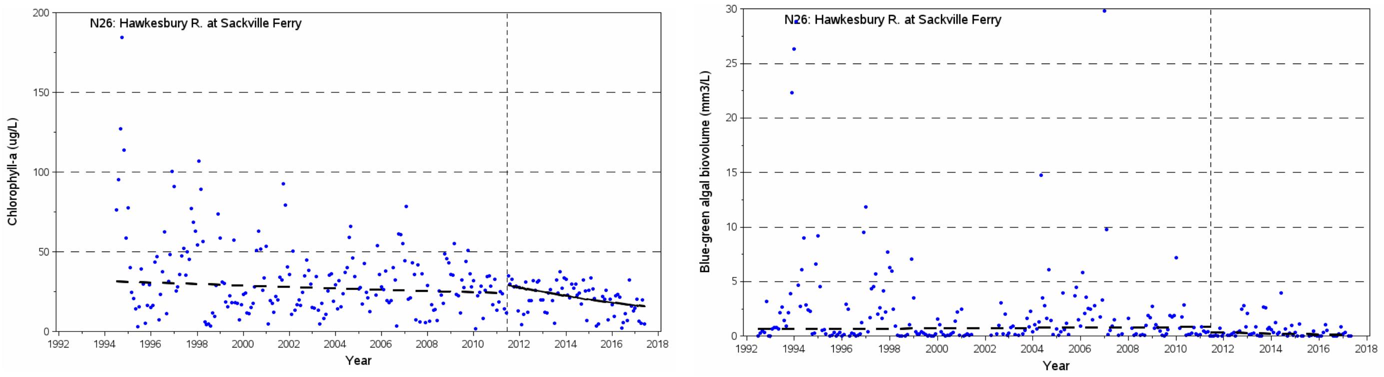
It was anticipated that river water quality would improve in the Hawkesbury River at Sackville following the completion of WWTP upgrades in 2011. Therefore, step trend analysis outcomes for the two stage periods before and after these upgrades was considered important to discuss in more detail.

Step trend analysis demonstrated significant decreases in chlorophyll-*a* concentrations in the short-term between 2011 and 2017 (46%, Figure 4-41). Analysis on limited algal data found no significant trends in both periods (Figure 4-41).

Nutrient concentrations in the Hawkesbury River at Sackville Ferry (N26) significantly decreased across all forms for the historical period between 1994 and 2011 with no further improvement or deterioration detected in the last six years from 2011 (Figure 4-42 and Figure 4-43). Total nitrogen and dissolved inorganic nitrogen decreased by 46% and 82%, respectively in the historical period, while total phosphorus and filterable total phosphorus decreased by 37% and 51%, respectively.

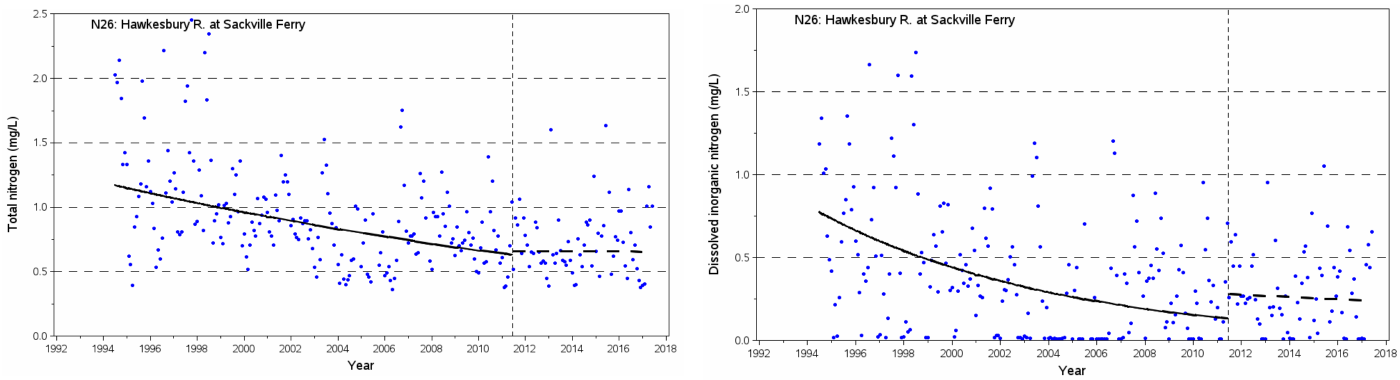
Step trend analysis on conductivity data found a significantly increasing trend (21%) in the historical period and no significant trend during the short-term recent period. For pH, a significantly decreasing trend (3%) was identified in the period between 1994 and 2011. There was no significant trend in` pH in the latest period after 2011.

All trend plots for the Hawkesbury River at Sackville Ferry are presented in Figure E-11 (Appendix E).



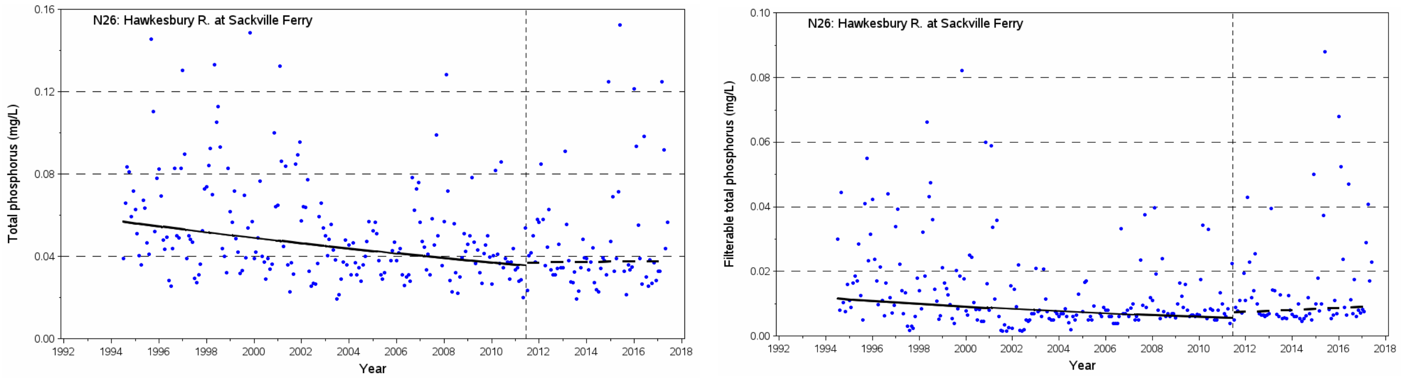
Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-41 Step trends in chlorophyll-*a* and blue-green algal biovolume at Sackville Ferry, Hawkesbury River (N26)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-42 Step trends in total nitrogen and dissolved inorganic nitrogen at Sackville Ferry, Hawkesbury River (N26)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-43 Step trends in total phosphorus and filterable total phosphorus at Sackville Ferry, Hawkesbury River (N26)

The results from the Spearman Correlation Analysis indicated that site-specific total nitrogen loads from Sydney Water's WWTPs (South and Cattai creeks WWTPs) had a weak significantly positive correlation (Rho=0.34, p=0.0004, n=102) on dissolved inorganic nitrogen concentrations in the Hawkesbury River at Sackville (N26). The total phosphorus load had no noticeable influence on total phosphorus or filterable total phosphorus concentrations as there was no significant relationship found between the parameters.

The relationship between chlorophyll-*a* and dissolved inorganic nitrogen (weak, Rho=-0.36, p=0.0002, n=102) and filterable total phosphorus (strong, Rho=-0.58, p=<0.0001, n=102) was significantly negative. Similarly, all four nutrient parameters were negatively correlated (weak and moderate) with the total algal biomass. The blue-green algal biovolume was strongly and negatively correlated with total nitrogen, dissolved inorganic nitrogen and filterable total phosphorus. These findings show that when chlorophyll-*a* is high and algal blooms are occurring, nutrients concentrations are low, possibly due to high algal uptake.

As expected, chlorophyll-*a* was weakly and positively correlated to the total algal biovolume and the blue-green algal biovolume. Chlorophyll-*a* and blue-green algal biovolume was negatively and strongly correlated to site-specific flow due to algal wash-out during high flows.

Total nitrogen, dissolved inorganic nitrogen and total phosphorus were moderately and positively correlated with the flow. Filterable total phosphorus was strongly and positively correlated with the flow. This suggests the influence of wet weather on nutrient levels in the Hawkesbury River at Sackville.

Turbidity was positively and strongly correlated with the total nitrogen, total phosphorus and filterable total phosphorus and moderately correlated with the dissolved inorganic nitrogen. This indicates particulate matter was contributing to nutrients in the river at Sackville.

The trend in algal composition data for the Hawkesbury River at Sackville based on the five major taxonomic groups is shown in Figure 4-44. Blue-green algae were more dominant at this site in high numbers compared to other monitoring sites along the Hawkesbury-Nepean River or the major tributaries. However, it is evident that the blue-green algal dominance has reduced in more recent years. Given the levels of blue-green algae present, it's not surprising that the potentially toxic blue-green algae were frequently found in high numbers as well. The most common potentially toxic species identified in the last two years were *Microcystis*, *Plantothrix* and *Phormidium*. *Microcystis* was recorded at a maximum density of 31,580 cells/mL.

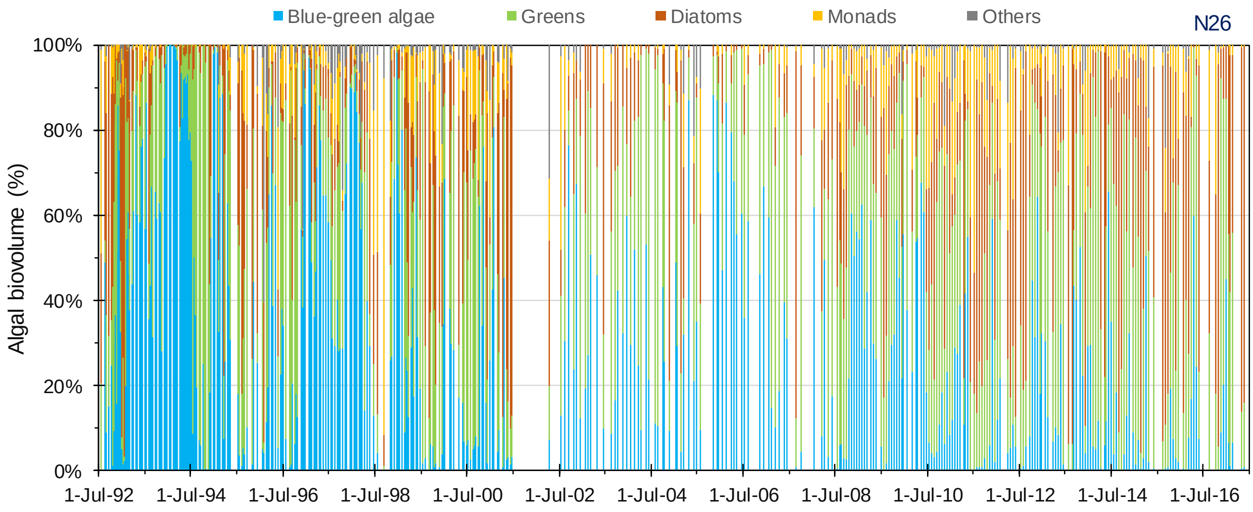


Figure 4-44 Algal composition at Sackville Ferry, Hawkesbury River (N26)

4.4.18 Colo River at Putty Road (N2202)

The Colo River is one of the major tributaries of the Hawkesbury River joining at Lower Portland. The Colo River catchment consists of mostly pristine and undisturbed wilderness areas. About 80% of the catchment is comprised of the Blue Mountains World Heritage Area while small areas support agricultural activities. The monitoring site is located at Putty Road, approximately 12 km upstream of the confluence with the Hawkesbury River. This site was not considered a key site, therefore minimal commentary on water quality trends is provided.

Monitoring at this site commenced in July 2008. Trend analysis was conducted for the entire nine year period and for two distinct periods before and after 2011. A maximum of 108 monthly observations, 36 for the historical period and 72 for the short-term recent period, was used to perform the trend analysis.

The analysis on the last six years data from 2011 to 2017 revealed decreasing trends in dissolved inorganic nitrogen (44%) and pH (11%). No significant trend was identified in any other parameters for the short-term period. Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.19 Hawkesbury River at Leets Vale (N18)

The Hawkesbury River at Leets Vale (N18) is located approximately 12 km downstream from the Colo River confluence and receives relatively good quality water inflows from Colo River as well as an occasional strong tidal influence causing high salt levels. This site was not considered a key site, therefore minimal commentary on water quality trends is provided.

Monitoring at this site commenced in January 1996. Trend analysis was conducted for the entire 21.5 year period with two distinct periods for this site before and after the major WWTP upgrade works to improve nutrient removal in 2011. A maximum of 253 monthly observations, 182 for the historical period leading to upgrade and 71 for the short-term recent period was used to perform the trend analysis.

The analysis on the last six years data from 2011 to 2017 revealed decreasing trends in chlorophyll-*a* (35%) and pH (3%). Significant increasing trends were identified in total nitrogen (37%), total phosphorus (61%) and filterable total phosphorus (85%) over the short-term. No significant trend was identified for any other parameters in the short-term.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

4.4.20 Berowra Creek off Square Bay (Oakey Point) (NB11)

The Berowra Creek site off Square Bay (NB11) is located at Oakey Point in the Berowra estuary of the Hawkesbury River catchment. This site was classed as a key site because of long-term data availability and being the only estuarine site downstream of the Berowra Creek catchment and its two WWTPs. This site is strongly influenced by tidal movements and cycles.

The water quality of this site is affected by various sources of pollution from the upstream Berowra Creek catchment such as urban runoff, runoff from unsewered areas, agricultural cultivation involving intense fertiliser usage, bushland and licensed treated wastewater discharge points including two Sydney Water WWTPs. Hornsby Heights WWTP discharges to Calna Creek, a tributary of the Berowra Creek while West Hornsby WWTP discharges to Waitara Creek, also a tributary of Berowra Creek. In the past, water quality at this site has been very poor with nutrient enrichment and algal blooms. Of most concern was the algal blooms in 2009 and 2016, typically known as ‘red tide’, formed by high densities of the potentially toxic dinoflagellate algae. These algal blooms reduce the aesthetic and recreational value of the creek and severely impact the local oyster industry.

Monitoring at this site commenced in January 1995. Trend analysis was conducted for the entire 22.5-year period with two distinct periods for this site before and after the major upgrades at the Berowra WWTPs to improve nutrient removal in 2005. There was a maximum of 265 monthly observations, with 125 for the historical period leading to the upgrade and 140 for the short-term recent period, used to perform the trend analysis.

Results of the trend analysis performed on flow-adjusted data showed that there have been significant decreases ($p<0.05$) in total nitrogen (15%), dissolved inorganic nitrogen (85%), total phosphorus (13%) and pH (1%) in the last 22.5 years from 1995 to 2017. In contrast, there were significantly increasing trends in chlorophyll-*a* (38%), filterable total phosphorus (84%) and temperature. No significant trends were detected in total algal biovolume (limited data), blue-green algal biovolume (limited data), conductivity, dissolved oxygen, dissolved oxygen saturation and turbidity over the long-term.

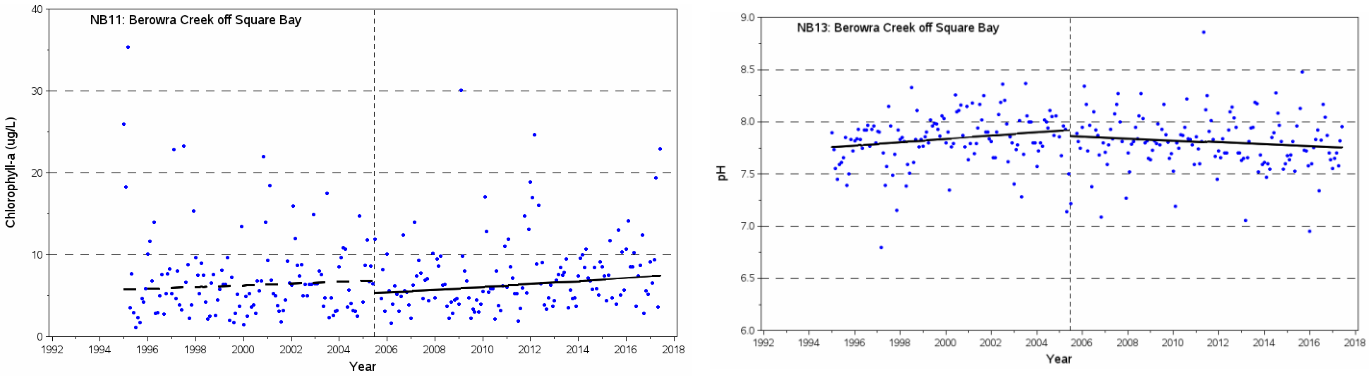
It was anticipated that the Berowra estuary water quality, especially in terms of nitrogen, would improve following the WWTP upgrades in 2005. Therefore, step trend analysis outcomes for the two different periods before and after the upgrade are discussed further

Step trend analysis demonstrated significant increases in chlorophyll-*a* concentrations (39%) in the short-term between 2005 and 2017 (Figure 4-45). Analysis of the limited algal data found no significant trends in 2005.

Both total nitrogen and dissolved inorganic nitrogen significantly decreased in the historical period. Total nitrogen reduced by 45% and dissolved inorganic nitrogen by 93% between 1995 and 2005. No further improvement or deterioration was detected from 2005 to 2017 (Figure 4-46). No specific trends were identified in total phosphorus and filterable total phosphorus when analysed separately for the two periods.

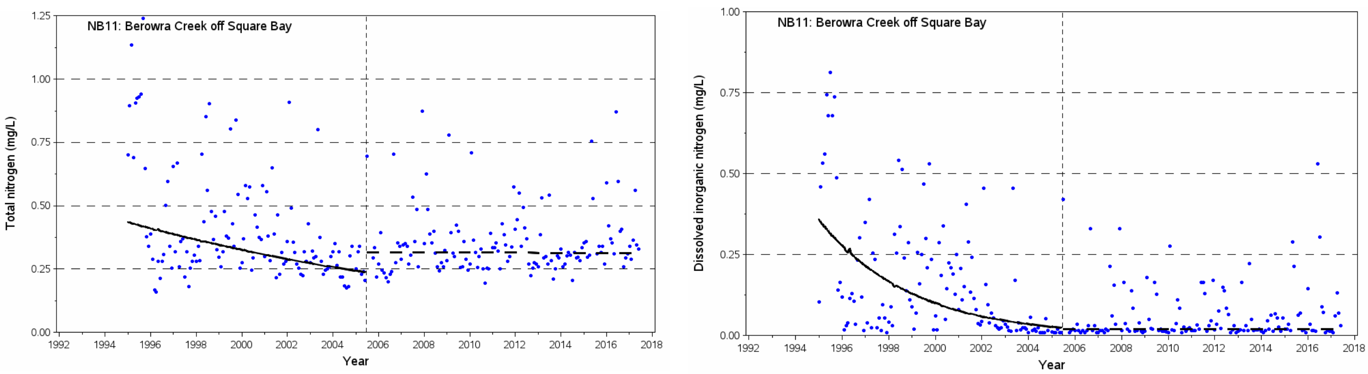
Step trend analysis on pH data from Berowra Creek (NB11) found a significantly increasing trend (2%) in the historical period and a significantly decreasing trend during the short-term period (1%) (Figure 4-45). There were no significant trends in conductivity in either historical or short-term periods.

All trend plots for Berowra Creek of Square Bay are presented in Figure E-12 (Appendix E).



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-45 Step trends in chlorophyll-*a* and pH at Berowra Creek off Square Bay (NB11)



Solid line: statistically significant trend; Dotted line: statistically insignificant trend

Figure 4-46 Step trends in total nitrogen and dissolved inorganic nitrogen at Berowra Creek off Square Bay (NB11)

In general, the Spearman Correlation Analysis found very few significant relationships among parameters. This is probably related to the strong tidal influence at this site which make water quality characteristics highly variable.

The total nitrogen load from the WWTPs was not significantly correlated to total nitrogen or dissolved inorganic nitrogen concentrations. Similarly, the total phosphorus load was not significantly correlated with the total phosphorus or filterable total phosphorus concentrations. These results suggest that the upstream Berowra Creek WWTPs have no noticeable impact on nutrient concentrations at Berowra Creek.

Chlorophyll-*a* showed a weak significant positive relationship with the total nitrogen (Rho=0.37, p=0.0001, n=102) and total phosphorus (Rho=0.36, p=0.0002, n=102) concentrations. No other significant relationships were found with chlorophyll-*a* and any other parameters with the exception of total algal biovolume. Total algal biovolume was also positively, significantly and weakly correlated with the blue-green algal biovolume which was to be expected.

Total nitrogen and dissolved inorganic nitrogen were strongly and moderately correlated with the flow which indicates nutrient rich inflows during wet weather. Turbidity was positively and moderately correlated with the total phosphorus, indicating particulate matter was the dominant source of phosphorus for this site.

Conductivity was strongly and negatively correlated with the total nitrogen and dissolved inorganic nitrogen proving tidal influence with nutrient poor salt water from the ocean mixing with the estuarine water.

The trend in the algal composition of Berowra Creek based on the five major taxonomic groups is shown in Figure 4-47. Generally, diatoms, monads and other algae were dominant, while blue-greens and greens were very rare. Dinoflagellates which are commonly found in the Berowra Creek estuarine waters are included in the ‘other’ taxonomic group of algae. Toxic dinoflagellates were also found at this site on many occasions, with a maximum of 1,460 cell/mL noted (*Prorocentrum minimum*).

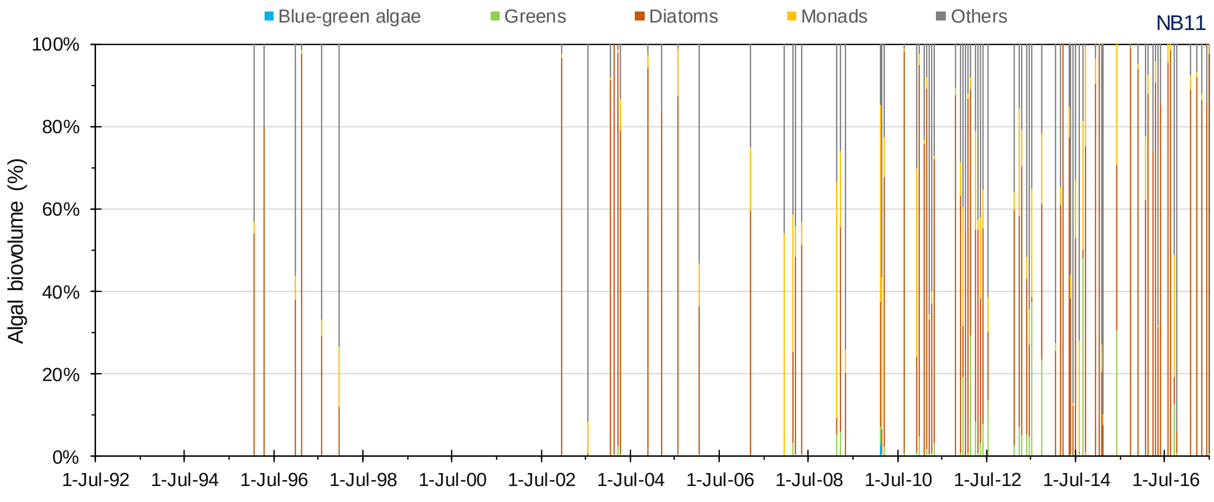


Figure 4-47 Algal composition at Berowra Creek off Square Bay (NB11)

4.4.21 Berowra Creek at Calabash Bay (Cunio Point) (NB13)

The Berowra Creek site at Calabash Bay (NB13) is located at Cunio Point in the Berowra estuary of the Hawkesbury River system. There is a strong tidal influence at this site. The catchment influences at this site are the same as explained for the earlier Berowra site (section 4.4.20) with the only difference being that this site is located in a closer proximity to wastewater discharges from West Hornsby and Hornsby Heights WWTPs. This site was not considered a key site, therefore minimal commentary on water quality trends is provided.

Monitoring at this site commenced from January 1997. Trend analysis was conducted for the entire 20.5-year period with two distinct periods for this site before and after the major WWTP upgrades of the Berowra WWTPs in 2005 to improve nutrient removal. A maximum of 229 monthly observations, 89 for the historical period and 140 for the short-term period, was used to perform the trend analysis.

The analysis of the last 12 years data from 2005 to 2017 revealed increasing trends in chlorophyll-*a* (74%) and total phosphorus (24%). No significant trend was identified in any other parameters for this period.

Further detailed results on long-term trends and step trends are included in Appendix E (Table E-1). Spearman Correlation Analysis was not conducted for this site.

5 Overall discussion

5.1 Nutrient loads

5.1.1 Sydney Water Initiatives

In the late 1990s, *Water Plan 21* was the major program undertaken by Sydney Water to reduce nutrient discharges to the Hawkesbury-Nepean River (Sydney Water 1997). This included upgrading WWTPs to improve nutrient removal, decommissioning of some WWTPs, transferring wastewater to plants with improved treatment capabilities and implementing wastewater reuse schemes. The major nutrient reduction programs were fully implemented to improve river health by 2006 (Sydney Water 2006).

The benefits of these improved wastewater strategies were in line with the planned targets. The phosphorus concentrations in discharges from all inland WWTPs to the Hawkesbury-Nepean River system has been consistently low at most WWTPs since 2002-03. The total nutrient load from all inland plants has ranged between 17 and 25 kg/day, well below the 35 kg/day target load specified in *Water Plan 21* (CSIRO 2003). In 2002-03, the phosphorus concentrations in the river downstream of the majority of WWTPs were at or below the upstream concentrations during dry weather (CSIRO, 2003). The same CSIRO study reported there was also evidence of fewer potentially toxic algal blooms at many sites along the river than in the past.

The phosphorus loads from Sydney Water's WWTPs discharging into the Hawkesbury-Nepean River system has reduced substantially in the last 10-12 years, resulting in reduced chlorophyll-*a* concentrations and changed algal dynamics in the river (Hassan *et al* 2005).

In 2006, The *NSW Metropolitan Water Plan 2006* was introduced with a key emphasis on increased water recycling (NSW Government 2006). This led to the implementation of the St Marys Water Recycling Project, where tertiary treated wastewater from St Marys, Quakers Hill and Penrith WWTPs is further treated using reverse osmosis to produce up to 50 ML/day of highly treated recycled water that is discharged into the Nepean River via Boundary Creek at Penrith. The objective of the project was to preserve drinking water supplies by providing a replacement for environmental flow releases from Warragamba Dam. This project was fully commissioned by September 2010.

The implementation of improved wastewater strategies at each WWTP and the resultant benefits in downstream river water quality were reported annually in the Environment Indicators Compliance Reports (EICRs) and STSIMP reports (Sydney Water 2002, Sydney Water 2003, Sydney Water 2004, Sydney Water 2005, Sydney Water 2009 and Sydney Water 2011).

The improved wastewater strategies and production of more recycled water contributed to a substantial reduction in nutrient loads, both nitrogen and phosphorus, to the downstream river system. Analysis of the long-term trends found that the total nitrogen and total phosphorus load from Sydney Water's WWTPs was reduced by 60 to 90% over 17 years between 1994 and 2011 (Sydney Water 2012). The same study analysed flow adjusted receiving water quality data and found total nitrogen and total phosphorus concentrations were reduced by approximately 40 to

60% and dissolved inorganic nitrogen by more than 80% in the same period. However, the study also found that chlorophyll-*a* only decreased by 25% during the same period.

Since 2011, population growth has seen increasing inflows of wastewater to WWTPs for treatment. This reduces the available capacity at our plants. WWTPs nutrient removal performance declines as they approach the limits of their design. This may account for the increased nutrient concentrations, especially nitrogen, in the discharges over the past 5-6 years, from West Camden, Penrith, Quakers Hill, Riverstone, Castle Hill, West Hornsby and Hornsby Heights WWTPs. Despite the increase in nutrient concentrations in the discharge from some WWTPs, concentrations remained well within the EPL limits

5.1.2 Long-term trend in nutrient loads

The Seasonal Kendall Test was used to determine the long-term trends in nutrient loads from Sydney Water WWTPs since 1992. This statistical technique was considered appropriate for the dataset not being normally distributed, having outliers or extreme results, gaps in data and influenced by seasonal factors. This analysis confirmed that nutrient loads, both total nitrogen and phosphorus have reduced significantly over the past 25 years. The reduction in total phosphorus loads was substantial (> 90%), as it was targeted in the late 1990's as the key nutrient responsible for the potentially toxic algal blooms in the lower Hawkesbury River (Sydney Water 1996). While presenting the recent outcome, it should also be noted that Sydney Water's WWTPs were also upgraded previously in the early eighties. This lead to the total phosphorus loads discharged from WWTPs downstream of the Penrith Weir reduced by 65% between the period 1980 and 1996 (Hawkins and Hassan, 1997).

The total nitrogen load discharged from the Hawkesbury Nepean catchment WWTPs consistently declined during the historical period from 1992 to 2011. However, the reduction in the phosphorus load was not evident until after 2002 when most of the targeted phosphorus improvement works were completed. By 2003, seven out of 10 major inland WWTPs were meeting the *Water Plan 21* target of median total phosphorus load in treated wastewater discharges (Sydney Water 2003). This was further demonstrated in this latest study, when no significant trend in total phosphorus load was detected for the mid-term period between 2002 and 2011.

Long-term trend analysis on the two sub-catchments of the Hawkesbury-Nepean River (Upper Nepean; and Lower Nepean and Upper Hawkesbury) and the three major tributary creeks (South, Cattai and Berowra creeks) did not show a similar upward or downward pattern in nutrient load due to localised population growth and other site specific WWTP issues (Table 5-1). The long-term trend in the total phosphorus load significantly decreased in all sub-catchments with the exception of Cattai Creek where no significant trend in total phosphorus loads was identified. Population growth in this catchment, 366% over the 25-year period from 1992 to 2017, is the likely reason why no reduction in total phosphorus levels has been observed in this catchment. Total phosphorus concentrations in the discharge from Castle Hill WWTP remained high although within the specified EPL limit.

The total nitrogen load significantly decreased over the long-term between 1992 and 2017 in the Lower Nepean/Upper Hawkesbury River, South Creek and Berowra Creek. However, in the Upper Nepean River and Cattai Creek, the total nitrogen load has significantly increased in the last 25 years. This is primarily related to the large increase in population in these catchments. Comparable to Cattai Creek, the population in the Upper Nepean River sub-catchment increased by 355% between 1992 and 2017.

Table 5-1 Summary of long-term and short-term trends WWTP nutrient loads for the five sub-catchments

Parameters	Upper Nepean	Lower Nepean and Upper Hawkesbury	South Creek	Cattai Creek	Berowra Creek	Total
Long-term period	1992-2017	1992-2017	1992-2017	1992-2017	1992-2017	1992-2017
Total nitrogen load						
Total phosphorus load						
Short-term period	2008-2017	2011-2017	2011-2017	2009-2017	2005-2017	2011-2017
Total nitrogen load						
Short-term period	2009-2017	2011-2017	2011-2017	2011-2017	2005-2017	2011-2017
Total phosphorus load						

Legend

- Insignificant trend in nutrient load
- Significant decreasing trend in nutrient load
- Significant increasing trend in nutrient load

5.1.3 Short-term trend in nutrient loads

Between 2011 and 2017, the total population serviced in the Hawkesbury-Nepean River catchment increased by 12%. As stated in section 5.1.2, population growth and the resultant increased volume of wastewater for treatment reduced the WWTP efficiency especially nitrogen removal. The influence of this was evident in total nitrogen load trends. Trend analysis showed the overall trend in average total nitrogen loads from all inland WWTPs has increased by 71% in the last six years between 2011 and 2017. However, the total phosphorus load continued a statistical downward trend from a historic low level in 2011 (51%).

The short-term recent trend for nutrient loads was highly variable throughout the sub-catchments as they were dependent on catchment specific issues (Table 5-1).

In the upper Nepean River between Picton and Warragamba, the poor performing Warragamba WWTP was shut down in 2005 with flows transferred to the new high performing Wallacia WWTP. The major upgrade to improve nutrient removal at West Camden was completed in 2008-09. From the historic low in 2009, the total nitrogen load increased by 369% and the total phosphorus load by 211% by 2017. In addition to population growth (59%), this increase in nutrient load can be attributed to increased discharges from Picton WWTP which now services additional trade waste customers and provides a new wastewater service to the townships of Bargo and Buxton. There was also a significant asset failure at West Camden WWTP which impacted this plants performance in 2014.

The Lower Nepean River and Upper Hawkesbury River sub-catchment between Penrith and North Richmond may be benefited from the transfer of all Blue Mountains WWTPs to Winmalee WWTP and the transfer of Glenbrook and Mt Riverview WWTPs to Penrith WWTP. With these transfers, Winmalee and Penrith become the major contributors to this sub-catchment of the river. Following the commissioning of the St Marys AWTP in September 2010, the impact from Penrith WWTP was reduced. In the year 2010-11, Winmalee WWTP contributed approximately 76% of the total wastewater discharged to the river in this sub-catchment (Sydney Water 2012).

Since 2011, the total phosphorus load discharged to the Lower Nepean River and Upper Hawkesbury River sub-catchment has decreased by 74% possibly because of further treatment refinement on phosphorus removal at Winmalee WWTP. However, the total nitrogen load increased by 41% from a historical low level in 2011. The population increase in this catchment was minor (1%) between 2011 and 2017. The increase in the nitrogen load may be attributed to an increased total nitrogen concentration in discharge from Penrith and North Richmond WWTPs. However, nitrogen concentrations were within the EPL specified limit. The recent shut down of the St Marys AWTP in January to June 2017 may also have contributed to the increase.

The nutrient-rich discharges to the South Creek catchment were believed to be responsible for the algal blooms in the Lower Hawkesbury River below Windsor. As such, improvement works on WWTPs in the South Creek catchment (St Marys, Quakers Hill, Riverstone) were undertaken initially and were mostly completed by 1999. A further series of WWTP upgrade work continued until 2011, including the commissioning of the St Marys AWTP in September 2010. The volume of recycled water discharged from the St Marys AWTP to Boundary Creek was approximately twice the pre-commissioning volume of treated wastewater discharged from the Penrith WWTP (Sydney Water 2012). There was about a 50% reduction in treated wastewater discharges from St Marys into South Creek and about a 35% reduction in discharges from Quakers Hill into Eastern Creek after St Marys AWTP commissioning. This provided a further benefit in nutrient reduction in the South Creek catchment.

The trends in both the total nitrogen and total phosphorus loads from the South Creek WWTPs were reversed in recent years from the historic low level in 2011. Since 2011, the total nitrogen and total phosphorus loads significantly increased by 120% and 96%, respectively. In addition to the 13% growth in population between 2011 and 2017, the recent increased concentrations of nutrients in the discharge from Quakers Hill and Riverstone WWTPs may be also be contributing to increasing loads. However, nutrient concentrations were within the EPL specified limit.

Upgrades to Rouse Hill and Castle Hill WWTPs that discharged to Cattai Creek were completed following the nitrogen removal upgrade at Rouse Hill in 2009. Whereas minor phosphorus upgrade work continued until 2011 at both Rouse Hill and Castle Hill WWTPs. The total nitrogen load from these WWTPs increased by 82% between 2009 and 2017. The total phosphorus load has increased by 70% between 2011 and 2017. The Cattai Creek sub-catchment is a fast-growing urban development area where the population has increased by 23% from 2011 to 2017. This places greater demands on WWTPs. Inferior discharge quality from the Castle Hill WWTP, in terms of both nitrogen and phosphorus, has also contributed to this increase.

In the Berowra Creek sub-catchment, nitrogen was targeted as the key nutrient to be reduced in wastewater discharges. This was based on earlier modelling studies that clearly indicated that a reduction in nitrogen from wastewater discharges from the Hornsby Heights and West Hornsby

WWTPs would reduce the level of chlorophyll-*a* and problematic algae in the downstream Berowra estuary (AWT 1997b, Qin and Fisher 2004). All planned upgrade works at the two WWTPs were completed in 2005 and although nitrogen reduction was the key target, phosphorus was also reduced (Hassan and Besley 2006). Urban development within the Berowra Creek catchment has been moderate with population growth of 16% over 12 years since 2005. To determine the recent nutrient trend, this comparatively longer 12 years period (from 2005 to 2017) was considered for analysis. There was a substantial increase in both total nitrogen (42%) and total phosphorus (72%) loads from these WWTPs. Population pressure and resultant poor performance caused elevated nitrogen concentrations in discharges from both West Hornsby and Hornsby Heights WWTPs.

5.1.4 Nutrient loads from other sources

Other point and non-point sources of nutrients to the Hawkesbury-Nepean River and tributaries include discharges from WWTPs operated by local Councils, wastewater overflows from Sydney Water's network system, seepage from unsewered areas, agricultural runoff and urban stormwater. While known point sources of nutrient loads are easily estimated, much less is known about the loadings derived from different land use areas and the relative impact compared to point sources (Bickford and Johnstone 2000). Bickford and Johnstone (2000) emphasised the need to make models more accurate to quantify point and non-point sources and the need for further studies on nutrient dynamic processes to determine the priority areas for nutrient reduction.

In the mid 1990's Sydney Water conducted extensive modelling to estimate nutrient loads from other non-point sources entering the Hawkesbury-Nepean River system. The estimated total nitrogen and phosphorus loads from non-point sources to the freshwater section of the river (not including Berowra) were 3,907 kg/day and 377 kg/day, respectively (AWT 1998). A recent study conducted by the New South Wales Office of Environment and Heritage (NSW OEH) estimated that total nitrogen and total phosphorus loads to the Hawkesbury-Nepean River (excluding Berowra Creek[2]) from agricultural activities alone were about 3,192 and 589 kg/day, respectively (Haine *et al* 2011). In comparison, it is estimated that total nitrogen and phosphorus loads from Sydney Water's WWTPs to the freshwater section (excluding Berowra Creek) of the Hawkesbury-Nepean River were about 885 and 9 kg/day, respectively. Assuming the agricultural load data remained constant from 2011, current total nitrogen and total phosphorus loads from Sydney Water WWTPs are about 27.7% and 1.5% of the agricultural loads, respectively. If nutrient loads from other non-agricultural sources are added, then the proportion of Sydney Water's WWTP contribution to the overall nutrient loads would be further less. However, WWTP nutrient discharges occur continuously, during dry weather and low flow periods when other sources of nutrients are low.

Considerable progress has been achieved in point sources of pollution and some diffuse sources such as stormwater, to the waterways of NSW (OEH 2009). However, diffuse source water

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[2] NSW OEH nutrient load calculation extends from the Upper Nepean River catchment to Wiseman Ferry including MacDonald River

pollution remains one of the biggest challenges in improving water quality for governments, industry and the community (OEH 2009). In an attempt to reduce nutrient loads to the river, the OEH developed a nutrient management strategy for the lower Hawkesbury River (OEH 2010).

The strategy highlighted many initiatives to reduce nutrient loads such as educational and compliance activities, extension programs, investment in capital projects, on-ground works, and partnership programs. It also identified strategic priorities and new actions that would build on the work to date and reduce nutrient loads from identified priority sources.

The success of overall nutrient management in the Hawkesbury-Nepean River depends on the combined effort of various parties. In addition to Sydney Water initiatives, other government and non-government organisations also conducted various programs to reduce the overall nutrient input into the Hawkesbury-Nepean River system:

- The Hawkesbury-Nepean River catchment action plan was developed by the Hawkesbury-Nepean Catchment Management Authority (HNCMA 2007) to improve river health, protect biodiversity and encourage best practice soil and land management within the catchment. The plan was later implemented by the NSW Government with a target to improve the condition of riverine ecosystem by 2015 (OEH 2010a).
- The Hawkesbury-Nepean River Recovery Program was funded by the Australian Government to make more water available for environmental flows and reduce nutrient inputs to the river system (WaterNSW 2013). The program included seven project areas: improving Hawkesbury-Nepean water balance accounting, licence purchase, smart farms, nutrient export monitoring, irrigation and landscape efficiency program and the South Windsor effluent reuse scheme. All these projects are now implemented and the expectation was that the overall nutrient loads to the river would have significantly improved.
- The Smart Farms project aimed to reduce the diffuse nutrient loads from agricultural activities through a nutrient management education program for landholders and on-ground works that included compost treatment. It is estimated that after the completion of 131 on-ground works projects, about 54 kg total nitrogen and 22 kg total phosphorus would be prevented from entering the river system each day (WaterNSW 2013a)
- The Hawkesbury City Council (HCC) implemented the McGrath Hill Effluent Reuse and Wetland Project to reduce nutrient loads from its McGrath Hill Sewage Treatment Plant, which discharges to South Creek (HCC 1995). About 40-50% of the effluent from this plant was reused in 2011 (HCC 2011). With State Government initiatives, the HCC has been implementing projects to provide recycled water for irrigation and toilet flushing from South Windsor Treatment Plant to council reserves and schools throughout South Windsor (HCC 2013, WaterNSW 2013b). This project aimed to save 10 ML of potable water used for open space irrigation each year and to prevent 1.2 kg total phosphorus entering the Hawkesbury-Nepean River daily.

5.2 Trends in water quality

5.2.1 Long-term trends

The benefit of reduced nutrient loads from Sydney Water WWTPs, as well as the other initiative as listed in section 5.1, was reflected in improved nutrient concentrations at the majority of sites along the Hawkesbury-Nepean River and its tributaries (Table 5-2). Among the 18 monitoring sites with consistent long-term water quality data (20-25 years), total nitrogen and dissolved inorganic nitrogen concentrations significantly decreased at 14 and 13 sites, respectively. A long-term decreasing trend in total phosphorus and filterable total phosphorus was also identified at 12 and 11 sites, respectively. However, a localised, significantly increasing trend in total phosphorus and filterable total phosphorus was identified at the Nepean River at Penrith Weir. Filterable total phosphorus also significantly increased in the Hawkesbury River at Leets Vale and Berowra Creek.

It was expected that the reduced WWTP nutrient loads in conjunction with other nutrient reduction initiatives would improve the chlorophyll-*a* concentration and algal densities of the downstream river and creeks. However, the actual benefit of the nutrient reduction was not reflected in long-term chlorophyll-*a* trends. Chlorophyll-*a* concentrations only significantly decreased at two of the 18 sites in the past 20 to 25 years (Winmalee Lagoon outflow and Hawkesbury River at Sackville Ferry) but significantly increased at three sites (Nepean River at Penrith Weir, Hawkesbury River at Leets Vale and Berowra Creek). Filterable total phosphorus also showed an increasing long-term trend at these sites.

Historically, the Hawkesbury River between Wilberforce and Wisemans Ferry was more prone to algal blooms especially blue-green algae because of nutrient enrichment and altered flow regimes (Hawkins and Hassan 1997, Church *et al* 1997). Over the past 20 years, there have been a number of initiatives undertaken by Sydney Water and other NSW organisations with the intent to reduce algal blooms in this reach of the river. However, two lower Hawkesbury River sites (Wilberforce and Off Cattai SRA) still have the highest median and maximum chlorophyll-*a* concentrations in the Hawkesbury-Nepean River and its tributaries. The Hawkesbury River at Sackville also had one of the highest median chlorophyll-*a* concentrations in 2016-17.

The benefit of the improved wastewater strategies and other government initiatives was improved algae conditions in the Hawkesbury River at Sackville where both chlorophyll-*a* and blue-green algal biovolume significantly decreased between 1994 and 2011 (Sydney Water 2012). That study also noted the decreasing trend in chlorophyll-*a* and algal biovolume at North Richmond, the uppermost site of the Hawkesbury River, where chlorophyll-*a*, total algal biovolume and blue-green algal biovolume decreased by 39%, 48% and 51%, respectively between 1994 and 2011. Hawkins and Hassan (1997) also reported an earlier shift with reduced blue-green algal blooms at this site between 1980 and 1996.

A comprehensive data analysis and review undertaken by NSW OEH found improved water quality of the Hawkesbury-Nepean River from 1980 to 2007 (OEH 2009a). The study highlighted that nitrogen and phosphorus levels were declining at most sites of the river, apart from a couple of upper Nepean River sites. Chlorophyll-*a* had mostly declined or remained stable throughout the river since 1980.

Table 5-2 Summary of long-term water quality trends from upstream to downstream sites along the Hawkesbury-Nepean River and tributaries

Site	Chlorophyll-a	Total algal biovolume	Blue-green algal biovolume	Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Filterable total phosphorus	Conductivity	pH	Dissolved oxygen	Dissolved oxygen saturation	Temperature	Turbidity
N92: Maldon Weir (key site)	Insignificant	Increasing #	Increasing #	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Increasing	Increasing	Insignificant	Insignificant	Decreasing
N911: Stonequarry Ck. (key site)	Insignificant	Insufficient data	Insufficient data	Decreasing	Insignificant	Decreasing	Decreasing	Increasing	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing
N91: Maldon Br	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Increasing	Insignificant	Insignificant	Insignificant	Decreasing
N75: Sharpes Weir (key site)	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Increasing	Decreasing
N67: Wallacia Br	Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing
N57: Penrith Weir (key site)	Increasing	Increasing #	Insignificant	Insignificant	Insignificant	Increasing	Increasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
N51: Op. Fitzgeralds Ck	Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Increasing
N48: Smith Road	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Increasing	Insignificant
N464: Winmalee Lagoon (key site)	Decreasing	Increasing #	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Increasing	Decreasing
N44: Yarramundi Br	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Increasing	Increasing	Increasing	Increasing	Decreasing
N42: North Richmond (key site)	Insignificant	Insignificant	Insignificant	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
N39: Freemans reach	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
NS04: South Ck (key site)	Insignificant	Increasing #	Insignificant	Decreasing	Decreasing	Decreasing	Decreasing	Increasing	Insignificant	Increasing	Insignificant	Insignificant	Decreasing
N35: Wilberforce (key site)	Insignificant	Increasing #	Insignificant	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Decreasing
NC11: Cattai Ck (key site)	Insignificant	Increasing #	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Increasing
N3001: Off Cattai SRA	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing	Increasing	Decreasing
N26: Sackville Ferry (key site)	Decreasing	Increasing #	Decreasing ##	Decreasing	Decreasing	Decreasing	Decreasing	Insignificant	Decreasing	Decreasing	Decreasing	Insignificant	Insignificant
N2202: Colo R.	Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Insignificant	Increasing	Decreasing	Decreasing	Decreasing	Increasing	Insignificant
N18: Leets Vale	Increasing	Insufficient data	Insufficient data	Insignificant	Decreasing	Insignificant	Increasing	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Increasing
NB11: Berowra Ck off Square Bay (key site)	Increasing	Insignificant	Insignificant	Decreasing	Decreasing	Decreasing	Increasing	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Insignificant
NB13: Berowra Ck Calabash Bay	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing	Insignificant	Insignificant	Increasing	Insignificant

Legend

- Insignificant trend for parameter
- Significant decreasing trend for parameter
- Significant increasing trend for parameter
- Insufficient data or not a key site
- Key site

#	Increasing trends include error due to algal samples not counted for low chlorophyll-*a* samples
##	Decreasing trend represents much stronger trend as algal counts were not performed on low chlorophyll-*a* samples

The long-term trend in algal data was most accurate for the Hawkesbury River site at North Richmond due to the large number of routine samples analysed for this site. This study found no significant long-term trend (1992 to 2017) at this site for total algal biovolume, blue-green algal biovolume and chlorophyll-*a* despite significant reductions in all four nutrient parameters. The decreasing trend identified in the earlier period (1992 to 2011) ceased due to elevated chlorophyll-*a* and algal biovolume after 2011. This may have been influenced by the flood in early 2012 that displaced established macrophyte beds from this site and input highly turbid nutrient rich runoff from the surrounding catchment. This change to the river ecosystem may have altered the availability of light and nutrients and given other environmental factors, provided more conducive conditions for increased algal growth at this site.

A macrophyte study (Sydney Water 2013) targeting the 2012 flood impact also demonstrated macrophyte assemblages before and after March 2012 flood were different. Macrophyte abundances were monitored at four sites along the Hawkesbury River from Penrith Weir to North Richmond before and after the 2012 flood event. The study demonstrated that the level of submerged macrophyte *Egeria densa,* which was dominant at all of four sites, decreased following the flood. At one site near Yarramundi, the abundance of *Egeria densa* decreased from 93% to 8%. In contrast, bare substrate coverage increased from 2% to 91%. Macrophytes also use nutrients from the water column so a decrease in their population has made more nutrients and light available for algae growth.

The long-term (1992-2017) increasing trends in total algal biovolume were identified at five sites including the upstream Nepean River reference site, the Nepean River at Maldon Weir, the Nepean River at Penrith Weir and two algal bloom prone sites in the lower Hawkesbury River at Wilberforce and Sackville (Table 5-2 Summary of). With the exception of Penrith Weir, there were no corresponding trends identified in chlorophyll-*a* for the same sites. Multiple reasons could be associated with this increasing trend in algal biovolume at these sites. Firstly, the algal dataset for these sites were selectively monitored, with algae counts only performed when chlorophyll-*a* was high (above the 7 μg/L threshold). Secondly, it is possible that there was a shift in algal taxa groups with low chlorophyll-*a* per unit algal biovolume. The increase in total algal biomass at Penrith Weir could also be related to the macrophyte displacement in 2012.

The analysis of the limited blue-green algal biovolume data identified a significant decrease in the biovolume in the Hawkesbury River at Sackville between 1992 and 2017. In fact, it demonstrated a much stronger decreasing trend as the low chlorophyll-*a* samples were not counted which normally would have low or no blue-green algal biovolume. This site was more prone to blue-green algal blooms in the 1990s and there was an expectation of a reduced number of algal blooms following the implementation of Sydney Water's wastewater strategies. Although chlorophyll-*a* data was only available from 1994 for this site, the trend analysis demonstrated a significant decrease to recent times (1994-2017).

The benefits of an improved wastewater strategy were not proportionately evident in the water quality of the downstream river and creeks. A case study conducted in 2012 demonstrated that the long-term chlorophyll-*a* reduction was not equivalent to reductions in nutrient loads and nutrient concentrations (Sydney Water 2012). It indicates either the scale of reduction in nutrient loads may not have been enough, stoichiometry of nitrogen and phosphorus plays a dominant role or that diffuse sources may be influencing the algal growth at these sites.

Like nutrients, chlorophyll-*a* and algae, significant long-term trends were also identified in other physico-chemical parameters. The conductivity significantly decreased over the long-term at two sites while at three other sites, there was a significant increase in conductivity. The conductivity of streams and rivers is determined by the catchment geology and the salt content entering from upstream tributaries. The increasing trend in conductivity was identified in three tributaries, which were Stonequarry Creek, South Creek and the Colo River.

Water pH significantly decreased over the long term at seven out of 21 monitoring sites. The majority of these sites were from Cattai Creek and further downstream along the Hawkesbury River, the Colo River and Berowra Creek. Water pH significantly increased at three upstream sites. It is unclear why the increasing or decreasing pH trend was seen at these sites. Presence of nutrients and algae in water play a key role in affecting the pH. In a diurnal cycle, pH can rise due to photosynthetic uptake of bicarbonate during the day and fall due to respiratory production of carbonic acid.

The dissolved oxygen and/or dissolved oxygen saturation significantly improved (an increase) in the Nepean River at Maldon Weir and Yarramundi Bridge and in South Creek. This coincides with a decrease in turbidity at these sites over the long-term. In relatively clear water more light penetration increases photosynthesis and high day time dissolved oxygen is expected. At five other sites, dissolved oxygen and/or dissolved oxygen saturation decreased over the long-term. The median turbidity was highest at most of these sites where decomposition of organic materials associated with suspended particles or dissolved oxygen consumption was expected.

There was an increasing long-term trend in water temperature at 10 out of the 21 sites tested with a 1.1^{o}C to 1.6^{o}C increase annually where long-term data, 20 to 25 years, was available. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) predicted that the average 1990 temperature would rise by 1.0^{o}C and a 5% decrease in rainfall by 2030 in the Sydney Metropolitan Catchments (CSIRO 2006).

The water clarity of the river has improved as evidenced by significantly decreasing long-term trends in turbidity at nearly half (10 out of 21) of the monitoring sites. Five of these sites are from the upper Nepean River from Maldon to Wallacia possibly reflecting the benefit of environmental flow releases from upstream water storages. In contrast, limited turbidity data for the three downstream sites showed significantly increasing trends between 2008 and 2017. These sites were Nepean River opposite Fitzgeralds Creek, Cattai Creek and Hawkesbury River at Leets Vale, indicating localised impacts.

5.2.2 Short-term trends

As explained previously, the last six years from 2011 to 2017 was considered as the short-term for most water quality sites for the step-trend analysis. Exceptions were the three upstream Nepean River sites (7 years), Nepean River at Sharpes Weir (8-9 years) and Berowra Creek sites (12 years).

The short-term trends for nutrient concentrations were occasionally aligned with the catchment specific increase or decrease in WWTP nutrient loads although this was not consistent across all sites. Total nitrogen concentrations significantly increased in recent years at ten out of 20 monitoring sites from Nepean River at Sharpes Weir to Hawkesbury River at Leets Vale (Table 5-3). Note that, there was insufficient data for Winmalee Lagoon for the trend analysis. A significant decreasing trend in total nitrogen was identified at the Nepean River upstream reference site at Maldon Weir. Low nutrient environmental flow releases from upstream storage dams may be contributing to this.

Table 5-3 Summary of short-term water quality trends from upstream to downstream sites along the Hawkesbury-Nepean River and tributaries

Site	Key site	Chlorophyll-*a*	Total algal biovolume	Blue-green algal biovolume	Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Filterable total phosphorus	Conductivity	pH
N92: Maldon Weir	Key site	Insignificant	Insufficient data	Insufficient data	Decreasing	Decreasing	Insignificant	Insignificant	Increasing	Decreasing
N911: Stonequarry Ck.	Key site	Increasing	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Decreasing	Increasing	Decreasing
N91: Maldon Br		Insignificant	Insufficient data	Insufficient data	Insignificant	Decreasing	Decreasing	Insignificant	Increasing	Decreasing
N75: Sharpes Weir	Key site	Decreasing	Increasing #	Insignificant	Increasing	Increasing	Decreasing	Insignificant	Decreasing	Decreasing
N67: Wallacia Br		Decreasing	Insufficient data	Insufficient data	Increasing	Increasing	Insignificant	Insignificant	Insignificant	Decreasing
N57: Penrith Weir	Key site	Insignificant	Insignificant	Insignificant	Increasing	Increasing	Decreasing	Decreasing	Insignificant	Decreasing
N51: Op. Fitzgeralds Ck		Decreasing	Insufficient data	Insufficient data	Increasing	Increasing	Decreasing	Insignificant	Increasing	Insignificant
N48: Smith Road		Insignificant	Insufficient data	Insufficient data	Increasing	Increasing	Decreasing	Insignificant	Increasing	Insignificant
N464: Winmalee Lagoon	Key site	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
N44: Yarramundi Br		Decreasing	Insufficient data	Insufficient data	Increasing	Increasing	Decreasing	Decreasing	Increasing	Insignificant
N42: North Richmond	Key site	Decreasing	Insignificant	Insignificant	Increasing	Increasing	Decreasing	Decreasing	Increasing	Decreasing
N39: Freemans reach		Insignificant	Insufficient data	Insufficient data	Increasing	Insignificant	Insignificant	Insignificant	Increasing	Insignificant
NS04: South Ck	Key site	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing
N35: Wilberforce	Key site	Insignificant	Insignificant	Insignificant	Increasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
NC11: Cattai Ck		Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing
N3001: Off Cattai SRA		Insignificant	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
N26: Sackville Ferry	Key site	Decreasing	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
N2202: Colo R.		Insignificant	Insufficient data	Insufficient data	Insignificant	Decreasing	Insignificant	Insignificant	Insignificant	Decreasing
N18: Leets Vale		Decreasing	Insufficient data	Insufficient data	Increasing	Insignificant	Increasing	Increasing	Insignificant	Decreasing
NB11: Berowra Ck off Square Bay	Key site	Increasing	Insufficient data	Insufficient data	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Decreasing
NB13: Berowra Ck Calabash Bay		Increasing	Insufficient data	Insufficient data	Insignificant	Insignificant	Increasing	Insignificant	Insignificant	Insignificant

Legend

- Insignificant trend for parameter
- Significant decreasing trend for parameter
- Significant increasing trend for parameter
- Insufficient data or not a key site
- Key site
- # Increasing trends include error due to algal samples not counted for low chlorophyll-*a* samples

Consistent with total nitrogen, an increasing trend in dissolved inorganic nitrogen was observed at seven sites from Nepean River at Sharpes Weir to the Hawkesbury River at North Richmond. In contrast, a decreasing trend in dissolved inorganic nitrogen was found in the Nepean River at Maldon Bridge downstream of Stonequarry Creek confluence and the Colo River.

Total phosphorus concentration significantly decreased at seven sites from upstream in the Nepean River at Maldon Bridge to downstream in the Hawkesbury River at North Richmond. This is consistent with the decreasing trends in the total phosphorus load discharged from Sydney Water's WWTPs in recent years. The increased total phosphorus loads in the WWTP discharge was not reflected in the phosphorus concentrations at three sites of the Upper Nepean River sub-catchment. Two of these sites may have benefited from the nutrient poor environmental releases from the Upper Nepean dams.

Total phosphorus concentrations decreased or showed no change at most sites, the exceptions being an increase at Hawkesbury River at Leets Vale and Berowra Creek at Calabash Bay. The former site also experienced an increasing trend in filterable total phosphorus. Consistent with the total phosphorus trend, total filterable phosphorus concentrations also decreased at four upstream sites.

Despite an increasing trend in total nitrogen concentrations, chlorophyll-*a* has decreased since 2011 at eight sites from upstream in the Nepean River at Sharpes Weir to downstream in the Hawkesbury River at Leets Vale. The decreasing trends in chlorophyll-*a* at the upstream sites mostly correspond with the decreasing trend in total phosphorus. Chlorophyll-*a* has significantly increased at Stonequarry Creek, and the two Berowra Creek sites. The decreasing trends in chlorophyll-*a* at many sites did not match expectations associated with the increasing total and dissolved inorganic nitrogen concentrations. Nutrient dynamics or cycles (both nitrogen and phosphorus) are complex and therefore nutrient bioavailability and algal growth are not often directly correlated because of the potential for continuous transfer of unavailable to available forms.

A study on the Waikato River in New Zealand also reported decreasing long-term trends in chlorophyll-*a* and an increasing trend in total nitrogen (Healthy River 2015). Neither nitrogen nor phosphorus alone promoted the growth of algae at any site at any time. Algae numbers increase more often with the addition of both nitrogen and phosphorus together (Healthy River 2015).

The short-term trend in conductivity data showed an increase at eight sites from upstream in the Nepean River at Maldon Weir to downstream in the Hawkesbury River at Freemans Reach. In the Nepean River at Sharpes Weir, there was a decreasing trend in conductivity since 2011. These variations in conductivity possibly indicate high or low salinity inflows at these sites over the short-term.

pH decreased at 12 out of 20 sites monitored between 2011 and 2017. No significantly increasing trend in pH was identified in the short-term data analysis.

5.3 Nutrient dynamics and algal blooms

5.3.1 Nutrient loads and concentrations

The relationship between site-specific nutrient loads from Sydney Water's WWTPs and the instream nutrient concentrations at 10 key sites in the Hawkesbury-Nepean River were tested by Spearman Correlation Analysis. Among these only two sites showed significant positive correlation with the total nitrogen concentration and three sites showed significant positive correlations for dissolved inorganic nitrogen concentrations (Table 5-4). Site-specific total nitrogen loads discharged upstream of the Nepean River at Sharpes Weir (by Picton and West Camden WWTPs) explained 55% of the variation in total nitrogen concentrations and 53% of the variation in dissolved inorganic nitrogen concentrations. The site-specific nitrogen load from WWTPs (North Richmond, Quakers Hill, Riverstone and St Marys) discharged to the lower Hawkesbury River site at Wilberforce explained 54% variation in total nitrogen and 57% variation in dissolved inorganic nitrogen. Further downstream the Hawkesbury River at Sackville Ferry, total nitrogen loads from upstream WWTPs (all South and Cattai creeks) explained a 34% variation in dissolved inorganic nitrogen concentrations. These findings show that nitrogen enrichment is occurring at most monitoring sites (with the exception of the three above mentioned sites) is more likely influenced by other catchment sources.

The relationship between site-specific total phosphorus loads discharge from WWTPs with total phosphorus and filterable total phosphorus concentrations in the river were significantly positive at the majority of the sites (six out of 10) (Table 5-4). The total phosphorus loads from WWTPs explained 39% to 71% variation in total or filterable total phosphorus concentrations in the receiving water. The strongest correlation was found at Stonequarry Creek and weakest in the Hawkesbury River at Wilberforce, downstream of South Creek. This indicates that WWTP phosphorus loads were the main influence on total phosphorus concentrations at these sites. No such significant relationship was found in the Nepean River at Penrith Weir, the Hawkesbury River at Sackville Ferry, and in the Cattai or Berowra creeks. These sites are located further away from upstream WWTP discharge points and/or influenced by phosphorus rich inflows from other catchment sources.

The relationship between nutrient loads from wastewater discharges and nutrient concentrations in downstream receiving water is complex and may depend on the distance between the actual discharge point and the receiving water site, river morphology, flow rate and other loss processes. An earlier desktop study on the Wallacia WWTP found that loss processes are expected to remove a significant fraction of nutrients entering the river system within a very short distance. The actual concentrations were about 84% less for total nitrogen and 96% less for total phosphorus, compared to those predicted by mass balance (Hawkins *et al* 2004).

Table 5-4 Summary of the Spearman Correlation Analysis outcome: site-specific WWTP nutrient loads vs. actual nutrient concentrations in the Hawkesbury-Nepean River or tributaries (2011-17 data)

Site	Total nitrogen load		Total phosphorus loads	
	vs	vs	vs	vs
	Total nitrogen concentration	Dissolved inorganic nitrogen concentration	Total phosphorus concentration	Filterable total phosphorus concentration
N92: Maldon Weir	No WWTP load upstream of this site			
N911: Stonequarry Ck.	No correlation	No correlation	Strong correlation (positive)	Strong correlation (positive)
N75: Sharpes Weir	Strong correlation (positive)	Strong correlation (positive)	Strong correlation (positive)	Strong correlation (positive)
N57: Penrith Weir	No correlation	No correlation	No correlation	No correlation
N464: Winmalee Lagoon	No correlation	No correlation	Weak correlation (positive)	Weak correlation (positive)
N42: North Richmond	No correlation	No correlation	Strong correlation (positive)	Strong correlation (positive)
NS04: South Ck	No correlation	No correlation	Moderate correlation (positive)	Strong correlation (positive)
N35: Wilberforce	Strong correlation (positive)	Moderate correlation (positive)	Moderate correlation (positive)	Moderate correlation (positive)
NC11: Cattai Ck	No correlation	No correlation	No correlation	No correlation
N26: Sackville Ferry	No correlation	Weak correlation (positive)	No correlation	No correlation
NB11: Berowra Ck off Square Bay	No correlation	No correlation	No correlation	No correlation

Legend

- Strong correlation: Rho>0.50 and p<0.0001
- Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
- Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05
- No correlation
- Insufficient data or not analysed
- Positive correlation
- Negative correlation

5.3.2 Chlorophyll-*a*, algal biovolume and flow

Flow influences algal populations in two ways:

- in dry weather and low flow conditions, river water is generally clear allowing increased light penetration, which combined with static conditions, encourages algal growth
- in wet weather and high flow conditions, river water is often turbid, limiting light penetration. High flow also wash-out the algae to further downstream.

In drought affected months with reduced river flows, the diffuse catchment inputs dry up and algal growth is predominantly driven by nutrients derived from point sources. Flow has previously been identified as the key determinant in the development of algal blooms in the Hawkesbury-Nepean

River (Hawkins and Hassan, 1995). Generally, low flows can allow algal populations to build up to problematic levels, while higher flows flush algal populations downstream. This was evident in the Hawkesbury-Nepean River in 1995, where three large flow events exceeding 1,000 ML/day at Penrith Weir diluted and displaced algal populations. In the same way, the estuarine algal populations can be displaced or diluted by increased tidal flushing by the relatively cleaner ocean water.

The results from the Spearman Correlation Analysis identified, a negative correlation (ranging between weak and strong) between chlorophyll-*a* and site-specific flow at nine out of 11 sites tested (Table 5-5). With the exception of Stonequarry and Berowra creeks, chlorophyll-*a* concentrations significantly decreased with increased flow at all other sites. This was expected due to algal wash-out during high flow events. The Hawkesbury River at Wilberforce (downstream of South Creek confluence) showed the largest impact of flow where 65% variation in chlorophyll-*a* was explained by the flow. Total algal biovolume and blue-green algal biovolume also showed moderate negative correlations (40% or more variation) with the site-specific flow in the Hawkesbury River at North Richmond. Limited algal biovolume data from four other sites also indicated a weak to strong negative correlation with the flow, especially at the lower Hawkesbury River sites downstream of South Creek where more frequent algal blooms occurred.

Oliver *et al* (1999) reported that concentrations of cyanobacteria (blue-green algae) in the Bourke Weir Pool on the Darling River were negatively correlated to the discharge rate. Populations greater than 1,000 cells/mL do not occur when discharge rates exceed 800-1,000 ML/day. At a discharge rate lower than 500 ML/day, large blooms occur more frequently. Biggs (2000) developed statistical models with nutrients, flow and chlorophyll-*a* data from New Zealand rivers and streams. These models explained 40% to 62% of variations in mean monthly chlorophyll-*a* with days of accrual, an indicator reflecting the frequency of flood disturbance events.

A recent modelling study on the Hawkesbury-Nepean River and South Creek found a clear response with reduced chlorophyll-*a* at South Creek with increased flow, irrespective of whether the increased flow was from high quality recycled water or tertiary treated wastewater (Sydney Water 2015). Consistent with the findings from this report, flow and other catchment factors were found to be the main drivers for algal abundance from the modelling.

Table 5-5 Summary of the Spearman Correlation Analysis outcome: site-specific flow vs. chlorophyll-*a*, total algal biovolume and blue-green algal biovolume

Site	flow		
	vs	vs	vs
	Chlorophyll-*a*	Total algal biovolume	Blue-green algal biovolume
N92: Maldon Weir	Weak correlation, negative	Insufficient data or not analysed	Insufficient data or not analysed
N911: Stonequarry Ck.	No correlation	No correlation	No correlation
N75: Sharpes Weir	Moderate correlation, negative	No correlation	Weak correlation, negative
N57: Penrith Weir	Moderate correlation, negative	No correlation	No correlation
N464: Winmalee Lagoon	Weak correlation, negative	No correlation	Weak correlation, positive
N42: North Richmond	Moderate correlation, negative	Moderate correlation, negative	Moderate correlation, negative
NS04: South Ck	Moderate correlation, negative	No correlation	No correlation
N35: Wilberforce	Strong correlation, negative	Moderate correlation, negative	Weak correlation, negative
NC11: Cattai Ck	Strong correlation, negative	No correlation	No correlation
N26: Sackville Ferry	Moderate correlation, negative	Weak correlation, negative	Strong correlation, negative
NB11: Berowra Ck off Square Bay	No correlation	No correlation	No correlation

Legend

- Strong correlation: Rho>0.50 and p<0.0001
- Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
- Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05
- No correlation
- Insufficient data or not analysed
- Positive correlation
- Negative correlation

5.3.3 Chlorophyll-*a*, algal biovolume and nutrients

Nutrients, such as phosphorus and nitrogen, have long been implicated in algal blooms. They may be derived from geological sources or from anthropogenic activities like fertilisers or wastewater discharges. Phosphorus and nitrogen are essential for algal growth. Some blue-green algal species, such as *Anabaena*, can fix nitrogen from atmospheric sources. Diatoms are a group of algae that possess an ornamental silicified cell wall (frustule) and require silica as an essential nutrient in addition to nitrogen and phosphorus.

The results of the Spearman Correlation Analysis did not support the common belief that chlorophyll-*a* and algae would increase with the increase in key nutrient concentrations. The relationship between chlorophyll-*a* and individual nutrient parameters was negative at most sites

(Table 5-6). That is, chlorophyll-*a* decreased as nutrients increased at most sites, from the upstream reference site to the downstream Hawkesbury River site at Sackville Ferry.

Table 5-6 Summary of the Spearman Correlation Analysis outcome: nutrient concentration vs chlorophyll-*a*, total algal biovolume and blue-green algal biovolume

Site	Total nitrogen			Dissolved inorganic nitrogen			Total phosphorus			Filterable total phosphorus		
	vs chla	vs totbv	vs bgbv	vs chla	vs totbv	vs bgbv	vs chla	vs totbv	vs bgbv	vs chla	vs totbv	vs bgbv
N92: Maldon Weir	No correlation	Insufficient data or not analysed	Insufficient data or not analysed	Weak, negative	Insufficient data or not analysed	Insufficient data or not analysed	No correlation	Insufficient data or not analysed	Insufficient data or not analysed	No correlation	Insufficient data or not analysed	Insufficient data or not analysed
N911: Stonequarry Ck.	No correlation	Weak, negative	No correlation	No correlation	Weak, negative	No correlation	Moderate, positive	Weak, positive	No correlation	Weak, positive	No correlation	Moderate, positive
N75: Sharpes Weir	Weak, negative	No correlation	No correlation	Weak, negative	No correlation	No correlation	No correlation	No correlation	No correlation	No correlation	No correlation	No correlation
N57: Penrith Weir	No correlation	No correlation	Weak, negative	Moderate, negative	Weak, negative	Weak, negative	No correlation	No correlation	No correlation	No correlation	No correlation	No correlation
N464: Winmalee Lagoon	No correlation	No correlation	Weak, negative	No correlation	No correlation	Weak, negative	No correlation	No correlation	No correlation	No correlation	Weak, negative	No correlation
N42: North Richmond	No correlation	No correlation	No correlation	Moderate, negative	Strong, negative	Strong, negative	Moderate, positive	Moderate, positive	Moderate, positive	No correlation	No correlation	No correlation
NS04: South Ck	No correlation	No correlation	Weak, negative	No correlation	Weak, negative	Weak, negative	Weak, negative	No correlation	No correlation	Strong, negative	No correlation	No correlation
N35: Wilberforce	Weak, negative	No correlation	Moderate, negative	Moderate, negative	No correlation	Strong, negative	No correlation	No correlation	No correlation	Strong, negative	Weak, negative	No correlation
NC11: Cattai Ck	No correlation	No correlation	Weak, negative	No correlation	Weak, negative	Strong, negative	No correlation	No correlation	Weak, positive	Strong, negative	No correlation	No correlation
N26: Sackville Ferry	No correlation	Weak, negative	Strong, negative	Weak, negative	Weak, negative	Strong, negative	No correlation	Weak, negative	No correlation	Strong, negative	Moderate, negative	Strong, negative
NB11: Berowra Ck off Square Bay	Weak, positive	No correlation	No correlation	No correlation	No correlation	No correlation	Weak, positive	No correlation	No correlation	No correlation	No correlation	No correlation

Legend

- Strong correlation: Rho>0.50 and p<0.0001
- Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
- Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05
- No correlation
- Insufficient data or not analysed
- Positive correlation
- Negative correlation

Chla = chlorophyll-*a*; totbv = Total algal biovolume; bgbv = Blue-green algal biovolume

The three exceptions where chlorophyll-*a* was positively correlated with the nutrients were Stonequarry Creek, Hawkesbury River at North Richmond and Berowra Creek:

- At Stonequarry Creek, chlorophyll-*a* increased significantly with increases in total phosphorus and filterable total phosphorus concentrations, explaining 49% and 37% of the datasets variation respectively
- At North Richmond on the Hawkesbury River, chlorophyll-*a* significantly increased with the increases in total phosphorus (48% variation explained)
- At Berowra Creek, chlorophyll-*a* significantly increased with the increase in both total nitrogen (37% variation explained) and total phosphorus (36% variation explained)

At these sites nutrients were readily available for algal growth. Further control on nutrients may reduce the algal growth at these sites.

At the Nepean River reference site at Maldon Weir, dissolved inorganic nitrogen had a negative correlation with the chlorophyll-*a* concentration (35% of variation explained). At the upper Nepean River site at Sharpes Weir, total nitrogen and dissolved inorganic nitrogen was negatively correlated with the chlorophyll-*a* concentrations (31% and 36% variation respectively). Dissolved inorganic nitrogen was also negatively correlated with the chlorophyll-*a* at four other sites from the Nepean River at Penrith Weir to the downstream Hawkesbury River at Sackville Ferry (38% to 41% variation explained).

Total algal biovolume and blue-green algal biovolume also showed similar negative correlations with the nitrogen parameters:

- Dissolved inorganic nitrogen concentrations were strongly and negatively correlated with the blue-green algal biovolume at seven out of 11 sites
- Dissolved inorganic nitrogen was also negatively correlated with chlorophyll-*a* concentrations at six sites
- Total algal biovolume also had negative correlations at six sites with dissolved inorganic nitrogen

These findings demonstrate when nitrogen concentrations approach zero or fall to very low levels, algae can continue to grow in high densities. The negative relationship between the available form of nitrogen and chlorophyll-*a* or algae is also reflected in the recent literature:

- A blue-green algal study on Missisqui Bay (Québec, Canada) found negative correlations between oxidised nitrogen and the biomass of various blue-green algal taxa (DPI 2014). In this situation, algae must be deriving nitrogen from sources other than the oxidised nitrogen. Nitrogen fixation from the atmosphere is also a possible source of nitrogen, when blue-green algae dominates.
- Significant negative correlation was also reported between chlorophyll-*a* with nitrate, nitrite and ammonia data collected from a wetland in Iran (Balali *et al* 2013).
- The relationship between chlorophyll-*a* and total nitrogen was explored using a comprehensive dataset from nutrient-rich lakes with dominant agricultural land uses in the United States (Filstrup and Downing 2017). Chlorophyll-*a* was weakly correlated with the

total nitrogen when total phosphorus was ≤0.100 mg/L. However, there was a stronger correlation at higher phosphorus concentrations, with chlorophyll-*a* increasing until the total nitrogen concentrations reached 3.00 mg/L.

- A small Canadian lake fertilised for 37 years with constant annual input of phosphorus but low nitrogen did not control algal blooms (Schindler *et al* 2008). Nitrogen limitation or shortage of dissolved nitrogen favoured nitrogen fixing blue-green algae to dominate or outperform other algae. Phosphorus control is suggested as a measure of controlling eutrophication, not nitrogen.
- Phosphorus control was recommended as the most effective way of controlling algal blooms in freshwater lakes (Schindler *et al* 2016). Schindler *et al* 2016 conducted long-term studies on various lakes in nine countries in Europe and North America to examine whether to control nitrogen alone, both nitrogen and phosphorus, or phosphorus alone was more effective in reducing the incidence of algal blooms. Studies of controlling nitrogen, either alone or with phosphorus, showed no discernible effect on algal blooms. Lakes where phosphorus reductions successfully reduced algal blooms ranged in size from small ponds to large lake, in a wide range of climatic and geological settings.
- In highly eutrophic systems, the amount of dissolved inorganic nutrients can approach zero when algal demand is high (Dodds 2006). Australian freshwater systems with long residence times show stoichiometric evidence of nitrogen limitation and the frequent occurrence of nitrogen-fixing cyanobacteria blooms (Harris 2001). Bickford and Smith (2006) suggested nitrogen fixation as an internal source of nitrogen in the lower estuary of the Hawkesbury River. The possible source of this nitrogen may be from mangroves in the lower estuary.
- A portion of dissolved organic nitrogen is also available to algae. In the past, this was considered largely as refractory and not important to algal growth. Cumulative evidence indicates that algae, including a number of harmful species, may obtain a substantial part of their nitrogen nutrition from organic compounds (Bronk *et al* 2006). An experimental study on the cyanobacterium *Aphanizomenon ovalisporum* suggested that components of the dissolved organic nitrogen pool were a major direct or indirect source of nitrogen for this alga and that nitrogen fixation was not a significant factor (Berman 1997). Algal species capable of utilising dissolved organic nitrogen may have a competitive advantage in organically enriched environments where the dissolved inorganic nitrogen supply is limited. Specifically, cyanobacteria algae and some dinoflagellates (eg. *Prorocentrum minimum*) seem to have an affinity for organic nitrogen (Bronk *et al* 2006).

Strong and negative correlations were also found between filterable total phosphorus and chlorophyll-*a* concentrations at four downstream sites from South Creek to the Hawkesbury River at Sackville Ferry (53% to 58%). Filterable total phosphorus was negatively correlated with the total algal biovolume and/or blue-green algal biovolume at three sites. South Creek was the only site where total phosphorus concentration was also negatively correlated with the chlorophyll-*a* concentrations (36% variation). These negative correlations indicated that, when chlorophyll-*a* concentration or algal density increases, algae utilise all readily available phosphorus very quickly and may rely on other non-available fractions.

Further evidences on nutrient chlorophyll-*a*/algal biomass relationships are included under following dot points:

- A study of 21 sites in the River Thames Basin reported a 90% reduction in soluble reactive phosphorus between 2009 and 2011 did not reduce algal blooms (Bowes *et al* 2012).
- Phosphorus bioavailability and algal growth is complex. In clear water, most phosphorus is readily available to algae because there is little refractory phosphorus (not available to algae or macrophytes) and the flux between the particulate and dissolved forms is very rapid and can happen within minutes or hours (Hawkins 1996). However, highly turbid waters contain a significant fraction of refractory (not readily available) phosphorus in the particulate form, which can take months to years to become available to algae (Oliver *et al* 1993). Total phosphorus is the most widely used indicator to predict the algal-nutrient relationships because eventually most other forms of phosphorus become available to algae by various processes. Filterable total phosphorus gives a gross indication of available phosphorus but can overestimate the biologically available phosphorus, especially in water with high-suspended particles (Oliver *et al* 1993). It includes phosphorus as polyphosphate, metaphosphate or organically bound phosphates which are not readily available to algae.
- In the Hawkesbury-Nepean River, filterable total phosphorus was occasionally less than the detection limit but this did not indicate phosphorus limitation (Hawkins and Hassan 1995). Total phosphorus is also not a good indicator of bioavailable phosphorus to algae as it contains non-bioavailable fractions. Additionally, certain species of algae can take phosphorus in excess of their requirements (luxury uptake) and store it internally for use when it is scarce in the environment (Hawkins, 1996).
- A modelling study (Sydney Water 2015) found that converting all of Sydney Water's WWTPs (existing and proposed new), to recycled water quality standard will result in no real benefit for chlorophyll-*a*, negligible or localised benefits for total phosphorus in South Creek, but a broader improvement in total nitrogen.

5.3.4 Seasonality

Spearman Correlation Analysis found a positive correlation between the water temperature and chlorophyll-*a* concentration at 9 out 11 sites (31% to 57% variation) (Table 5-7). This is expected given the long day light hours and warm weather favouring algal growth. The downstream site at Sackville on the Hawkesbury River and Berowra Creek were exceptions where no significant relationships were found between chlorophyll-*a* concentrations and water temperature. This indicates at some sites algae are abundant irrespective of seasons.

Total algal biovolume and blue-green algal biovolume also showed positive relationships with water temperature. Blue-green algal biovolume was positively correlated (31% to 58%) with water temperature at six sites.

Nutrient parameters, particularly dissolved inorganic nitrogen, were negatively correlated with the water temperature. Water temperature explained 49% to 71% variation in dissolved inorganic nitrogen concentration at nine out of 11 sites. Total nitrogen concentration was also negatively correlated with the water temperature (40% to 67%) at seven sites. This indicates during the winter months, more nitrogen is available due to shorter days limiting algal growth and nutrient utilisation.

Table 5-7 Summary of the Spearman Correlation Analysis outcome: temperature vs. chlorophyll-a, total algal biovolume, blue-green algal biovolume and nutrients

Site	Temperature						
	vs chla	vs totbv	vs bgbv	vs tn	vs din	vs tp	vs ftp
N92: Maldon Weir	Weak, positive	Insufficient data or not analysed	Insufficient data or not analysed	Moderate, negative	Strong, negative	No correlation	Moderate, negative
N911: Stonequarry Ck.	Moderate, positive	No correlation	No correlation	No correlation	No correlation	No correlation	No correlation
N75: Sharpes Weir	Moderate, positive	No correlation	Weak, positive	Moderate, negative	Moderate, negative	No correlation	No correlation
N57: Penrith Weir	Moderate, positive	Weak, positive	Strong, positive	Strong, negative	Strong, negative	No correlation	No correlation
N464: Winmalee Lagoon	Strong, positive	No correlation	No correlation	No correlation	No correlation	Weak, positive	No correlation
N42: North Richmond	Moderate, positive	Moderate, positive	Strong, positive	Moderate, negative	Strong, negative	No correlation	No correlation
NS04: South Ck	Weak, positive	Weak, positive	Weak, positive	Strong, negative	Strong, negative	No correlation	No correlation
N35: Wilberforce	Moderate, positive	No correlation	Moderate, positive	No correlation	Strong, negative	Moderate, positive	No correlation
NC11: Cattai Ck	Strong, positive	Strong, positive	Strong, positive	Strong, negative	Strong, negative	Weak, positive	No correlation
N26: Sackville Ferry	No correlation	No correlation	No correlation	Moderate, negative	Strong, negative	No correlation	No correlation
NB11: Berowra Ck off Square Bay	No correlation	No correlation	No correlation	No correlation	Strong, negative	Weak, positive	No correlation

Legend

- Strong correlation: Rho>0.50 and p<0.0001
- Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
- Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05
- No correlation
- Insufficient data or not analysed
- Positive correlation
- Negative correlation

Chla = chlorophyll-*a*; totbv = Total algal biovolume; bgbv = Blue-green algal biovolume; tn = total nitrogen; din = dissolved inorganic nitrogen; tp = total phosphorus; ftp = filterable total phosphorus.

5.3.5 Flow and nutrients

Spearman Correlation Analysis demonstrated that wet weather or high flow had a positive correlation with nutrient concentrations at most sites (Table 5-8). The exception was Winmalee Lagoon outflow where flow was negatively correlated with the total nitrogen (-45%, variation) and dissolved inorganic nitrogen (-53% variation). This indicates that nitrogen rich inflows, particularly discharges from Winmalee WWTP in dry weather, may influence this site.

The influence of wet weather on nutrients was highest at Stonequarry Creek, where all four nutrient parameters were strongly and positively correlated with the flow (71% to 82% variation). This demonstrates the influence of Picton WWTP discharges and other upstream sources. At the Nepean River site at Penrith Weir all four nutrient parameters were also positively correlated with the flow (31% to 50% variation).

Altogether eight of the 11 sites demonstrated a positive correlation between the flow and filterable total phosphorus (41% to 82% variation) and total phosphorus (31% to 73% variation). Flow was also positively correlated with the total nitrogen (43% to 73% variation) at four sites and dissolved inorganic nitrogen (31% to 71%) at five sites. All these findings demonstrated strong influence of high flow and wet weather on nutrient concentrations. That is, wet weather driven nutrients from other catchments sources are driving the elevated levels of nutrients at many sites of the main stream river and tributaries (except Winmalee Lagoon).

Table 5-8 Summary of the Spearman Correlation Analysis outcome: flow vs. actual nutrient concentrations in the Hawkesbury-Nepean River or tributaries

Water quality site	flow			
	vs	vs	vs	Vs.
	Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Filterable total phosphorus
N92: Maldon Weir	No correlation	No correlation	Moderate, positive	Moderate, positive
N911: Stonequarry Ck.	Strong, positive	Strong, positive	Strong, positive	Strong, positive
N75: Sharpes Weir	No correlation	No correlation	Weak, positive	Strong, positive
N57: Penrith Weir	Moderate, positive	Moderate, positive	Weak, positive	Strong, positive
N464: Winmalee Lagoon	Weak, negative	Strong, negative	No correlation	No correlation
N42: North Richmond	No correlation	No correlation	No correlation	Weak, positive
NS04: South Ck	No correlation	No correlation	Strong, positive	Strong, positive
N35: Wilberforce	No correlation	Weak, positive	Weak, positive	Strong, positive
NC11: Cattai Ck	No correlation	No correlation	Moderate, positive	Moderate, positive
N26: Sackville Ferry	Moderate, positive	Moderate, positive	Moderate, positive	Strong, positive
NB11: Berowra Ck off Square Bay	Strong, positive	Moderate, positive	No correlation	No correlation

Legend

Dark blue	Strong correlation: Rho>0.50 and p<0.0001
Light blue	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
Grey	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05
Peach	No correlation
White	Insufficient data or not analysed
Rising diagonal line	Positive correlation
Falling diagonal line	Negative correlation

6 Conclusions

This study provides a clear picture of both the long-term and short-term trends in nutrient loads discharged from Sydney Water's WWTPs to the Hawkesbury-Nepean and tributaries, and the receiving water quality at 21 current monitoring sites. Factors responsible for the variation in nutrients, chlorophyll-*a* and algae condition were also identified at 11 key sites. The key findings from this study are:

- The WWTP nutrient loads (both nitrogen and phosphorus) discharged to the Hawkesbury-Nepean River and tributaries have considerably decreased over the long-term (1992 to 2017). This decrease was in response to improvements in wastewater treatment processes, as well as decommissioning the older WWTPs.
- Since 2011, there has been an increase in the total nitrogen load discharged from the WWTPs. This increase is thought to be a result of population growth increasing the overall volume of inflow, as well as reducing the efficiency of nitrogen removal in the treatment process resulting in increased nitrogen concentration in the discharge. Despite the increasing trend, loads remain well within the current Environment Protection Licence load limits and well below pre-1992 figures. Sydney Water is investigating what these load increases mean in terms of the impact on the environment.
- The total nitrogen and total phosphorus loads discharged to the freshwater section of the Hawkesbury-Nepean River from Sydney Water's WWTPs in 2016-2017 were approximately 885 kg/day and 9 kg/day, respectively. This represents approximately 27.7% and 1.5% of the total nitrogen and total phosphorus loads from all agricultural activities[3].
- Instream nutrient concentrations (both nitrogen and phosphorus) have decreased at most sites since 1992 (consistent with the long term decrease in WWTP nutrient loads).
- Since 2011 there has been an increase in total nitrogen and dissolved inorganic nitrogen concentrations at approximately half the instream monitoring sites, while total phosphorus and filterable total phosphorus concentrations remained static or decreased.
- Chlorophyll-*a*, a key indicator of algal biomass, showed little change over the long-term (since 1992), despite the reduction in nutrient loads discharged from WWTPs.
- Since 2011, the increase in WWTP nitrogen loads and/or instream nitrogen concentrations showed no influence on chlorophyll-*a* concentrations, with chlorophyll-*a* decreasing at 40% of sites.
- Statistical analysis of the short-term data (2011-2017) did not identify any significant correlations between site-specific WWTP nitrogen loads and downstream nitrogen concentrations at most sites. However, WWTP phosphorus loads correlated with instream

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[3] agricultural loads were calculated by the NSW OEH which extend to Wisemans Ferry (Haine *et al* 2011)

phosphorus concentrations, despite contributing a small proportion compared to loads from other catchment sources.

- Flow, or wet weather, was an important factor driving chlorophyll-*a* or algal biomass as demonstrated by a significant negative correlation at all sites. High flow washes out the algae and low flow or static conditions encourages algal growth.
- The correlation between the site-specific WWTP nutrient loads and instream nutrient concentrations was variable and not consistent for all sites. There was either a negative or no correlation between nitrogen and chlorophyll-*a* and/or algal biomass. This indicates continuous uptake of nitrogen or alternative sources. However, there was a positive correlation between phosphorus concentrations and chlorophyll-*a* and/or algal biomass at some sites.

Way forward

Sydney Water has consistently complied with the vast majority of EPL conditions for wastewater discharge volumes, nutrient concentrations and overall loads to the Hawkesbury-Nepean catchment. However, since 2011 there has been an increase in nutrient loads from some WWTPs, especially for total nitrogen. This is likely due to increasing population pressures for many sites. The rapid population growth planned for the catchment over the next 40 years means that these pressures, and nutrient loads, are likely to increase.

Population growth will impact many other sources of nutrients in the catchment, not just wastewater discharges. The future of the Hawkesbury Nepean River therefore requires a ‘whole of catchment’ approach to nutrient management that will integrate water cycle management solutions.

To assist in planning for growth we need robust scientific evidence to inform management decisions and protect the environment. The current STSIMP is limited in its ability to discern the impact of wastewater discharge from diffuse sources. Sydney Water is reviewing the ability of the current monitoring plan to target the impact of wastewater discharge on the environment, and consider new emerging technologies. Improved monitoring data, supported by the NSW Government Hawkesbury Nepean Model, will enable evidence-based decisions to protect the iconic Hawkesbury-Nepean River.

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Appendix A: Glossary

Table A-1 Glossary

Acronyms/ Abbreviations	Full meanings
APHA	American Public Health Association
St Marys AWTP	St Marys Advanced Water Treatment Plant
bgbv	Blue-green algal biovolume
chla	Chlorophyll-*a*
cond	Conductivity
CSIRO	Commonwealth Scientific and Industrial Research Organisation
din	Dissolved inorganic nitrogen, (ammonia plus oxidised nitrogen)
EICR	Environmental Indicators Compliance Report
EIMP	Environmental Indicators Monitoring Program
EPA	Environment Protection Authority
EPL	Environment Protection Licence
ftp	Filterable total phosphorus
flow	Site specific river flow
HRC	Healthy River Commission
IDAL	intermittently decanted aerated lagoons
kg	Kilogram
kg/day	Kilogram/day
KL/day	Kilolitre/day
km	kilometre(s)
L	litre(s)
LOWESS	locally weighted regression and smoothing scatterplots
median	Median or 50^{th} percentile value
mg/L	milligrams per litre
mL	Millilitre
ML	Megalitre
ML/day	Megalitre/day
mm	millimetre(s)
n or No. of Obs.	Number of observations
nc	Not computed
NSW	New South Wales
NTU	Nephelometric Turbidity unit
OEH	Office of Environment and Heritage, New South Wales
PRP	Pollution Reduction Program

Acronyms/ Abbreviations	Full meanings
p value	The value which determines the level of significance (<0.05)
Rho	Spearman correlation coefficient
SCA	Sydney Catchment Authority
SRA	States Recreational Areas
STSIMP	Sewage Treatment System Impact Monitoring Program
temp	Temperature
TKN	Total Kjeldahl Nitrogen
tn	Total nitrogen
tnload	Total nitrogen loads from WWTPs
totbv	Total algal biovolume
tp	Total phosphorus
tpload	Total phosphorus loads from WWTPs
turb	Turbidity
WWTP	Wastewater Treatment Plant
µS/cm	micro Siemens per centimetre (unit of conductivity)
µg/L	micrograms per litre

Appendix B: Monitoring sites and method of measurements

Table B-1 List of WWTPs operating in the Hawkesbury-Nepean River catchment since 1992

WWTP/ St Marys AWTP	Treated wastewater discharge location	Operating history	Data availability
Picton[1]	Stonequarry Creek and then to Nepean River	Operating since Nov 2000 More precautionary discharges in recent years	No missing data, but discharges were made infrequently
West Camden	Matahil Creek and then to Nepean River	Nitrogen upgrade complete by 30 Sept 2008; Phosphorus upgrade complete by 31 Mar 2009 Increase nitrogen failure and infrequent phosphorus failure since 2015 in relation to EPLs	Minor gaps in 1992-93 data
Warragamba	Megarritys Creek to Warragamba River and then to Nepean River	Phosphorus upgrade in 2002 Decommissioned in 31 August 2006	Minor gaps in 1992-93 data
Wallacia	Warragamba River and then to Nepean River	Operating since Sept 2006	Consistent, no data gaps
Glenbrook	Lapstone Creek and then to Nepean River	Phosphorus upgrade in 1994 Decommissioned in Aug 2005;	Consistent, no data gaps
Penrith	Boundary Creek and then to Nepean River and wastewater also transferred to St Marys AWTP for advance treatment	Phosphorus upgrade in 2001 Upgraded (both nitrogen and phosphorus) in 2010 after the AWTP commissioning Increasing nitrogen failure in relation to EPL since 2015	Consistent, no data gaps
St Marys AWTP	Advance treated wastewater from St Marys discharged via Boundary Creek	Operating since September 2011 Currently off-line since Jan 2017	Consistent, no data gaps
Mount Riverview	Cripple Creek and then to Nepean River	Decommissioned in Dec 1999	Nutrient data missing 1996-99
Valley Heights	Tributary of Fitzgerald's Creek and then to Nepean River	Phosphorus upgrade in 1993 Decommissioned in Nov 1993	Consistent, no data gaps, very limited data
Winmalee	Unnamed Creek and then to Nepean River	Increased nitrogen load after the transfer of all Blue Mountains plants Phosphorus load increase in 2012	Consistent, no data gaps
Blackheath	Hat Hill Creek and then to Grose River	Phosphorus upgrade in 2001 Decommissioned in Jun 2008;	Consistent, no data gaps
Hazelbrook	Hazelbrook Creek and then to Grose River	Decommissioned in Aug 1993	Consistent, but very limited data
North Katoomba	Katoomba Creek and then to Grose River	Decommissioned in Jun 1996	Consistent, but very limited data
Wentworth Falls	Tributary of Blue Mountains Creek and then to Grose River	Decommissioned in Jun 1996	Consistent, but very limited data
North Richmond	Redbank Creek and then to Hawkesbury River	Phosphorus upgrade in 1999	Consistent, no data gaps

WWTP/ St Marys AWTP	Treated wastewater discharge location	Operating history	Data availability
		Both nitrogen and phosphorus upgrade in 2010 after AWTP commissioning	
Richmond[2]	Rickaby's Creek and then to Hawkesbury River	Production and use of more recycled water since 2002 Both nitrogen and phosphorus upgrade in 2005	Consistent, no data gaps
Quakers Hill	Breakfast Creek to South Creek and then to Hawkesbury River	Phosphorus upgrade in 1999 Nitrogen upgrade in 2010 Nitrogen removal performance has deteriorated since 2011	Minor gaps in 1992-93 data
Riverstone	Eastern Creek to South Creek and then to Hawkesbury River	Both nitrogen and phosphorus upgrade in 2000, recent performance on nutrient removal deteriorated (since 2014)	Consistent, no data gaps
St Marys	Tributary of South Creek and then to Hawkesbury River and advanced treated wastewater also discharged to Boundary Creek via Penrith	Both nitrogen and phosphorus upgrade in 2000 More upgrade in 2010 when AWTP commissioned	Minor gaps in 1992-93 data
Castle Hill	Cattai Creek and then to Hawkesbury River	Phosphorus upgrade in 1994 Consistently operating More loads in recent years	Consistent, no data gaps
Rouse Hill	Second Ponds Creek to Cattai Creek and then to Hawkesbury River	Operating since Jul 1994 Phosphorus upgrade in 2006 Nitrogen upgrade in 2009	Consistent, no data gaps
Kellyville	Smalls Creek to Cattai Creek and then to Hawkesbury River	Phosphorus upgrade in 1993 Decommissioned in Mar 1994	Consistent, but very limited data
Round Corner	O'Hares Creek to Cattai Creek and then to Hawkesbury River	Nitrogen and phosphorus upgrade in 1993-94 Decommissioned in Dec 2000	Consistent, no data gaps
West Hornsby	Waitara Creek to Berowra Creek and then to Hawkesbury River	Operating since 1994; Upgrade in 2003-05 (mostly nitrogen)	Consistent, no data gaps
Hornsby Heights	Calna Creek to Berowra Creek and then to Hawkesbury River	Phosphorus upgrade in 1993 Upgrade in 2003-05 (mostly nitrogen)	Consistent, no data gaps
Brooklyn	Hawkesbury River at 14m depth at old road bridge adjacent to Kangaroo Point	Operating since 2007	Consistent, no data gaps

[1] Mainly reused for onsite agricultural irrigation; wet weather discharges only

[2] Mostly reused since 2002 at University of Western Sydney Richmond campus and Richmond Golf Club; excess overflows to Rickabys Creek

Note that, this list excludes two other inland decommissioned WWTPs (Mount Victoria and South Katoomba) which were operating in upstream Lake Burragorang catchment.

Table B-2 List of water quality monitoring locations and data availability

Site codes	Site name	Description	Monitoring history / data availability#
N92*	Nepean River at Maldon Weir	Upstream of all Sydney Water's WWTPs, Reference site	Consistent, no data gaps
N911*	Stonequarry Creek at Picton Farm,	Downstream of precautionary discharge point from Picton WWTP	Since January 1997, earlier data inconsistent
N91	Nepean River at Maldon Bridge,	Downstream of Stonequarry Creek and Picton WWTP	Minor gap in 1994-95
N75*	Nepean River at Sharpes Weir	Downstream Matahil Ck and West Camden WWTP	Consistent, no data gaps
N67	Nepean River at Wallacia Bridge	Upstream of Warragamba River	No monitoring from 2001 to 2008
N57*	Nepean River at Penrith Weir	Upstream of Penrith Weir and Penrith WWTP	Consistent, no data gaps
N51	Nepean River opposite Fitzeralds Creek	Downstream of Boundary Creek and Penrith WWTP	Since July 2008, no data gaps
N48	Nepean River at Smith Road	Upstream of Winmalee WWTP	Consistent, no data gaps
N464*	Winmalee Lagoon outflow at Springwood Road before Shaws Creek	Downstream of Winmalee WWTP	Long gap from December 2010 to June 2015
N44	Nepean River at Yarramundi Bridge	Downstream of Winmalee WWTP, upstream Grose River	Long gap from 2001 to 2008
N42*	Hawkesbury River at North Richmond	Downstream of Grose River	Inconsistent turbidity data pre 2002
N39	Hawkesbury River at Freemans Reach	Downstream of North Richmond WWTP	Since January 1996, consistent, no data gaps
NS04*	South Creek at Fitzroy pedestrian bridge, Windsor	Lower South Creek before the confluence with the Hawkesbury River	Long data gaps 1994-1995, 1998-2001
N35*	Hawkesbury River at Wilberforce, Butterfly farm	Downstream of South Creek	Consistent, no data gaps
NC11*	Cattai Creek at Cattai Road Bridge, 100m downstream of bridge	Lower Cattai Creek before the confluence with the Hawkesbury River	Since January 2008, consistent no data gaps
N3001	Hawkesbury River off Cattai State Recreational Area,	Downstream of Cattai Creek	Since July 1994, long data gaps 2001 to June 2008;
N26*	Hawkesbury River at Sackville	Downstream of Cattai Creek	Consistent from July 1994, missing turbidity

Site codes	Site name	Description	Monitoring history / data availability#
	Ferry,		data pre 2002, turbidity from July 1999
N2202	Lower Colo River at Putty Road Bridge,	Lower Colo River, Reference site	Since July 2008, no data gaps
N18	Hawkesbury River at Leets Vale, opposite Leets Vale Caravan Park,	Downstream of Colo River	Consistent from January 1996, missing turbidity data pre 2002, turbidity from July 2008
NB11*	Berowra Creek off Square Bay (Oaky Point)	Berowra Creek estuary, downstream of West Hornsby and Hornsby Heights WWTPs	Since January 1995, missing turbidity data pre 2002, turbidity from July 2008
NB13	Berowra Creek at Calabash Bay (Cunio Point)	Berowra Creek estuary, downstream of West Hornsby and Hornsby Heights WWTPs	Since January 1997, some physico-chemical parameters missing, pre 2000, turbidity from July 2008

* Key sites for this study

Dissolved Oxygen saturation data missing for all sites: pre July 1996

Figure B-1 Flow monitoring locations in Hawkesbury-Nepean River catchment

Table B-3 List of hydrometric monitoring locations

Site codes	Site Name	Owner	Code used in calculation
212208	Nepean River at Maldon Weir	Water NSW	Maldon
2122006	Stonequarry Creek, downstream of Picton WWTP discharge point	Sydney Water	Stonequarry
212216	Nepean River at Camden Weir	Water NSW	Camden
212217	Matahil Creek, downstream of West Camden WWTP discharges	Sydney Water	Matahil
212202	Nepean River at Wallacia	Water NSW	Wallacia
212201	Nepean River at Penrith Weir	Water NSW	Penrith
212291	Grose River at Burralow	Water NSW	Grose
212297	South Creek Richmond Road	Sydney Water	SouthCk_RR
212296	Eastern Creek Garfield Road	Sydney Water	EastCk_GR
212342	Eastern Creek Richmond Road	Sydney Water	EastCk_RR
212295	Cattai Creek at Maralaya	Sydney Water	CattaiCK_M
2122951	Cattai Creek at Cattai Ridge Rd	Sydney Water	CattaiCK_CRR
212290	Colo River at Upper Colo	Water NSW	Colo
212228	MacDonald River at St Albans	Sydney Water	Mcdonald
212294	Berowra Creek at Galston Gorge	Sydney Water	Berowra

Table B-4 List of wastewater discharge quality analytes and method of measurements

Analytes	Detection limit	Unit of measure ment	Method/Reference
Treated wastewater discharge or bypass volume	-	KL	*In-situ* data logger
Total nitrogen (by FIA)	0.05	mg/L	APHA (2005) 4500- Norg/NO3- I/J
Ammonia nitrogen		mg/L	APHA (2005) 4500-NH3 H
Oxidised nitrogen		mg/L	APHA (2005) 4500-NO3 I
Total Kjeldahl Nitrogen		mg/L	
Total phosphorus	0.01	mg/L	APHA (2005) 4500-P – H/J
Soluble reactive phosphorus		mg/L	APHA (2005) 4500 P G

Table B-5 List of water quality analytes and method of measurements

Analytes	Detection limit	Unit of measurement	Method/Reference	Place of measurement
Temperature	-	ºC	Yeo-Kal Meter or WTW	Field
Dissolved oxygen	-	mg/L and % sat	Yeo-Kal Meter	Field
pH	-	pH unit	Yeo-Kal Meter	Field
Conductivity	-	µS/cm	Yeo-Kal Meter	Field
Turbidity	-	NTU	Hach Turbidity Meter (White light)	Field
Ammonia nitrogen	0.01	mg/L	APHA (2005) 4500-NH3 H	Laboratory
Oxidised nitrogen	0.01	mg/L	APHA (2005) 4500 NO3—I	Laboratory
Total nitrogen	0.05	mg/L	APHA (2005) 4500-Norg/NO3-	Laboratory
Total phosphorus	0.002	mg/L	APHA (2005) 4500-P – H	Laboratory
Total filterable phosphorus	0.002	mg/L	APHA (2005) 4500-P – H	Laboratory
Chlorophyll-a	0.2	µg/L	APHA (2005) 10200-H ½	Laboratory
Algal biovolume and cell count *	-	mm^3/L and cells/mL	APHA (2005) 10200-F	Laboratory

* when chlorophyll-a exceeds 7 µg/L

Appendix C: Method of data analysis

Table C-1 Nutrient load calculation by five sub-catchments of the river and population served over time by each WWTP

WWTPs/ Sub-catchments	Population served				Percent increase in population		
	1992-93*	2008-09	2010-11	2016-17	1992-09	2009-17	1992-17
Picton		9,310	14,360	14,470			
West Camden	20,600	49,860	64,560	81,830			
Warragamba	1,500	3,910					
Wallacia			6,420	4,230			
Upper Nepean	**22,100**	**63,080**	**85,340**	**100,530**	**186%**	**59%**	**355%**
Yearly average					**11.4%**	**6.7%**	**14.2%**
	1992-93		2010-11	2016-17	1992-11	2011-17	1992-17
Glenbrook	14,900						
Penrith	81,500		102,250	108,600			
Mount Riverview	5,000						
Valley Heights	2,600						
Winmalee	15,220		59,750	59,790			
Blackheath	4,050						
Hazelbrook	8,200						
North Katoomba	2,250						
Wentworth Falls	5,840						
North Richmond	3,700		5,570	4,990			
Richmond	9,950		18,600	15,410			
Lower Nepean and Upper Hawkesbury	**153,210**		**186,170**	**188,790**	**22%**	**1%**	**23%**
Yearly average					**1.1%**	**0.2%**	**0.9%**
	1992-93		2010-11	2016-17	1992-11	2011-17	1992-17
Quakers Hill	99,300		148,270	162,560			
Riverstone	8,500		7,530	18,410			
St Marys	131,000		149,180	165,110			
South Creek	**238,800**		**304,980**	**346,080**	**28%**	**13%**	**45%**
Yearly average					**1.5%**	**2.2%**	**1.8%**
	1992-93		2010-11	2016-17	1992-11	2011-17	1992-17
Castle Hill	23,300		30,040	29,320			
Rouse Hill			75,300	100,730			
Kellyville	3,400						
Round Corner	1,200						
Cattai Creek	**27,900**		**105,340**	**130,050**	**278%**	**23%**	**366%**
Yearly average					**14.6%**	**3.9%**	**14.6%**

WWTPs/ Sub-catchments	Population served				Percent increase in population		
	1992-93*	2008-09	2010-11	2016-17	1992-09	2009-17	1992-17
	1992-93	2004-05	2010-11	2016-17	1992-05	2005-17	1992-17
West Hornsby	32,200	51,585	55,650	58,570			
Hornsby Heights	20,200	26,618	28,610	30,780			
Brooklyn				1,460			
Berowra Creek	**52,400**	**78,203**	**84,260**	**90,810**	**49%**	**16%**	**73%**
Yearly average					**3.8%**	**1.3%**	**2.9%**
	1992-93		2010-11	2016-17	1992-11	2011-17	1992-17
Total population served	**494,410**		**766,090**	**856,260**	**55%**	**12%**	**73%**
Yearly average					**2.9%**	**2.0%**	**2.9%**

* 1992-93 population data from Sydney Water (1993), other years data are projections from STSIMP report

Table C-2 Method of calculating site specific nutrient load parameters for the key water quality sites

Monitoring sites	Possible impact from upstream WWTP discharges
N91 & N911	Picton
N75	Picton and West Camden
N57	Warragamba, Wallacia and Glenbrook
N464	Winmalee
N42	Winmalee, Blackheath, Hazelbrook, North Katoomba and Wentworth Falls
NS04	Quakers Hill, Riverstone and St Marys
N35	Richmond, Quakers Hill, Riverstone and St Marys
NC11	Castle Hill, Rouse Hill, Kellyville and Round Corner
N26	Quakers Hill, Riverstone, St Marys, Castle Hill, Rouse Hill, Kellyville and Round Corner
NB11	West Hornsby and Hornsby Heights

Table C-3 Step trend periods for nutrient load by different sub-catchment of the river

Sub-catchment	Parameters	Periods	Justification on data splits or step trends
Total from all WWTPs	Total nitrogen and total phosphorus loads	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-02	By June 2002, all major nitrogen upgrades were completed at most contributing WWTPs
		Mid-term: Jul-02 to Jun-11	All planned nitrogen upgrades were completed, after the commissioning of St Marys AWTP in September 2010
		Short-term: Jul-11 to Jun17	Recent condition when there were no major capital works carried out
Upper Nepean River	Total nitrogen loads	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Sep-08	Warragamba transferred to upgraded Wallacia in 2006 and by September 2008 West Camden in terms of total nitrogen
		Short-term: Oct-08 to Jun-17	Recent condition when there were no major capital works carried out at these WWTPs
	Total phosphorus loads	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-02	By June 2002, all major phosphorus upgrades were completed at most contributing WWTPs
		Mid-term: Jul-02 to Mar-09	By March 2009, West Camden upgrades in terms of total phosphorus were completed
		Short-term: Apr-09 to Jun-17	Recent condition when there were no major capital works carried out at these WWTPs
Sub-catchment	**Parameters**	**Periods**	**Justification on data splits or step trends**
Lower Nepean and Upper Hawkesbury River	Total nitrogen and total phosphorus loads	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-02	By June 2002, all major nitrogen upgrades were completed at most contributing WWTPs
		Mid-term: Jul-02 to Jun-11	Glenbrook transferred to upgraded Penrith in 2006, transfer of all blue-mountains WWTPs to Winmalee by 2008 and implementation of St Marys AWTP in late 2010 upgraded Penrith further
		Short-term: Jul-11 to Jun-17	Recent condition when there were no major capital works carried out at these WWTPs
Sub-catchment	**Parameters**	**Periods**	**Justification on data splits or step trends**
South Creek		Long-term: Jul-92 to Jun-17	Long-term trend

Sub-catchment	Parameters	Periods	Justification on data splits or step trends
	Total nitrogen and total phosphorus loads	Historical: Jul-92 to Dec-99	Major upgrades in South and Creek WWTPs were completed by 2002 (both nitrogen and phosphorus)
		Mid-term: Jan-00 to Jun-11	Further planned upgrades were completed by June 2011 after AWTP commissioning
		Short-term: Jul-11 to Jun17	Recent condition when there were no major capital works carried out at these WWTPs
Cattai Creek	Total nitrogen load	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-09	Castle Hill upgraded by June 2009 in terms of total nitrogen
		Short-term: Jul-09 to Jun-17	Recent condition when there were no major capital works carried out at these WWTPs
	Total phosphorus load	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Dec-99	By December 1999, all major phosphorus upgrades were completed at most contributing WWTPs
		Mid-term: Jan-00 to Jun-11	By June 2011, all planned upgrades in terms of total phosphorus were completed
		Short-term: Jul-11- to Jun-17	Recent condition when there were no major capital works carried out at these WWTPs
Berowra Creek	Total nitrogen load	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-05	Major nitrogen upgrade by June 2005
		Short-term: Jul-05 to Jun17	Recent condition when there were no major capital works carried out at these WWTPs
	Total phosphorus load	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-05-	By June 2005 major phosphorus upgrades were completed in both WWTPs
		Short-term: Jul-05 to Jun-17	Recent condition when there were no major capital works carried out at these WWTPs

Table C-4 Step trend periods for water quality parameters by different site and justification

Site codes	Parameters	Periods	Justification on data splits or step trends
N92	All parameters except dissolved oxygen, dissolved oxygen saturation, temperature and turbidity	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-10	From start date of riparian releases from upper Nepean dams
		Short-term: Jul-10 to Jun-17	Recent condition
N911	As above	Long-term: Jan-97 to Jun-17	Long-term trend
		Historical: Jan-97 to Jun-10	Precautionary discharges from Picton plant increases after June 2010
		Short-term: Jul-10 to Jun-17	Recent condition
N91	As above	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-10	Precautionary discharges from Picton plant increases after June 2010
		Short-term: Jul-10 to Jun-17	Recent condition
N75	All parameters except total phosphorus and filterable total phosphorus	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Sep-08	By September 2008, West Camden upgrade in terms of total nitrogen completed
		Short-term: Oct-09 to Jun-17	Recent condition
	Total phosphorus and filterable total phosphorus	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Mar-09	By March 2009, West Camden upgrade in terms of total phosphorus completed
		Short-term: Apr-09 to Jun-17	Recent condition
N67, N57, N48, N464, N44, N42, NS04 and N35	All parameters except dissolved oxygen, dissolved oxygen saturation, temperature and turbidity	Long-term: Jul-92 to Jun-17	Long-term trend
		Historical: Jul-92 to Jun-11	Major upgrades completion date
		Short-term: Jul-11 to Jun-17	Recent condition
N51, NC11, and N2202	As above	Long-term: Jul-08 to Jun-17	Long-term trend
		Historical: Jul-08 to Jun-11	Major upgrades completion date
		Short-term: Jul-11 to Jun-17	Recent condition
N39 and N18	As above	Long-term: Jan-96 to Jun-17	Long-term trend
		Historical: Jan-96 to Jun-11	Major upgrades completion date
		Short-term: Jul-11 to Jun-17	Recent condition

Site codes	Parameters	Periods	Justification on data splits or step trends
N3001 and N26	As above	Long-term: Jul-94 to Jun-17	Long-term trend
		Historical: Jul-94 to Jun-11	Major upgrades completion date
		Short-term: Jul-11 to Jun-17	Recent condition
NB11	As above	Long-term: Jan-95 to Jun-17	Long-term trend
		Historical: Jan-95 to Jun-05	Major upgrades completion date
		Short-term: Jul-05 to Jun-17	Recent condition
NB13	As above	Long-term: Jan-96 to Jun-17	Long-term trend
		Historical: Jan-96 to Jun-05	Major nitrogen upgrade by June 2005
		Short-term: Jul-05 to Jun=17	Recent condition when there were no major capital works carried out at these plants

Table C-5 Method of calculating site-specific derived flow parameters

Flow parameters	Flow from monitoring stations and formula
N92_flow	Maldon
N911_flow	Stonequarry
N75_flow	Camden + Matahil
N57_flow, N464_flow	Penrith
N42_flow	Penrith + Grose
NS04_flow	[SouthCk_RR +(EastCk_GR +EastCk_RR)/2]
N35_flow	Penrith + Grose + SouhCk_RR + EastCk_GR + EastCk_RR
NC11_flow	CattaiCK_M+CattaiCK_CRR
N26_flow	[Penrith + Grose + SouhCk_RR + (EastCk_GR + EastCk_RR)/2 + CattaiCK_M + CattaiCK_CRR]
NB11_flow	Berowra

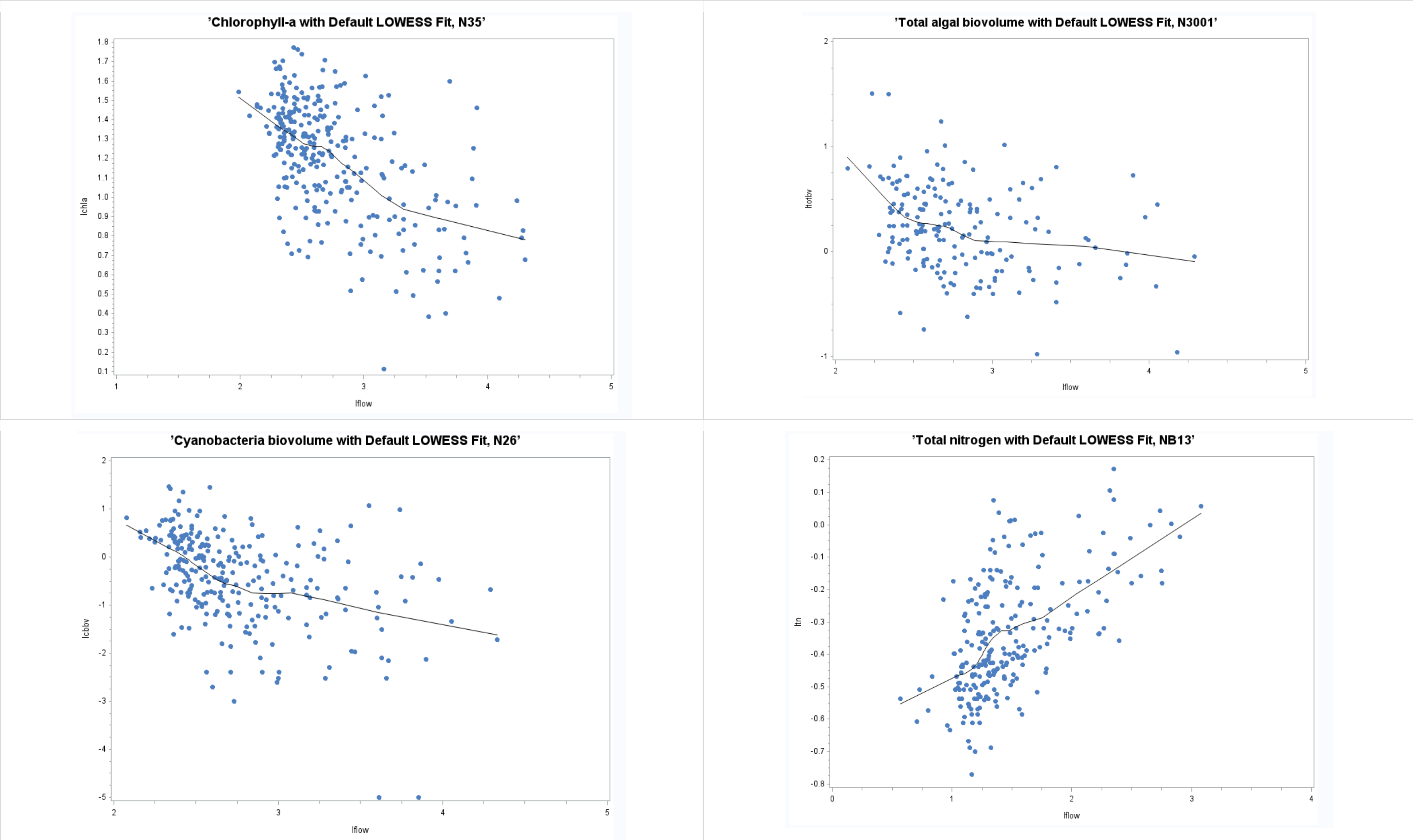
Table C-6 Spearman Correlation Analysis variable code and description

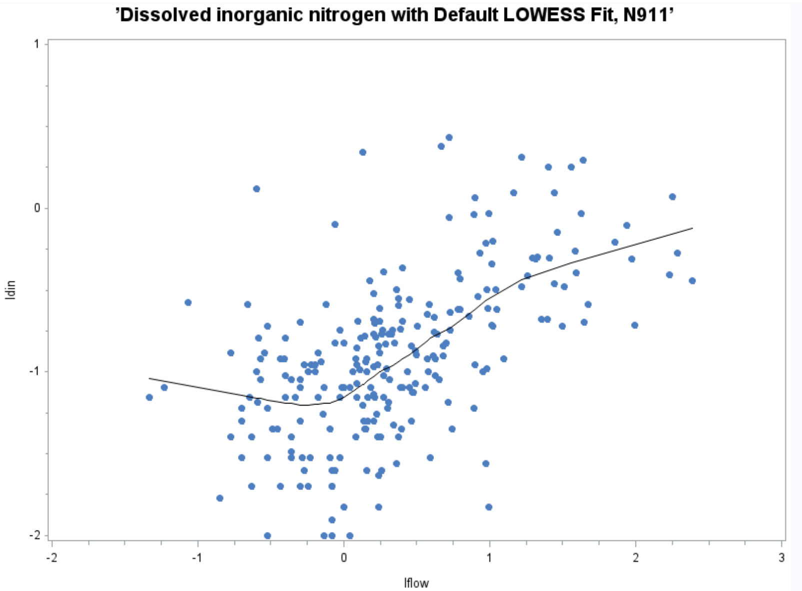
Water quality variable code	Descriptions
chla	Chlorophyll-*a*
totbv	Total algal biovolume: total of all groups, algal species
bgbv	Blue-green algal biovolume: total biovolume made up of all species of cyanobacteria/blue-green algae (Cyanophyta family)
flow	Flow: site-specific flow
tn	Total nitrogen
tnload	Total nitrogen loads: site-specific total nitrogen load
din	Dissolved inorganic nitrogen: ammonia nitrogen plus oxidised nitrogen
tpload	Total phosphorus loads: site-specific total phosphorus load
tp	Total phosphorus
turb	Turbidity
cond	Conductivity
temp	Temperature

Table C-7 Water Quality guidelines

<table>
<tr><th>Water quality and algae</th><th>Main stream Hawkesbury Nepean River sites: Mixed rural use and sandstone plateau (N92, N91, N75, N67, N51, N48, N44, N39, N35, N3001, N26, N2202 and N18)</th><th>Main stream Hawkesbury Nepean River sites: Predominantly urban (N57and N42)</th><th>Tributary stream of Hawkesbury Nepean River sites: predominantly urban (N464, NS04 and NC11)</th><th>Estuarine and brackish sites of the Hawkesbury Nepean River (NB11 and NB13)</th><th>Guideline references</th></tr>
<tr><td>Chlorophyll a (μg/L)</td><td><7.0</td><td><15.0</td><td><20.0</td><td><7.0</td><td>Water quality objectives for nutrients (HRC, 1998</td></tr>
<tr><td>Blue-green biovolume (mm³/L)</td><td colspan="4">Green alert: >0.04; Amber alert ≥0.4; Red alert ≥4</td><td>Cyanobacteria alert levels for recreational water (NHMRC 2008)</td></tr>
<tr><td>Total nitrogen (mg/L)</td><td><0.70</td><td><0.50</td><td><1.00</td><td><0.40</td><td rowspan="2">Water quality objectives for nutrients (HRC, 1998)</td></tr>
<tr><td>Total phosphorus (mg/L)</td><td><0.035</td><td><0.030</td><td><0.050</td><td><0.030</td></tr>
<tr><td>pH</td><td colspan="3">>6.5 and <8.5**</td><td>>7 and <8.5</td><td rowspan="3">ANZECC (2000): default trigger value for lowland river (**NSW lowland rivers) and estuarine sites</td></tr>
<tr><td>Dissolved oxygen saturation (%)</td><td colspan="3">>85 and <110*</td><td>>80 and <110**</td></tr>
<tr><td>Turbidity</td><td colspan="4">50 NTU</td></tr>
</table>

Figure C-1 A good example of LOWESS plots for each water quality variable

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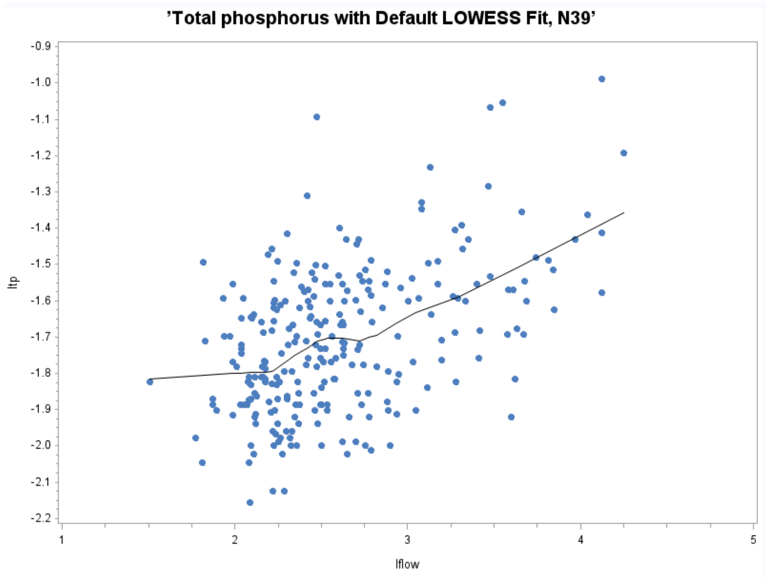
ldin
lflow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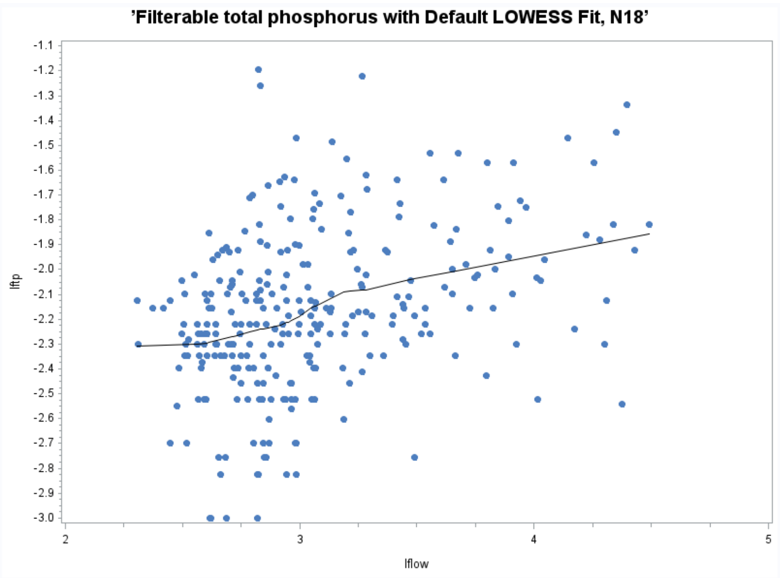
ltp
lflow


'Filterable total phosphorus with Default LOWESS Fit, N18'
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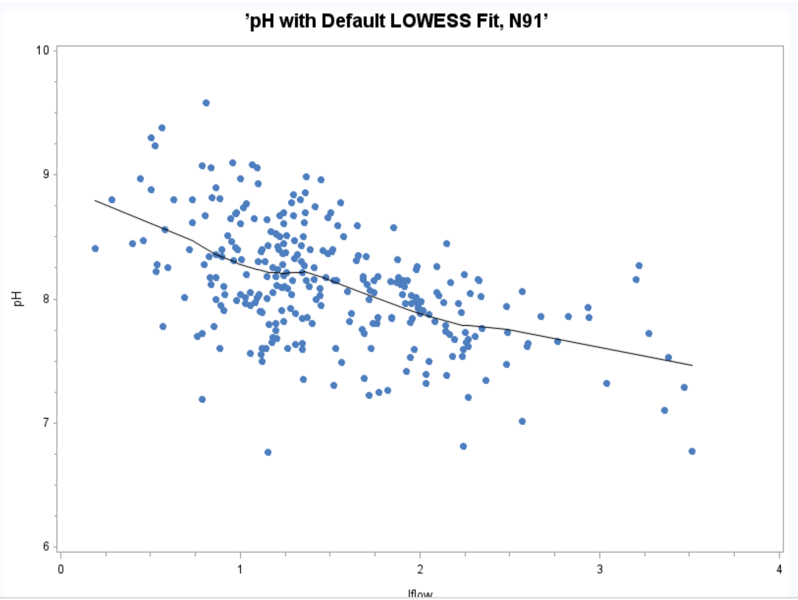
lflow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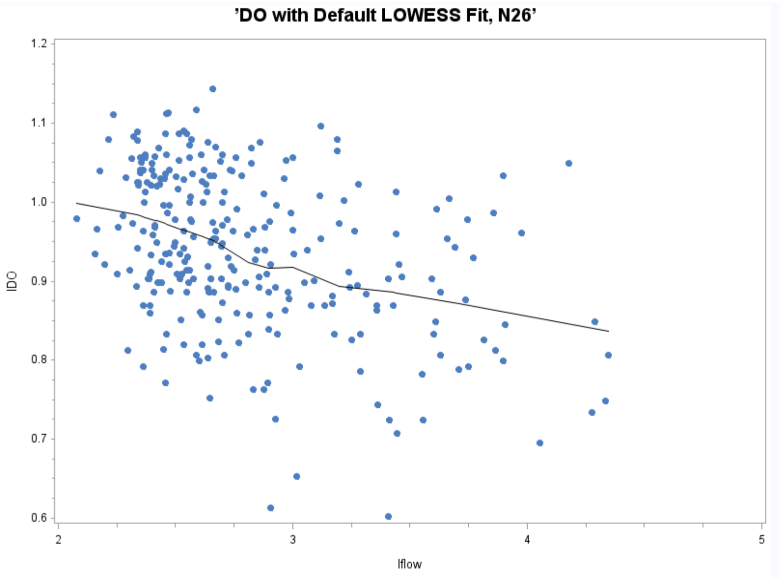
pH
lflow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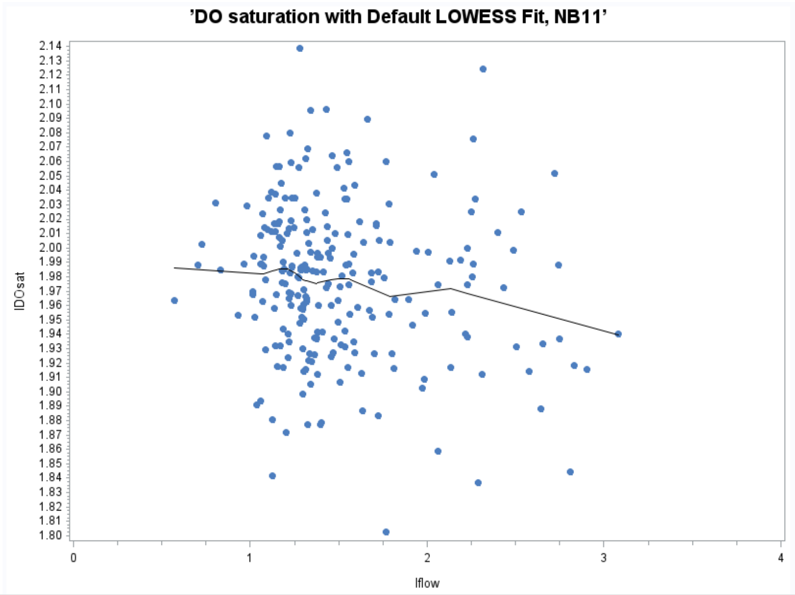
1.1
1.0
0.9
0.8
0.7
0.6
lDO
2
3
4
5
lflow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2.13
2.12
2.11
2.10
2.09
2.08
2.07
2.06
2.05
2.04
2.03
2.02
2.01
2.00
1.99
1.98
1.97
1.96
1.95
1.94
1.93
1.92
1.91
1.90
1.89
1.88
1.87
1.86
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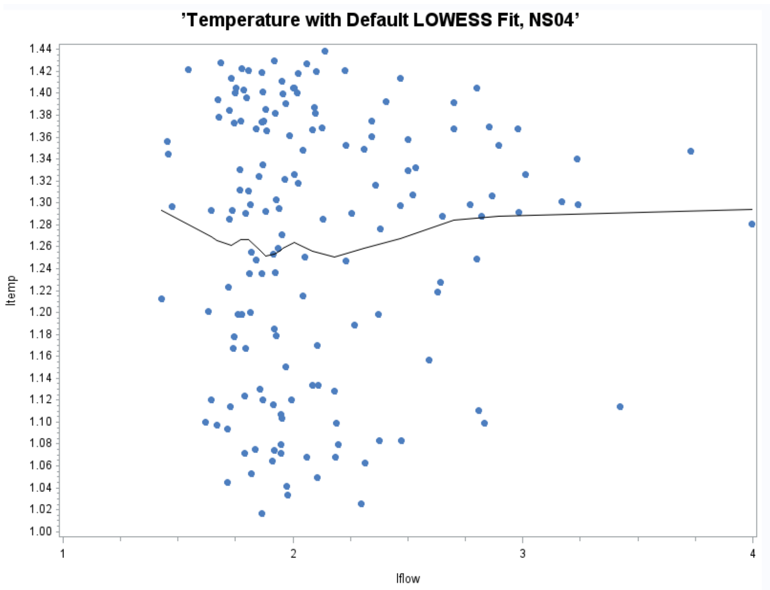
1.81
1.80
lDOsat
0
1
2
3
4
lflow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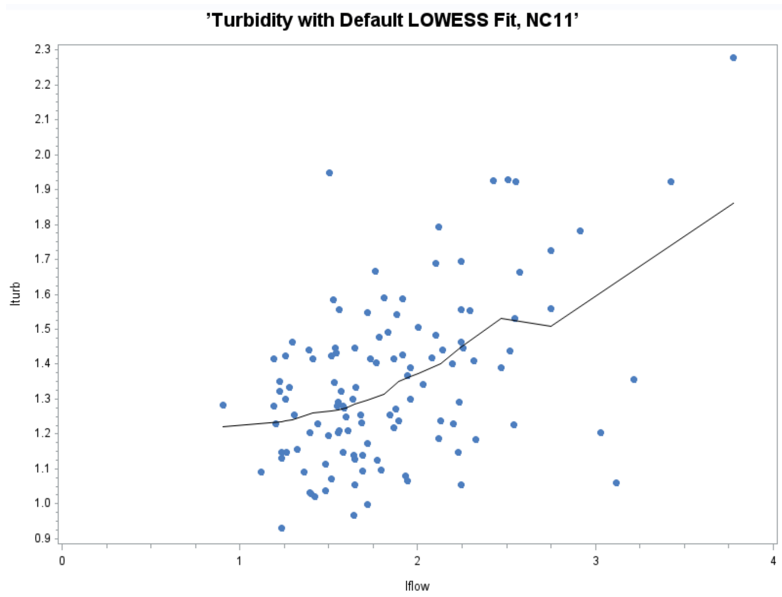
1.26
1.24
1.22
1.20
1.18
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
ltemp
1
2
3
4
lflow


'Turbidity with Default LOWESS Fit, NC11'
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
lturb
0
1
2
3
4
lflow

Appendix D: Long-term trend analysis results and trend plots on nutrient loads

Table D-1 Long-term trends in key nutrient loads from WWTP discharges (detailed results)

Sub-catchment	Nutrient loads	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
Total	Total nitrogen	Long-term: 92-17	25.0	300	-18.01	0.00000	decreasing	non-seasonal	-0.02484	-0.02644	-0.02316	-76%	-74.58
		Historical: 92-02	10.0	120	-10.84	0.00000	decreasing	seasonal	-0.02230	-0.02494	-0.01939	-40%	-106.95
		Mid-term: 02-11	9.0	108	-7.434	0.00000	decreasing	seasonal	-0.02019	-0.02384	-0.01599	-34%	-42.25
		Short-term: 11-17	6.0	72	4.692	0.00000	increasing	seasonal	0.03867	0.02537	0.05111	71%	83.37
Total	Total phosphorus	Long-term: 92-17	25.0	300	-15.96	0.00000	decreasing	non-seasonal	-0.04873	-0.05249	-0.04508	-94%	-5.62
		Historical: 92-02	10.0	120	-11.73	0.00000	decreasing	non-seasonal	-0.06653	-0.07199	-0.06080	-78%	-11.61
		Mid-term: 02-11	9.0	108	-0.125	0.90070	insignificant	non-seasonal	-0.00049	-0.00660	0.00627	-1%	-0.02
		Short-term: 11-17	6.0	72	-3.661	0.00025	decreasing	non-seasonal	-0.05150	-0.07601	-0.02520	-51%	-1.61
Upper Nepean	Total nitrogen	Long-term: 92-17	25.0	300	4.356	0.00001	increasing	seasonal	0.00787	0.00462	0.01108	57%	1.57
		Historical: 92-08	16.3	195	10.267	0.00000	increasing	seasonal	0.01969	0.01699	0.02250	109%	4.58
		Short-term: 08-17	8.8	105	5.817	0.00000	increasing	non-seasonal	0.07668	0.05752	0.09591	369%	17.70
Upper Nepean	Total phosphorus	Long-term: 92-17	25.0	300	-12.68	0.00000	decreasing	non-seasonal	-0.02984	-0.03343	-0.02613	-82%	-0.12
		Historical: 92-02	10.0	120	-2.139	0.03244	decreasing	non-seasonal	-0.00950	-0.01696	-0.00068	-20%	-0.07
		Mid-term: 02-09	6.8	81	-2.598	0.00938	decreasing	non-seasonal	-0.01781	-0.03195	-0.00448	-24%	-0.06
		Short-term: 09-17	8.3	99	3.235	0.00122	increasing	non-seasonal	0.05976	0.02308	0.09327	211%	0.07
Lower Nepean and Upper Hawkesbury	Total nitrogen	Long-term: 92-17	25.0	300	-16.09	0.00000	decreasing	non-seasonal	-0.02207	-0.02390	-0.02019	-72%	-13.64
		Historical: 92-02	10.0	120	1.414	0.15748	insignificant	seasonal	0.00334	-0.00110	0.00672	8%	4.16
		Mid-term: 02-11	9.0	108	-4.41	0.00000	decreasing	non-seasonal	-0.01418	-0.02017	-0.00823	-25%	-9.44
		Short-term: 11-17	6.0	72	4.215	0.00003	increasing	non-seasonal	0.02508	0.01258	0.03886	41%	11.47
Lower Nepean and Upper Hawkesbury	Total phosphorus	Long-term: 92-17	25.0	300	-14.86	0.00000	decreasing	non-seasonal	-0.05601	-0.05983	-0.05207	-96%	-3.72
		Historical: 92-02	10.0	120	-11.25	0.00000	decreasing	non-seasonal	-0.05902	-0.06449	-0.05364	-74%	-7.37
		Mid-term: 02-11	9.0	108	5.72	0.00000	increasing	non-seasonal	0.03137	0.02119	0.04053	92%	0.71
		Short-term: 11-17	6.0	72	-4.672	0.00000	decreasing	non-seasonal	-0.09725	-0.13130	-0.06188	-74%	-1.48
South Creek	Total nitrogen	Long-term: 92-17	25.0	300	-17.67	0.00000	decreasing	non-seasonal	-0.03402	-0.03648	-0.03117	-86%	-44.42
		Historical: 92-99	7.5	90	-10.28	0.00000	decreasing	non-seasonal	-0.06123	-0.06833	-0.05428	-65%	-122.53

Sub-catchment	Nutrient loads	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
		Mid-term: 00-11	11.5	138	-6.846	0.00000	decreasing	seasonal	-0.01241	-0.01563	-0.00911	-28%	-8.13
		Short-term: 11-17	6.0	72	5.381	0.00000	increasing	non-seasonal	0.05698	0.03922	0.07399	120%	37.72
South Creek	Total phosphorus	Long-term: 92-17	25.0	300	-12.25	0.00000	decreasing	non-seasonal	-0.04491	-0.05048	-0.03887	-92%	-1.39
		Historical: 92-99	7.5	90	-8.553	0.00000	decreasing	non-seasonal	-0.12904	-0.15070	-0.10670	-89%	-3.50
		Mid-term: 00-11	11.5	138	-1.907	0.05652	insignificant	non-seasonal	-0.01016	-0.02011	0.00019	-24%	-0.07
		Short-term: 11-17	6.0	72	3.972	0.00007	increasing	non-seasonal	0.04878	0.02760	0.06911	96%	0.32
Cattai Creek	Total nitrogen	Long-term: 92-17	25.0	300	13.563	0.00000	increasing	seasonal	0.01329	0.01181	0.01469	115%	4.35
		Historical: 92-09	17.0	204	10.525	0.00000	increasing	seasonal	0.01785	0.01523	0.02028	101%	5.63
		Short-term: 09-17	8.0	96	7.536	0.00000	increasing	non-seasonal	0.03240	0.02610	0.03838	82%	13.71
Cattai Creek	Total phosphorus	Long-term: 92-17	25.0	300	-0.305	0.76066	insignificant	seasonal	-0.00078	-0.00606	0.00427	-4%	-0.01
		Historical: 92-99	7.5	90	-3.938	0.00008	decreasing	non-seasonal	-0.10026	-0.14294	-0.05070	-82%	-1.05
		Mid-term: 00-11	11.5	138	-5.1	0.00000	decreasing	seasonal	-0.03884	-0.05301	-0.02651	-64%	-0.09
		Short-term: 11-17	6.0	72	2.737	0.00620	increasing	non-seasonal	0.03845	0.01093	0.06194	70%	0.13
Berowra Creek*	Total nitrogen	Long-term: 92-17	25.0	300	-13.72	0.00000	decreasing	non-seasonal	-0.04309	-0.04681	-0.03912	-92%	-19.10
		Historical: 92-05	13.0	156	-8.782	0.00000	decreasing	non-seasonal	-0.04409	-0.05400	-0.03281	-73%	-29.38
		Short-term: 05-17	12.0	144	3.777	0.00016	increasing	non-seasonal	0.01278	0.00624	0.01992	42%	2.50
Berowra Creek*	Total phosphorus	Long-term: 92-17	25.0	300	-5.289	0.00000	decreasing	non-seasonal	-0.01265	-0.01724	-0.00799	-52%	-0.11
		Historical: 92-05	13.0	156	-2.901	0.00372	decreasing	non-seasonal	-0.02142	-0.03586	-0.00765	-47%	-0.20
		Short-term: 05-17	12.0	144	3.777	0.00016	increasing	non-seasonal	0.01964	0.00909	0.03016	72%	0.06

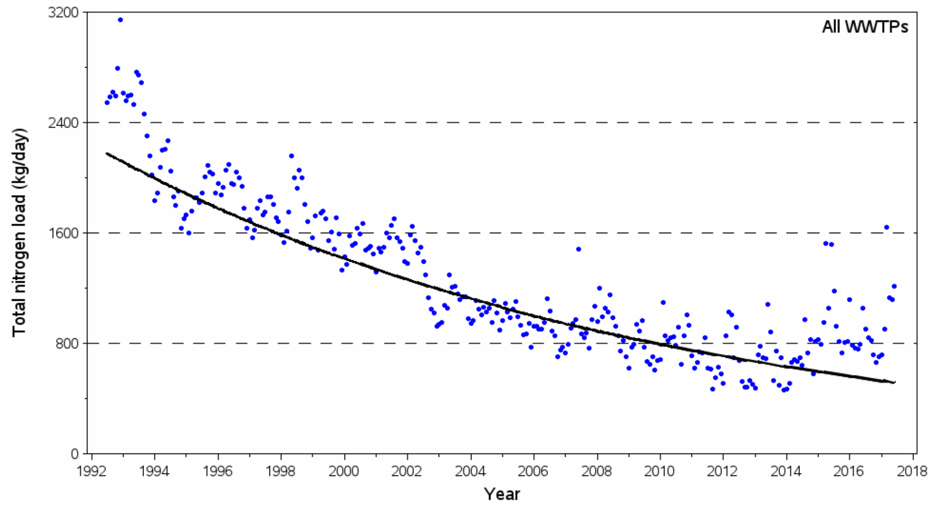
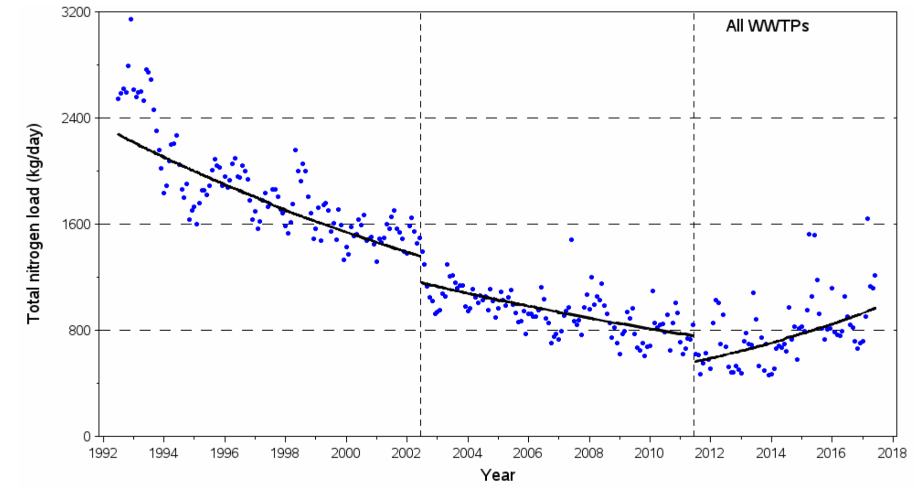
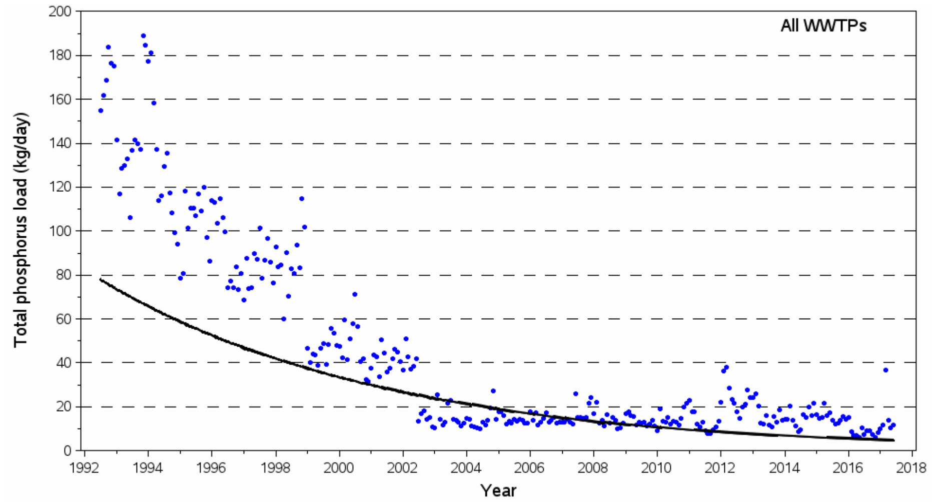
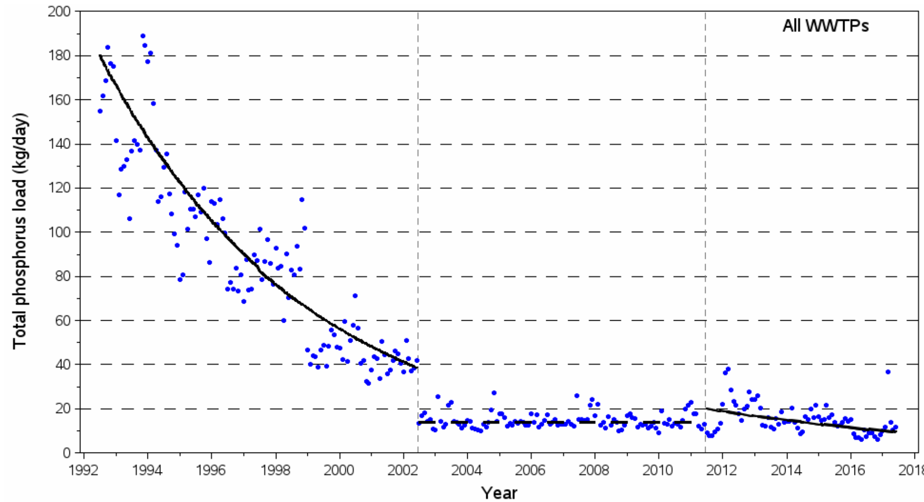
* Minor loads from Brooklyn WWTP were added to this region

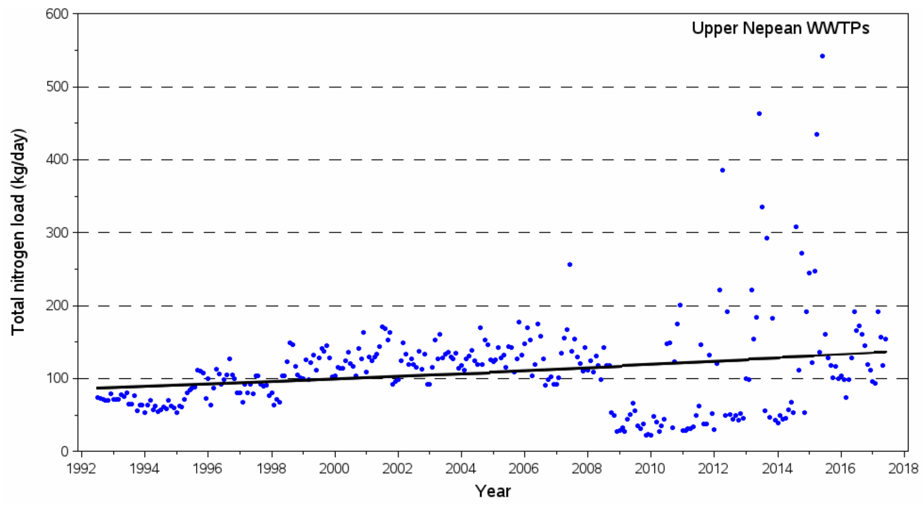
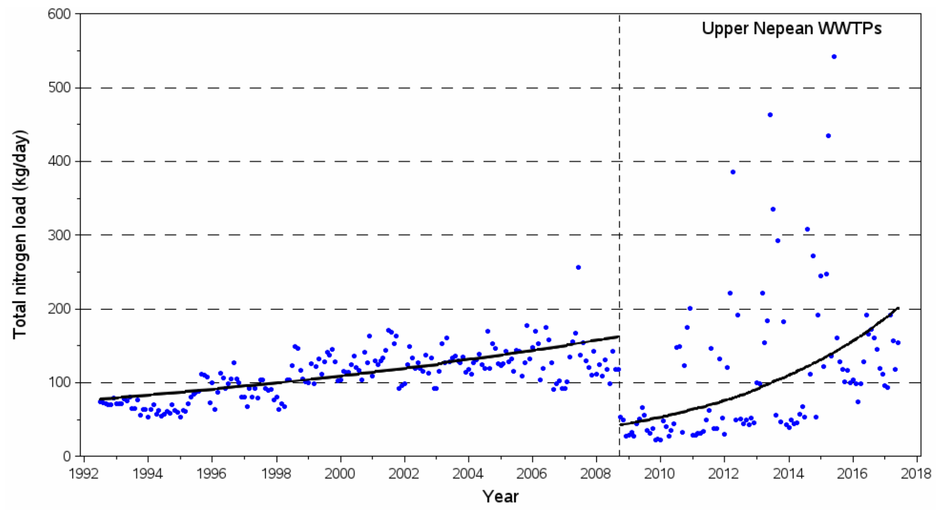
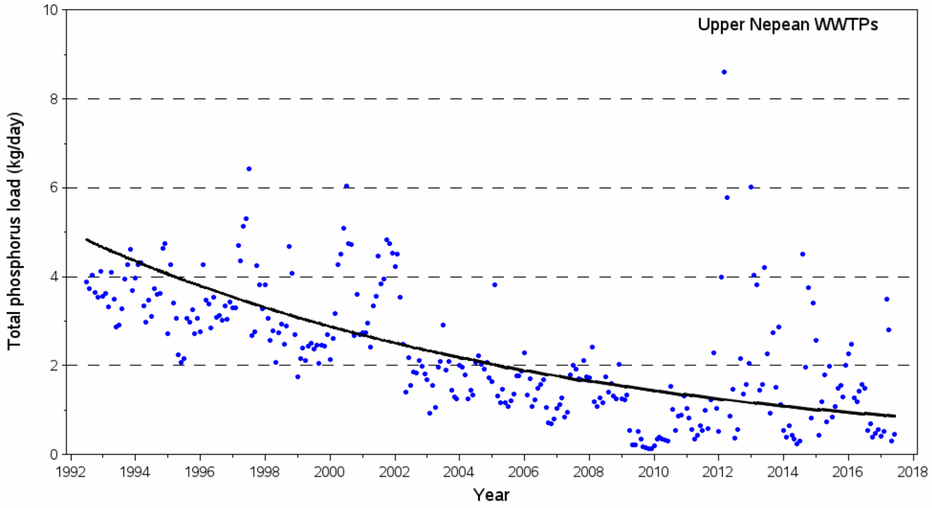
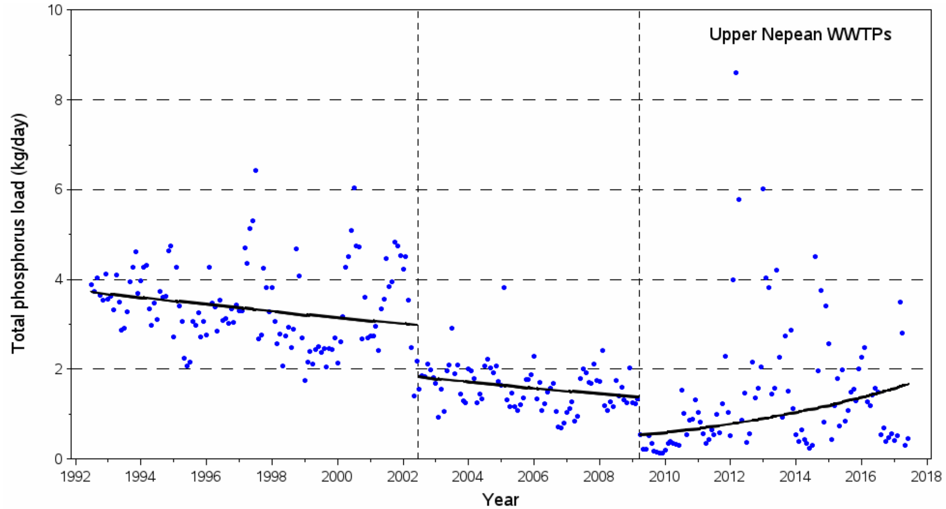
Significant decreasing trend in nutrient load

Significant increasing trend in nutrient load

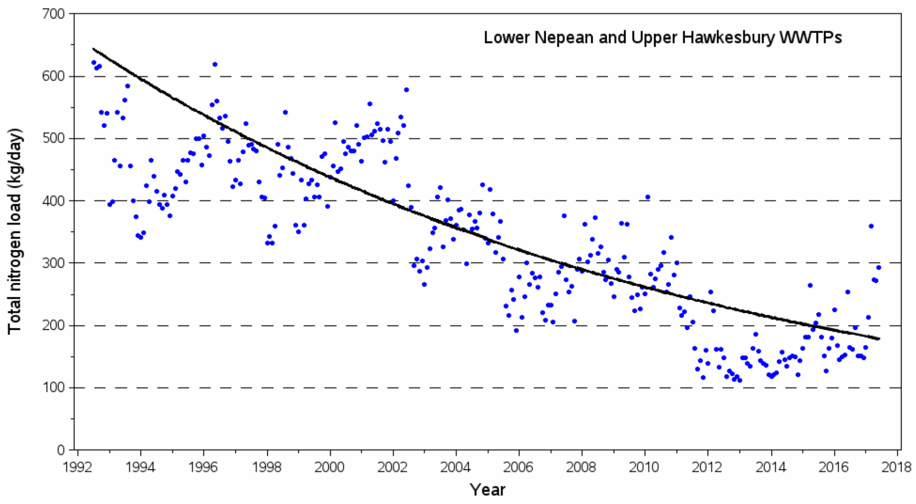
Figure D-1 Temporal trend plots on nutrient loads: all WWTPs and by each sub-catchment of the river and/or tributaries

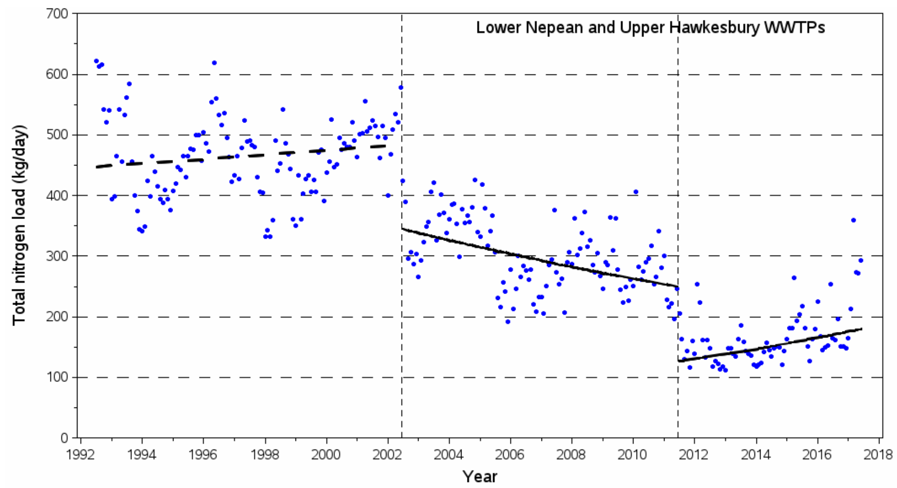
Solid line: statistically significant trend; Dotted line: statistically insignificant trend

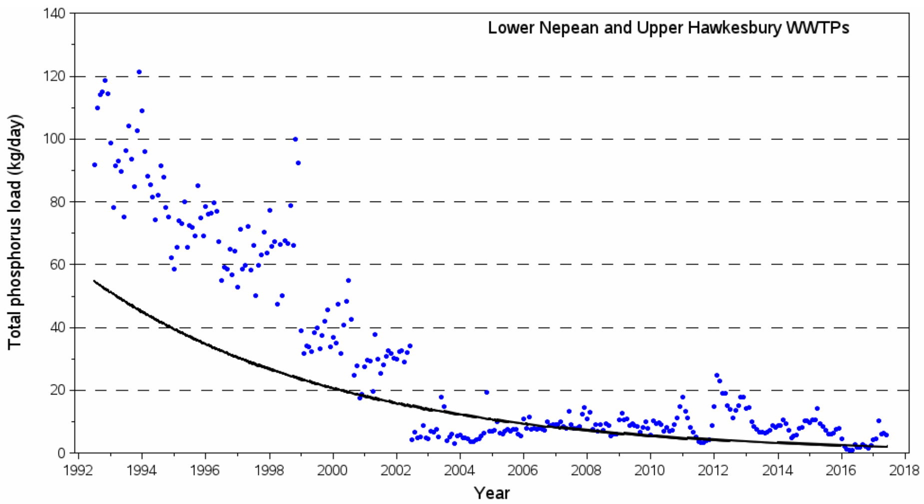
One trend for the entire period (long-term)	Step trends for two to three distinct periods (historical, mid-term & short-term)
	
	

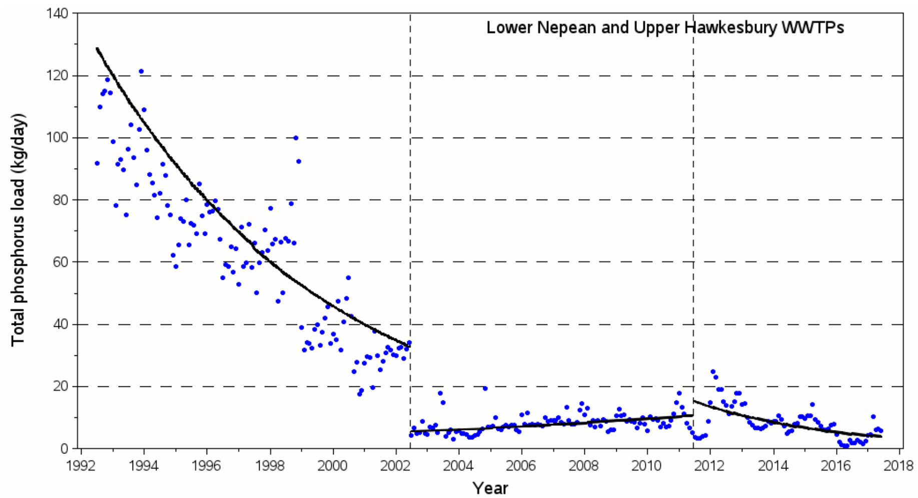
One trend for the entire period (long-term)	Step trends for two to three distinct periods (historical, mid-term & short-term)
	
	

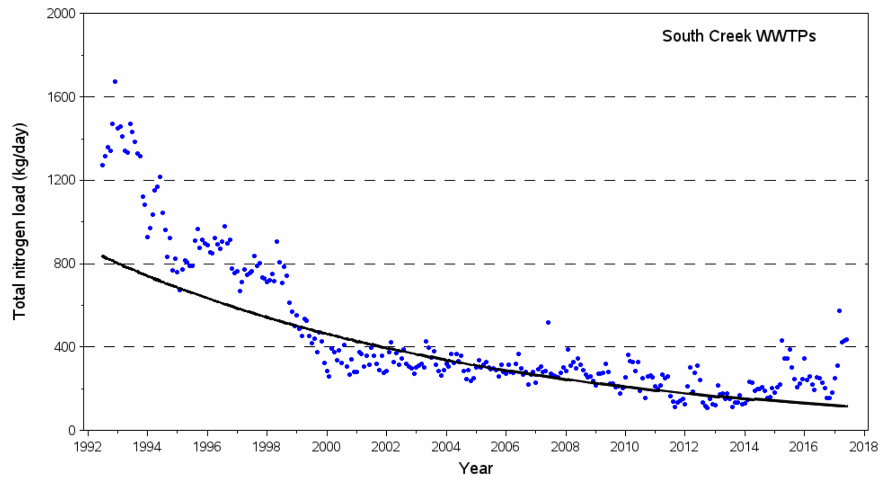
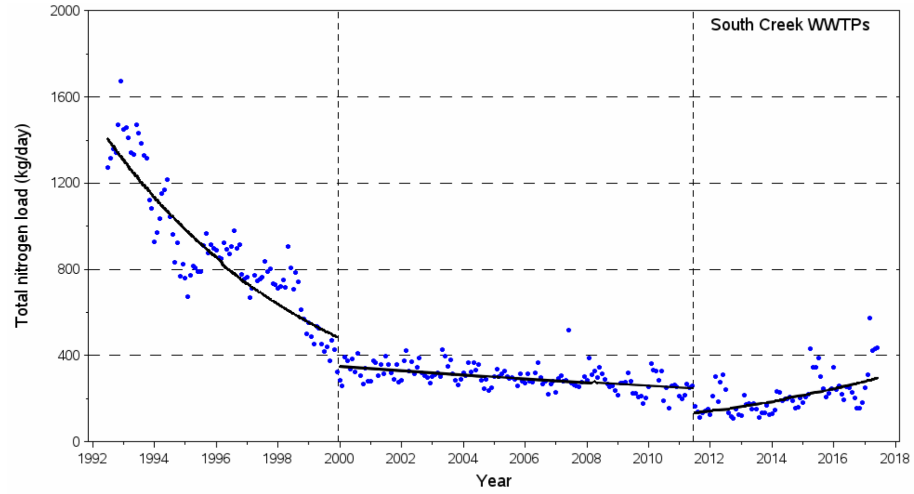
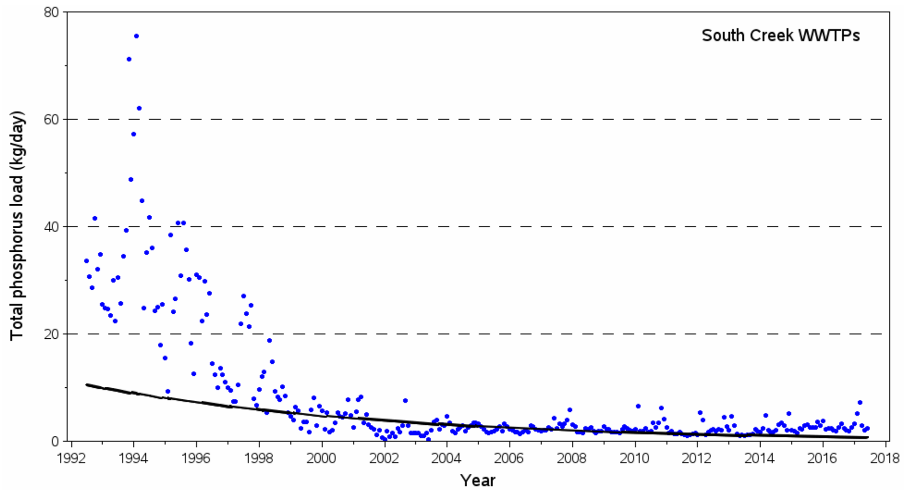
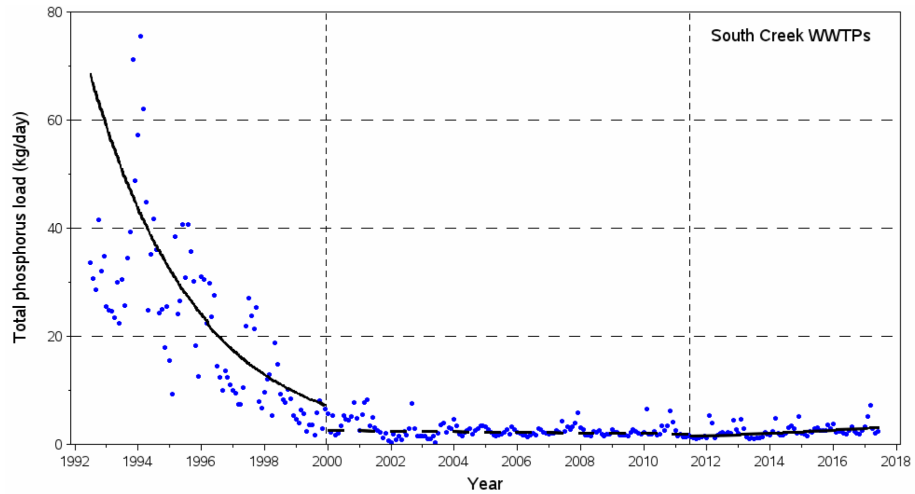
One trend for the entire period (long-term)	Step trends for two to three distinct periods (historical, mid-term & short-term)

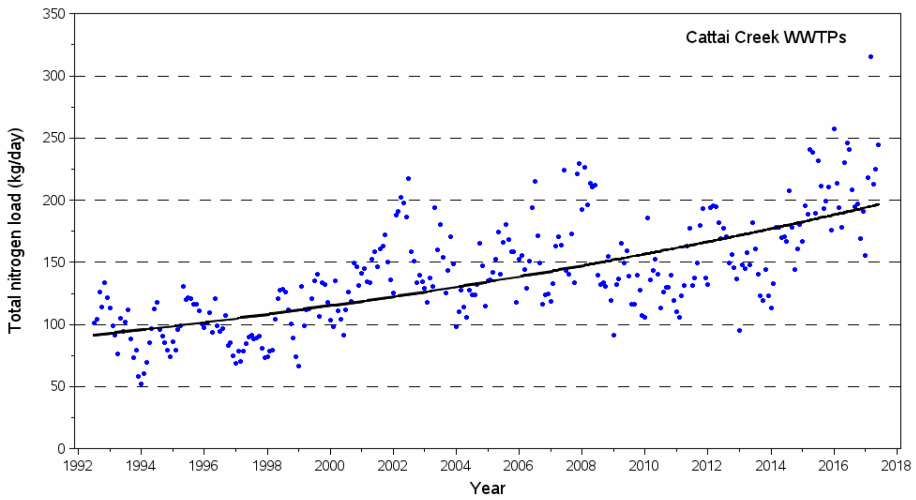
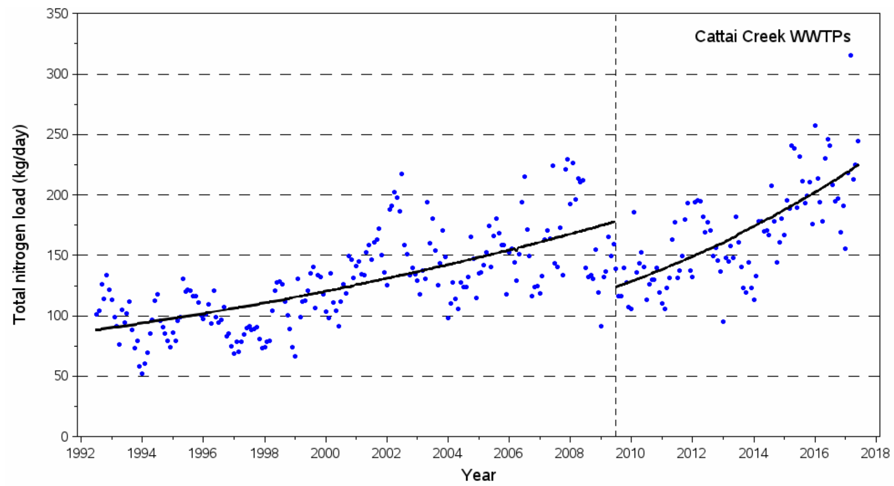
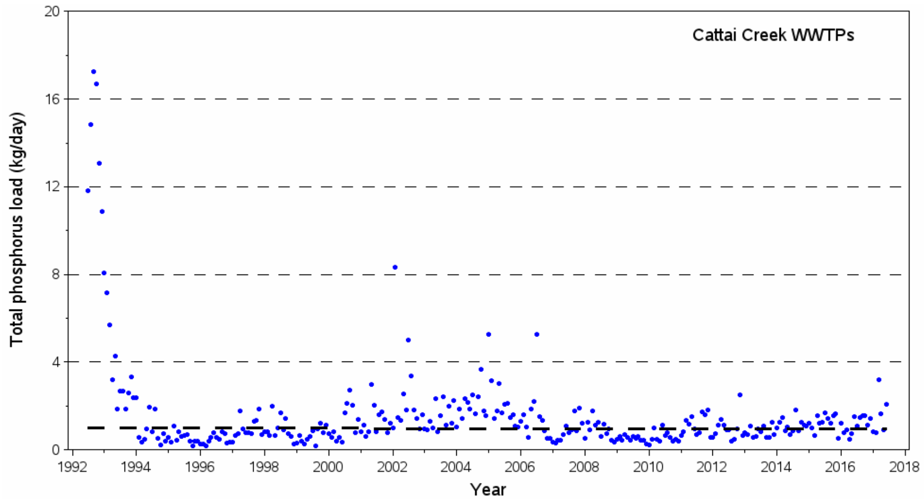
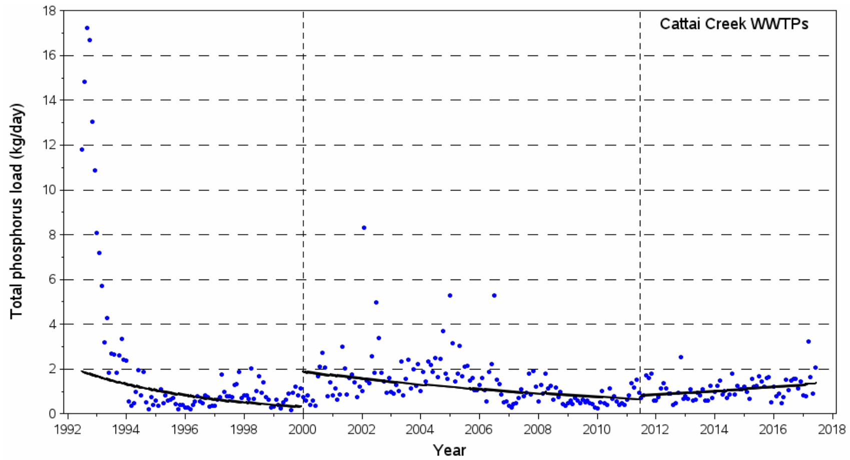




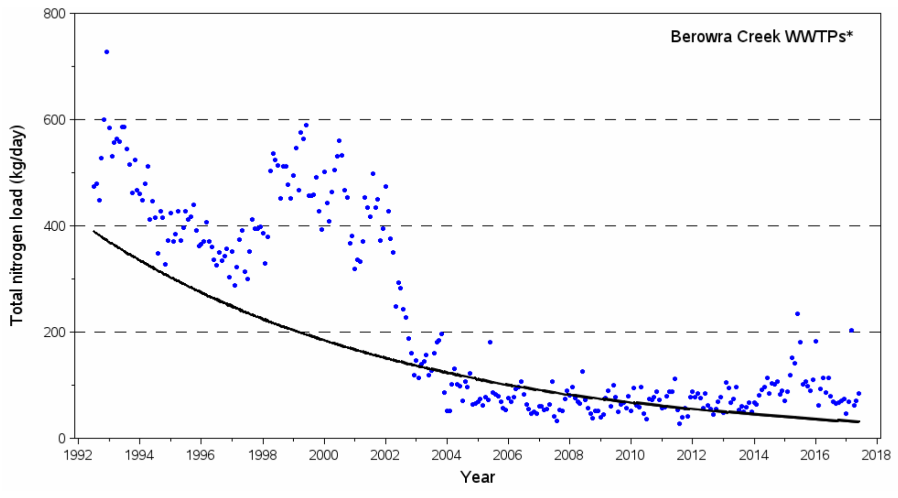


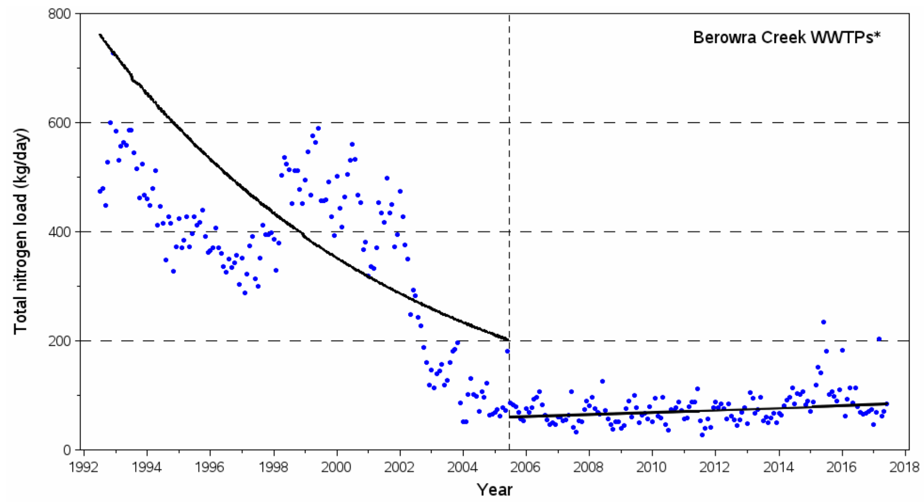


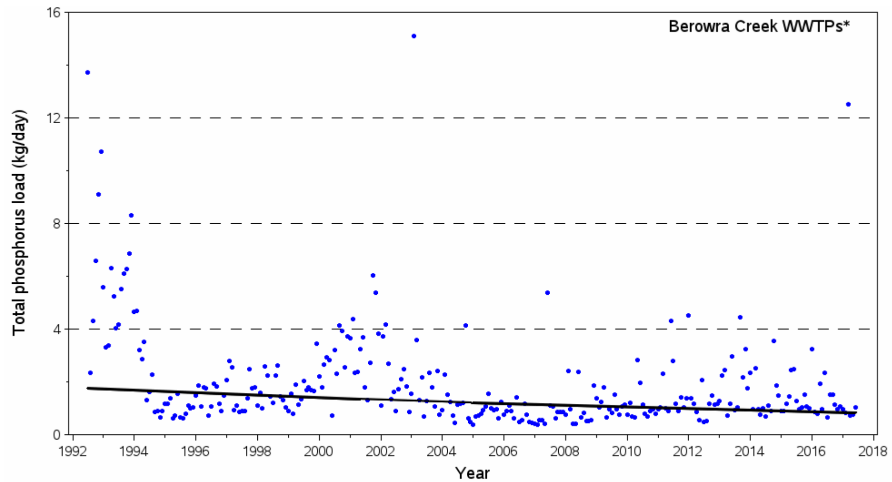
One trend for the entire period (long-term)	Step trends for two to three distinct periods (historical, mid-term & short-term)
	
	

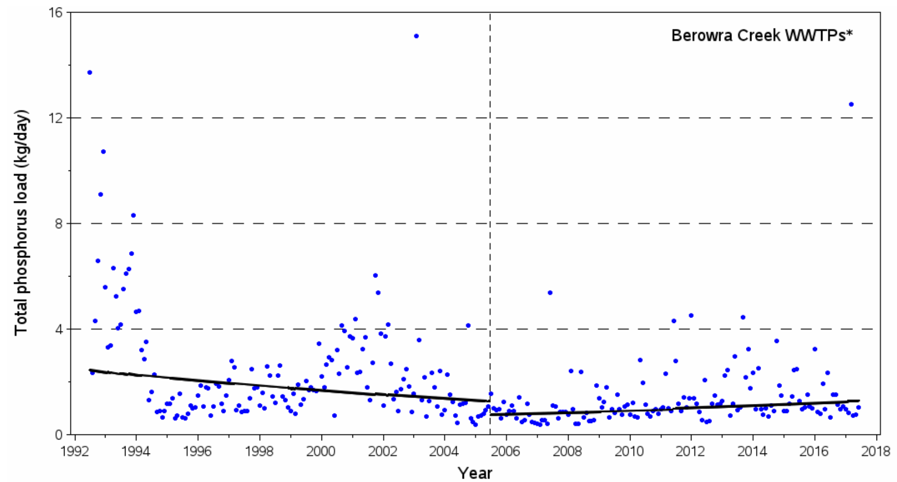
One trend for the entire period (long-term)	Step trends for two to three distinct periods (historical, mid-term & short-term)
	
	

One trend for the entire period (long-term)	Step trends for two to three distinct periods (historical, mid-term & short-term)





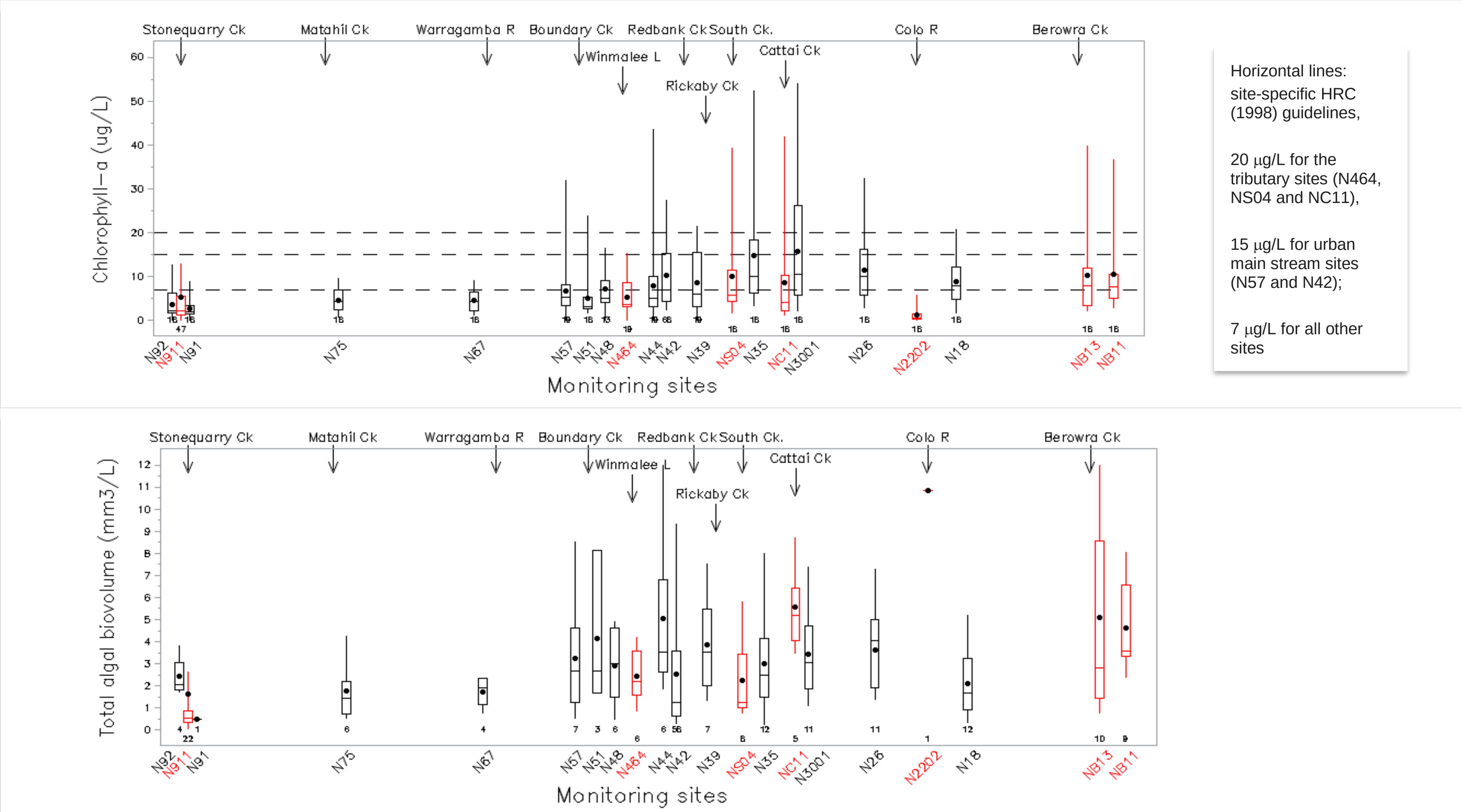


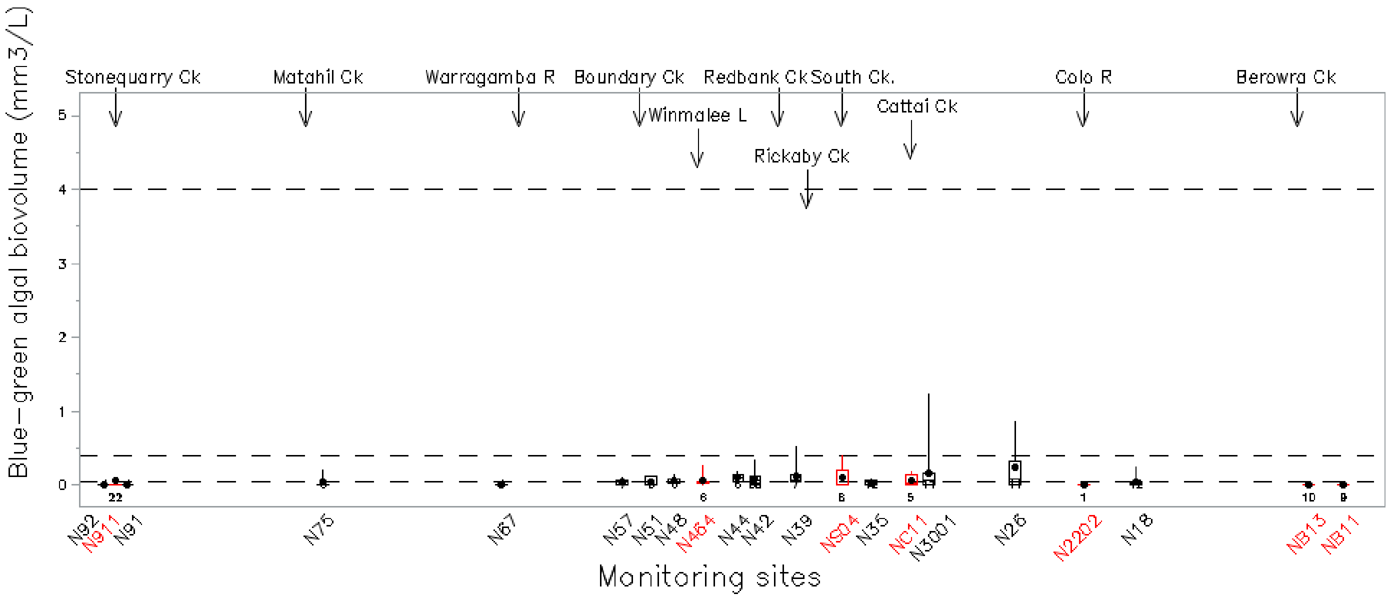


* Minor loads from Brooklyn WWTP were added to this

Appendix E: Water quality data analysis outcome (detailed results)

Figure E-1 Longitudinal variation on water quality parameters along the Hawkesbury-Nepean River and tributaries (2016-17 data)



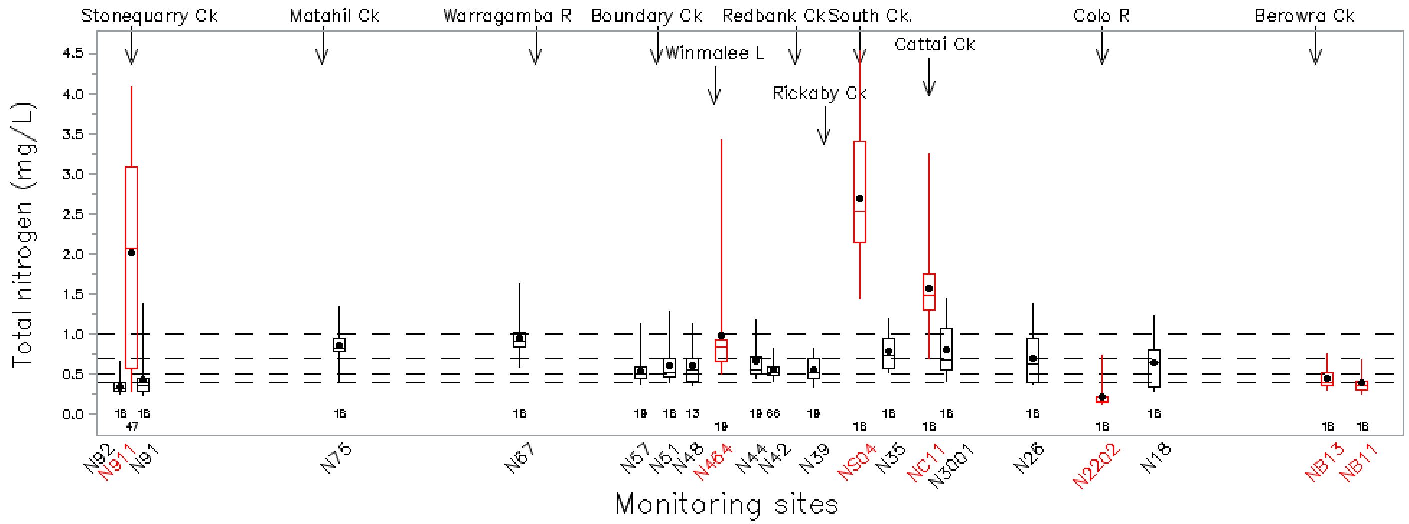


Horizontal lines:
NHMRC (2008) guidelines,

Green alert: 0.04 mm^3/L

Amber alert: 0.40 mm^3/L

Red alert: 4.00 mm^3/L



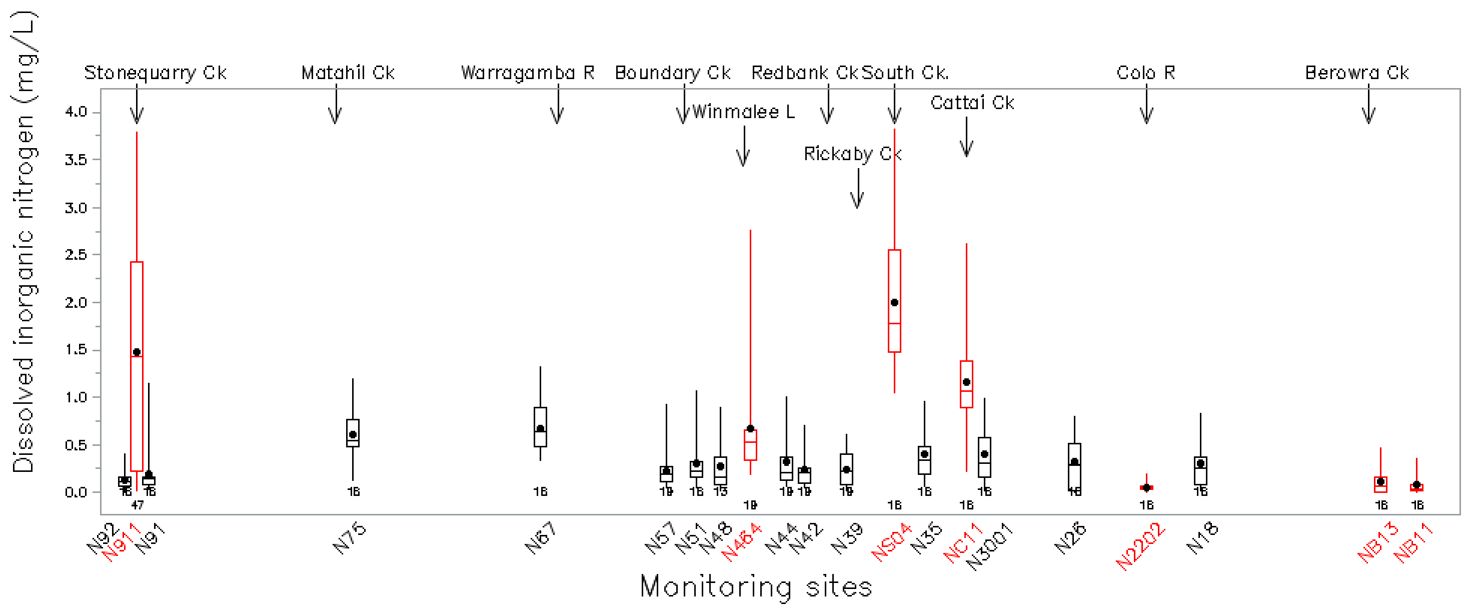
Horizontal lines:
site-specific HRC (1998) guidelines,

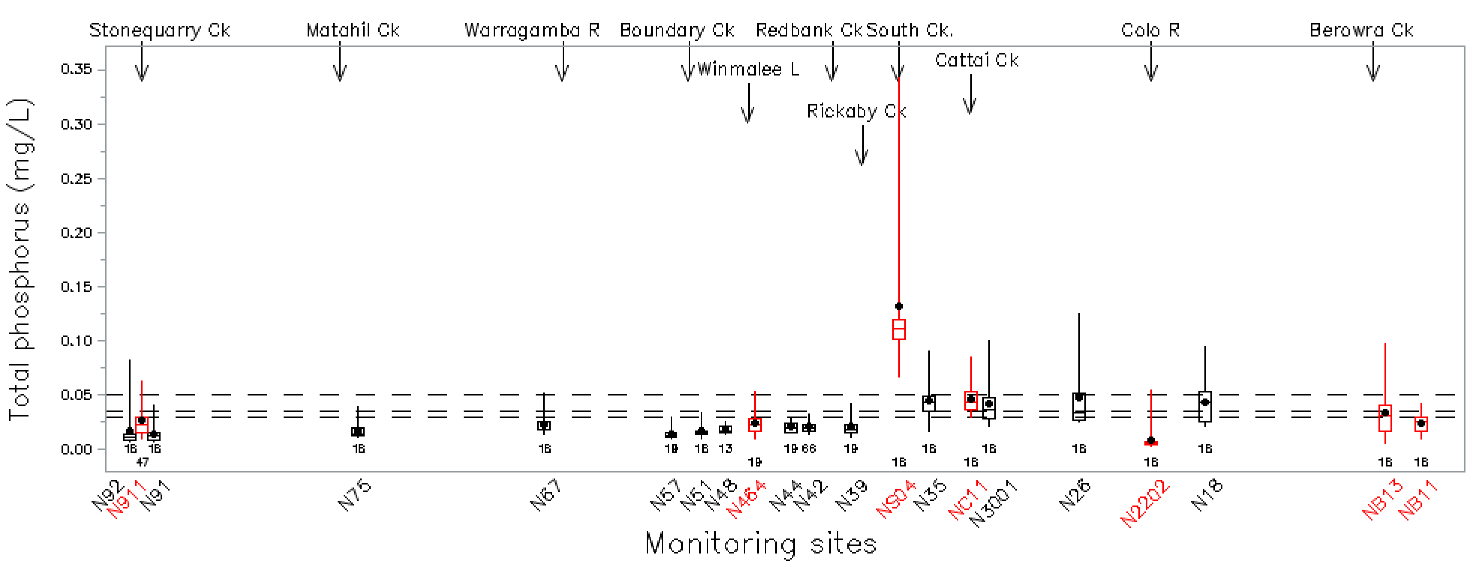
1.00 mg/L for the tributary sites (N464, NS04 and NC11),

0.50 mg/L for urban main stream sites (N57 and N42);

0.30 mg/L for the estuarine sites (NB13 and NB11)

0.70 mg/L for all other sites



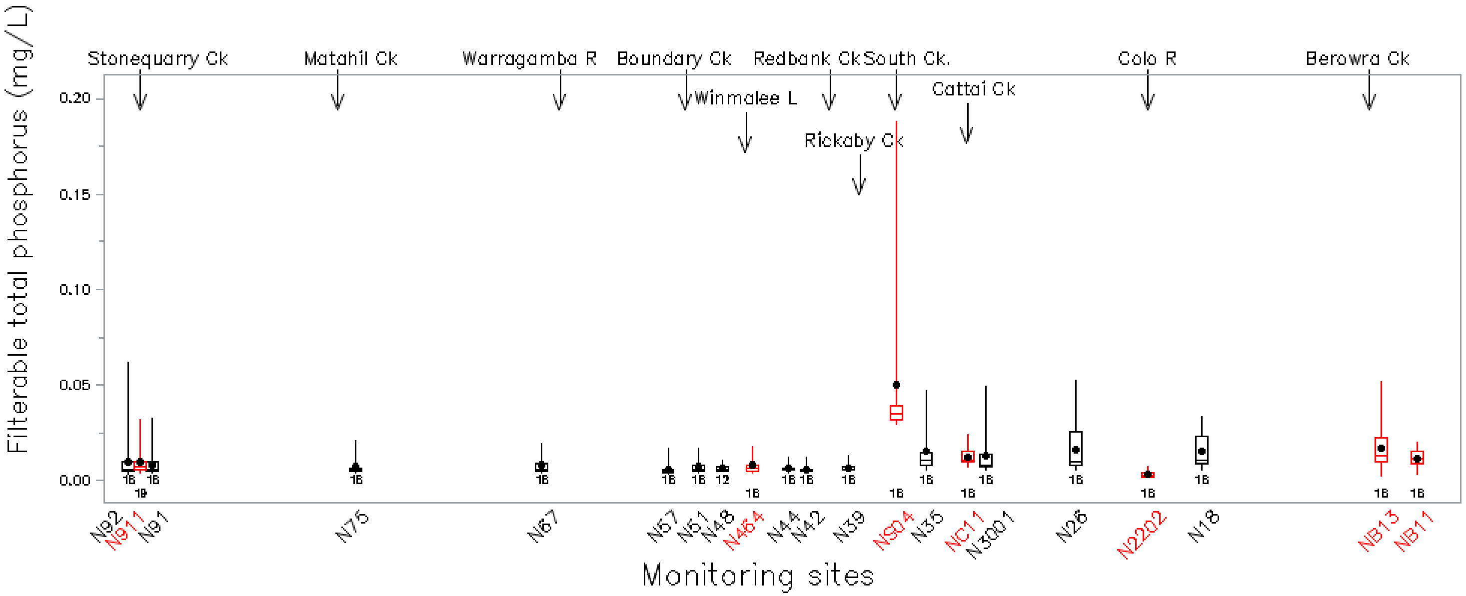


Horizontal lines:
site-specific HRC (1998) guidelines,

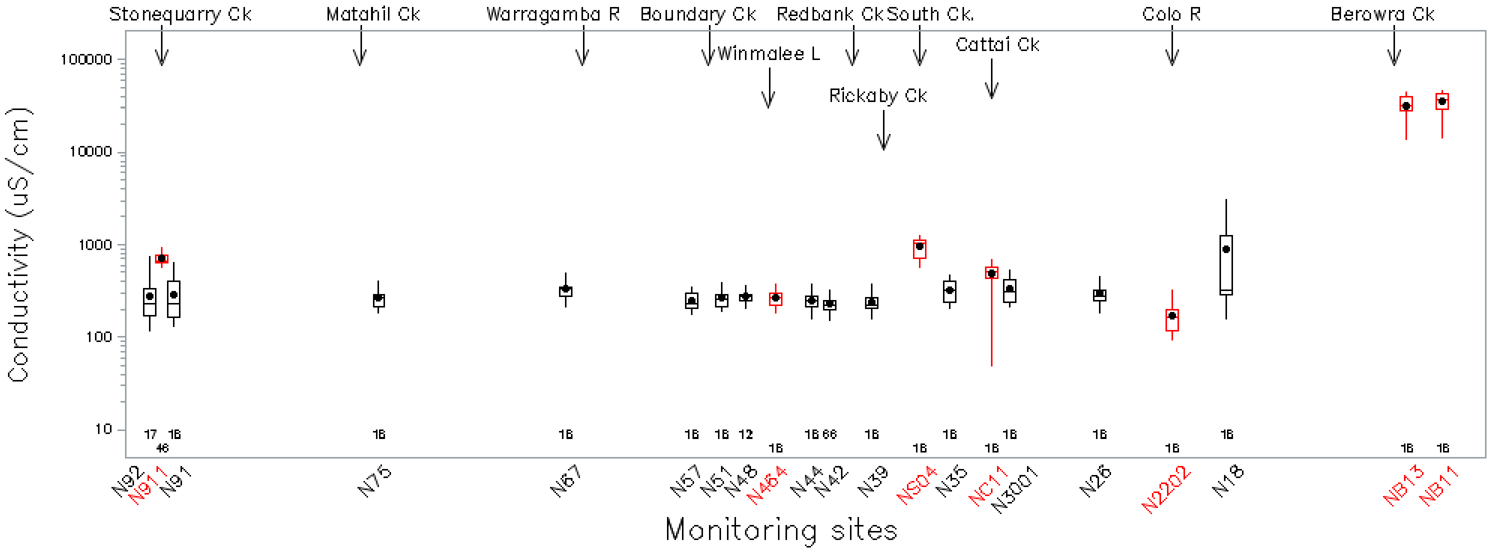
0.050 mg/L for the tributary sites (N464, NS04 and NC11),

0.030 mg/L for urban main stream and estuarine sites (N57, N42, NB13 and NB11);

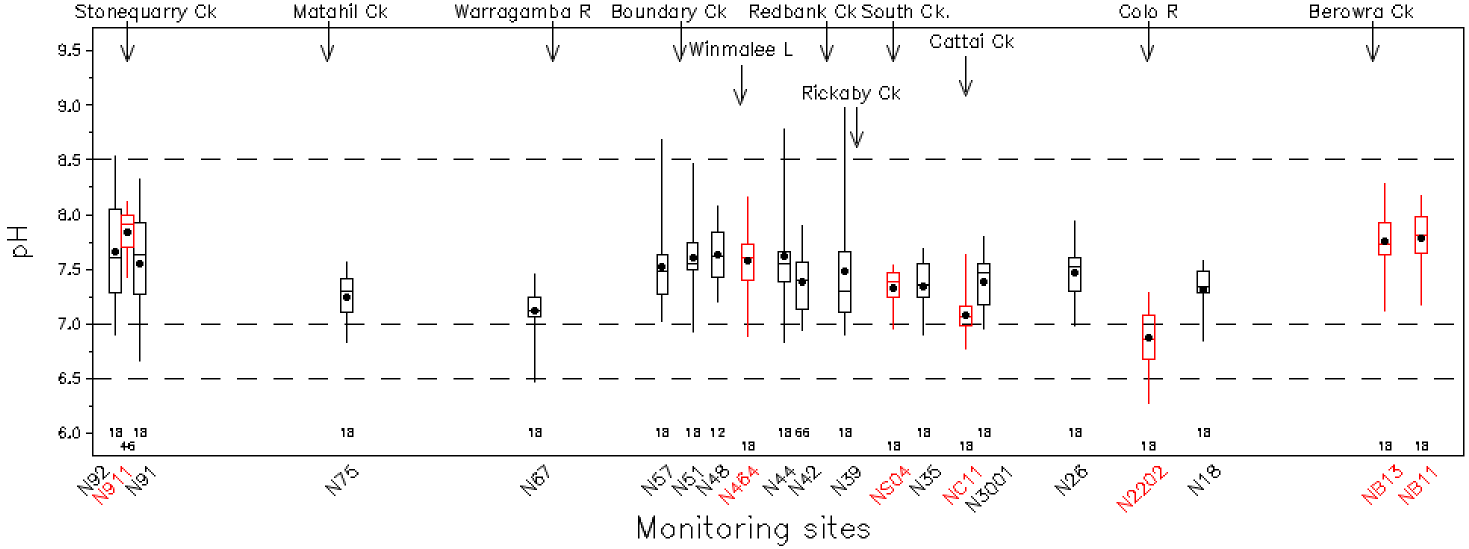
0.035 mg/L for all other sites



Filterable total phosphorus (mg/L)
Stonequarry Ck
Matahil Ck
Warragamba R
Boundary Ck
Winmalee L
Redbank Ck
Rickaby Ck
South Ck.
Cattai Ck
Colo R
Berowra Ck
0.20
0.15
0.10
0.05
0.00
N92
N911
N91
N75
N67
N57
N51
N48
N464
N44
N42
N39
NS04
N35
NC11
N3001
N26
N2202
N18
NB13
NB11
Monitoring sites



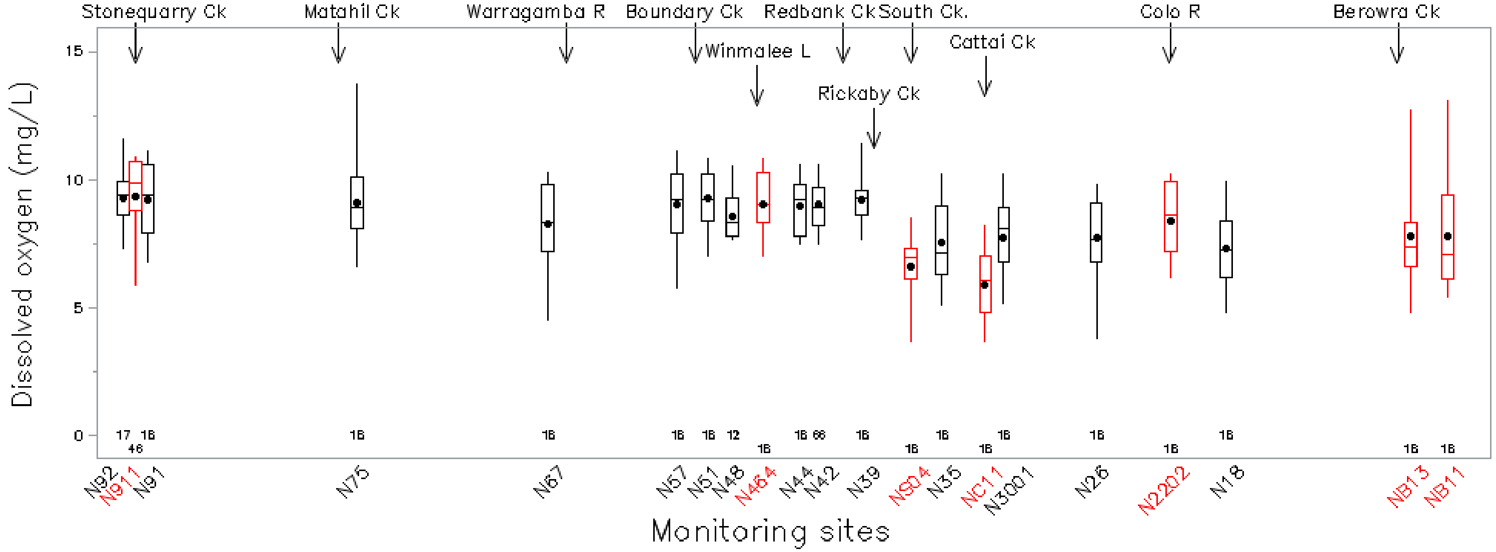
Conductivity (uS/cm)
Stonequarry Ck
Matahil Ck
Warragamba R
Boundary Ck
Winmalee L
Redbank Ck
Rickaby Ck
South Ck.
Cattai Ck
Colo R
Berowra Ck
100000
10000
1000
100
10
N92
N911
N91
N75
N67
N57
N51
N48
N464
N44
N42
N39
NS04
N35
NC11
N3001
N26
N2202
N18
NB13
NB11
Monitoring sites

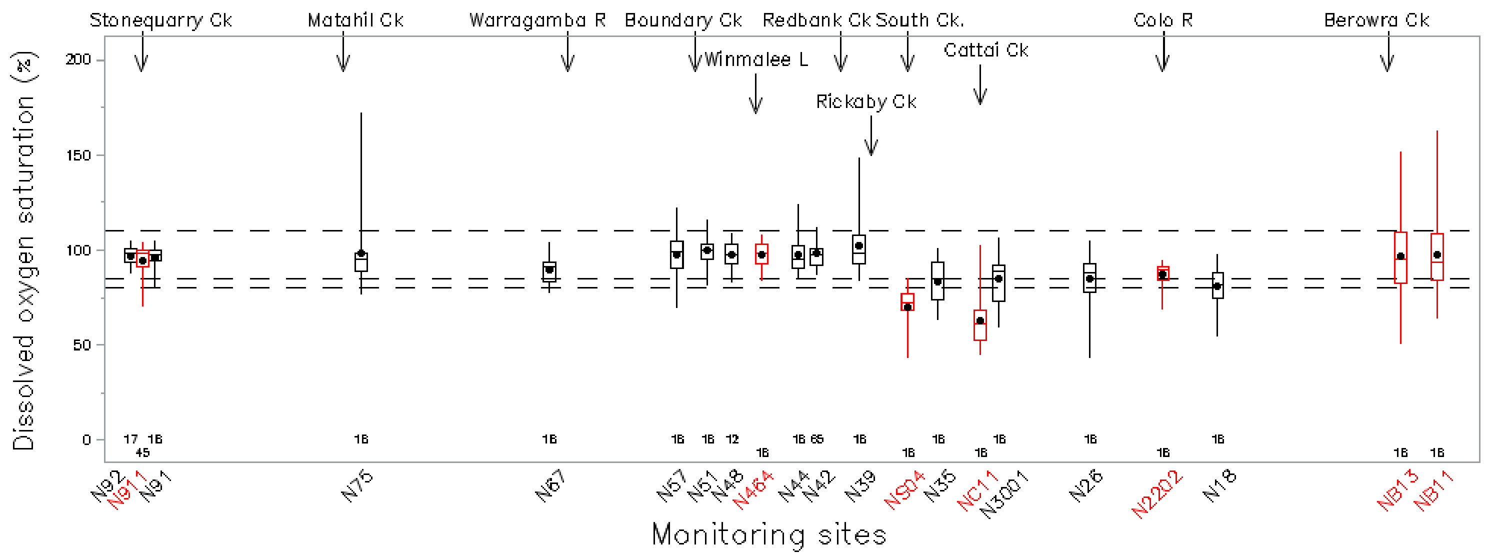


Horizontal lines: ANZECC (2000) guideline:

Estuarine site (NB13 and NB11): 7.0 to 8,5

All other sites: 6.5 to 8.5

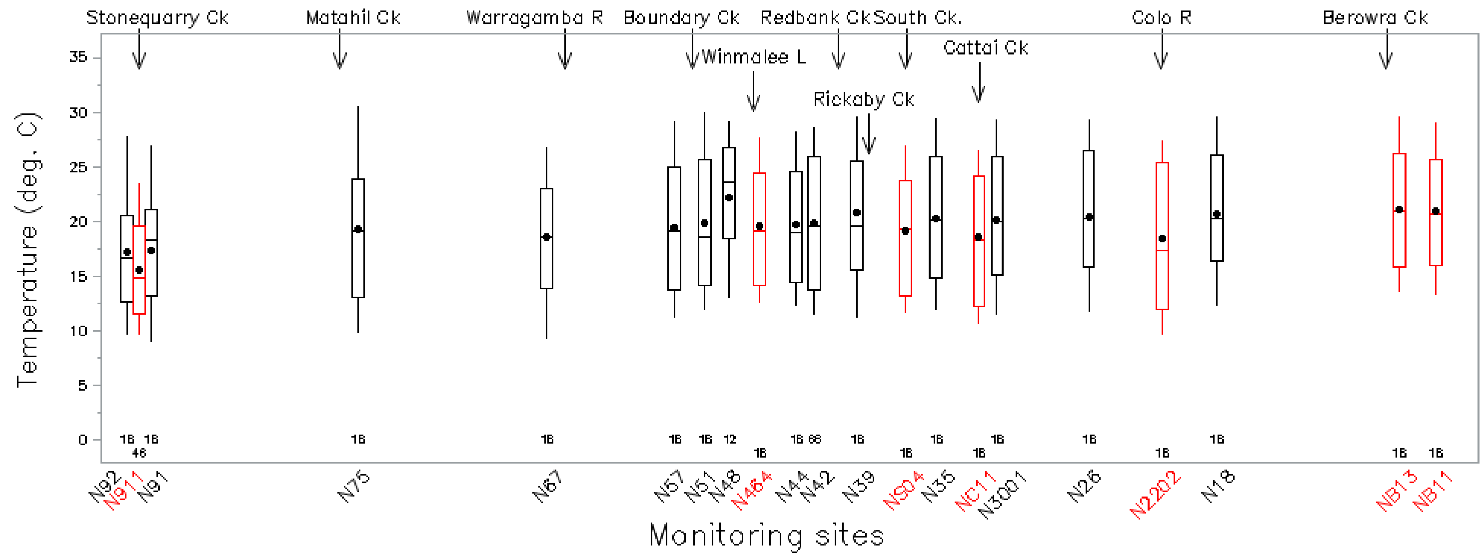


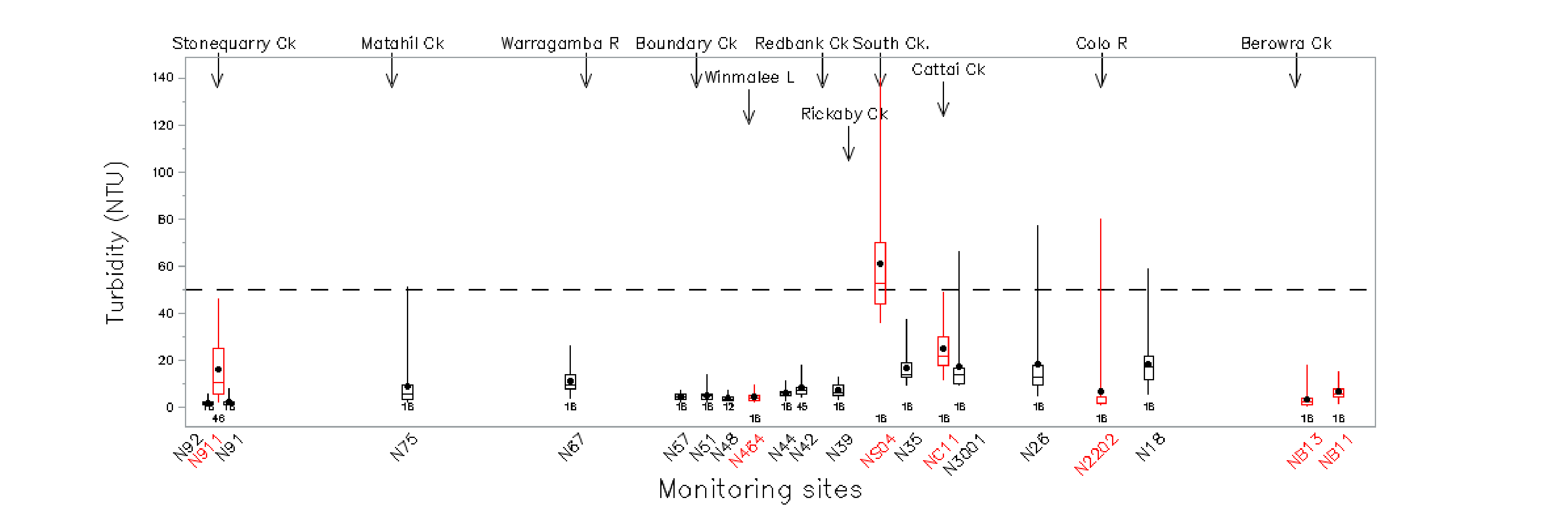


Horizontal lines:
ANZECC (2000) guideline:

Estuarine site (NB13 and NB11): 80 to 110

All other sites: 85 to 110





Stonequarry Ck
Matahil Ck
Warragamba R
Boundary Ck
Redbank Ck
South Ck.
Cattai Ck
Colo R
Berowra Ck
Winmalee L
Rickaby Ck
Turbidity (NTU)
Monitoring sites

Table E-1 Temporal trend analysis results on all water quality parameters (upstream to downstream sites)

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N92	Chlorophyll-*a*	Long-term	25.0	298	0.739	0.46006	insignificant	seasonal	0.00203	-0.00327	0.00773	12%	0.0222
		Historical	18.0	214	3.279	0.00104	increasing	non-seasonal	0.01628	0.00688	0.02624	96%	0.2402
		Short-term	7.0	84	-0.15	0.88087	insignificant	seasonal	-0.00293	-0.02976	0.02972	-5%	-0.0243
N92	Total algal biovolume	Long-term	25.0	114	8.522	0.00000	increasing	non-seasonal	0.06285	0.05007	0.08004	3634%	0.3514
		Historical	19.0	106	8.021	0.00000	increasing	non-seasonal	0.07877	0.06137	0.09713	3044%	0.3874
		Short-term	7.0	8	Insufficient data								
N92	Blue-green algal biovolume	Long-term	25.0	114	4.016	0.00006	increasing	non-seasonal	0.09645	0.04213	0.15657	25780%	0.0277
		Historical	19.0	106	4.346	0.00001	increasing	non-seasonal	0.13248	0.06468	0.20039	32901%	0.0466
		Short-term	7.0	8	Insufficient data								
N92	Total nitrogen	Long-term	25.0	298	-4.316	0.00002	decreasing	seasonal	-0.00490	-0.00699	-0.00273	-25%	-0.0054
		Historical	18.0	214	-0.852	0.39402	insignificant	seasonal	-0.00179	-0.00556	0.00205	-7%	-0.0022
		Short-term	7.0	84	-2.502	0.01236	decreasing	seasonal	-0.01242	-0.02259	-0.00252	-18%	-0.0106
N92	Dissolved inorganic nitrogen	Long-term	25.0	298	-4.890	0.00000	decreasing	seasonal	-0.01167	-0.01652	-0.00749	-49%	-0.0051
		Historical	18.0	214	-1.810	0.07027	insignificant	seasonal	-0.00780	-0.01609	0.00061	-28%	-0.0040
		Short-term	7.0	84	-3.124	0.00178	decreasing	seasonal	-0.03635	-0.05473	-0.01573	-44%	-0.0116
N92	Total phosphorus	Long-term	25.0	298	-1.813	0.06983	insignificant	seasonal	-0.00276	-0.00578	0.00024	-15%	-0.0001
		Historical	18.0	214	2.225	0.02607	increasing	non-seasonal	0.00666	0.00081	0.01262	32%	0.0003
		Short-term	7.0	84	-1.789	0.07368	insignificant	non-seasonal	-0.01532	-0.03265	0.00152	-22%	-0.0005
N92	Filterable total phosphorus	Long-term	25.0	298	-0.282	0.77829	insignificant	non-seasonal	-0.00050	-0.00437	0.00349	-3%	0.0000
		Historical	18.0	214	3.921	0.00009	increasing	non-seasonal	0.01389	0.00676	0.02139	78%	0.0003
		Short-term	7.0	84	-0.772	0.43987	insignificant	seasonal	-0.00750	-0.02678	0.00905	-11%	-0.0001
N92	Conductivity	Long-term	25.0	298	0.183	0.85507	insignificant	non-seasonal	0.00023	-0.00221	0.00266	1%	0.1746
		Historical	18.0	214	3.367	0.00076	increasing	non-seasonal	0.00660	0.00273	0.01040	31%	5.6260
		Short-term	7.0	84	2.453	0.01416	increasing	non-seasonal	0.01940	0.00361	0.03516	37%	9.7682
N92	pH	Long-term	25.0	298	2.397	0.01653	increasing	seasonal	0.00910	0.00169	0.01647	3%	
		Historical	18.0	214	5.984	0.00000	increasing	seasonal	0.03856	0.02654	0.05064	9%	
		Short-term	7.0	84	-3.573	0.00035	decreasing	non-seasonal	-0.05922	-0.09301	-0.02945	-5%	

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N92	Dissolved oxygen	Long-term	25.0	298	2.825	0.00473	increasing	seasonal	0.00134	0.00043	0.00242	8%	0.0257
	DO Saturation	Long-term	21.0	250	0.598	0.54998	insignificant	non-seasonal	0.00030	-0.00071	0.00129	1%	0.0632
	Temperature	Long-term	25.0	298	1.816	0.06930	insignificant	seasonal	0.00085	-0.00005	0.00177		0.0355
	Turbidity	Long-term	25.0	298	-3.941	0.00008	decreasing	seasonal	-0.00760	-0.01107	-0.00370	-35%	-0.0346
N911	Chlorophyll-*a*	Long-term	20.5	229	-0.628	0.52975	insignificant	seasonal	-0.00250	-0.01181	0.00557	-11%	-0.0346
		Historical	13.5	155	-1.453	0.14609	insignificant	seasonal	-0.01284	-0.03168	0.00470	-33%	-0.1555
		Short-term	7.0	74	2.472	0.01342	increasing	seasonal	0.05036	0.01119	0.09570	125%	0.5420
N911	Total algal biovolume	Long-term	20.5	28	Insufficient data								
		Historical	13.5	17	Insufficient data								
		Short-term	7.0	11	Insufficient data								
N911	Blue-green algal biovolume	Long-term	20.5	28	Insufficient data								
		Historical	13.5	17	Insufficient data								
		Short-term	7.0	11	Insufficient data								
N911	Total nitrogen	Long-term	20.5	239	-2.656	0.00790	decreasing	seasonal	-0.00487	-0.00864	-0.00130	-21%	-0.0080
		Historical	13.5	155	-3.068	0.00215	decreasing	seasonal	-0.01224	-0.01894	-0.00465	-32%	-0.0186
		Short-term	7.0	84	0.993	0.32080	insignificant	non-seasonal	0.00812	-0.00793	0.02448	14%	0.0128
N911	Dissolved inorganic nitrogen	Long-term	20.5	239	-1.849	0.06446	insignificant	seasonal	-0.00717	-0.01475	0.00041	-29%	-0.0055
		Historical	13.5	155	-2.838	0.00454	decreasing	seasonal	-0.02214	-0.03661	-0.00649	-50%	-0.0145
		Short-term	7.0	84	0.980	0.32712	insignificant	seasonal	0.01606	-0.02319	0.04783	30%	0.0109
N911	Total phosphorus	Long-term	20.5	239	-6.874	0.00000	decreasing	seasonal	-0.01568	-0.02032	-0.01128	-52%	-0.0012
		Historical	13.5	155	-3.295	0.00099	decreasing	seasonal	-0.01390	-0.02464	-0.00561	-35%	-0.0012
		Short-term	7.0	84	-1.902	0.05714	insignificant	seasonal	-0.01712	-0.03592	0.00068	-24%	-0.0010
N911	Filterable total phosphorus	Long-term	20.5	229	-5.125	0.00000	decreasing	seasonal	-0.01318	-0.01876	-0.00837	-46%	-0.0004
		Historical	13.5	155	-2.067	0.03872	decreasing	seasonal	-0.01075	-0.02281	-0.00042	-28%	-0.0003
		Short-term	7.0	74	-2.598	0.00939	decreasing	seasonal	-0.02403	-0.04521	-0.00577	-32%	-0.0006
N911	Conductivity	Long-term	20.5	232	5.592	0.00000	increasing	seasonal	0.00483	0.00328	0.00645	26%	9.0772
		Historical	13.5	148	-0.351	0.72561	insignificant	seasonal	-0.00048	-0.00379	0.00243	-1%	-0.7964
		Short-term	7.0	84	2.144	0.03203	increasing	non-seasonal	0.00825	0.00044	0.01615	14%	13.6487

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N911	pH	Long-term	20.5	236	1.194	0.23241	insignificant	seasonal	0.00327	-0.00256	0.00873	1%	
		Historical	13.5	152	3.612	0.00030	increasing	seasonal	0.02026	0.00899	0.03142	4%	
		Short-term	7.0	84	-4.946	0.00000	decreasing	seasonal	-0.04906	-0.06768	-0.03107	-4%	
N911	Dissolved oxygen	Long-term	20.5	232	-1.142	0.25343	insignificant	seasonal	-0.00083	-0.00248	0.00058	-4%	-0.0155
	DO Saturation	Long-term	20.0	226	-3.213	0.00131	decreasing	seasonal	-0.00208	-0.00323	-0.00080	-9%	-0.4285
	Temperature	Long-term	20.5	237	-1.945	0.05178	insignificant	seasonal	-0.00141	-0.00271	0.00001		-0.0535
	Turbidity	Long-term	20.5	237	-2.845	0.00444	decreasing	seasonal	-0.00838	-0.01428	-0.00260	-33%	-0.2315
N91	Chlorophyll-*a*	Long-term	25.0	275	0.557	0.57781	insignificant	seasonal	0.00156	-0.00364	0.00667	9%	0.0119
		Historical	18.0	200	2.492	0.01271	increasing	non-seasonal	0.01169	0.00231	0.02147	62%	0.1098
		Short-term	7.0	75	0.232	0.81683	insignificant	seasonal	0.00371	-0.01923	0.03086	6%	0.0289
N91	Total nitrogen	Long-term	25.0	285	-4.845	0.00000	decreasing	seasonal	-0.00591	-0.00821	-0.00362	-29%	-0.0059
		Historical	18.0	201	-0.920	0.35751	insignificant	seasonal	-0.00201	-0.00610	0.00203	-8%	-0.0023
		Short-term	7.0	84	-1.764	0.07775	insignificant	seasonal	-0.01027	-0.02101	0.00091	-15%	-0.0099
N91	Dissolved inorganic nitrogen	Long-term	25.0	285	-4.834	0.00000	decreasing	seasonal	-0.01145	-0.01595	-0.00726	-48%	-0.0048
		Historical	18.0	201	-1.940	0.05233	insignificant	seasonal	-0.00762	-0.01596	0.00014	-27%	-0.0038
		Short-term	7.0	84	-2.386	0.01701	decreasing	seasonal	-0.02802	-0.04446	-0.00608	-36%	-0.0107
N91	Total phosphorus	Long-term	25.0	285	-3.863	0.00011	decreasing	non-seasonal	-0.00736	-0.01102	-0.00360	-35%	-0.0003
		Historical	18.0	201	1.270	0.20402	insignificant	non-seasonal	0.00406	-0.00228	0.01116	18%	0.0002
		Short-term	7.0	84	-2.044	0.04100	decreasing	non-seasonal	-0.01897	-0.03601	-0.00120	-26%	-0.0008
N91	Filterable total phosphorus	Long-term	25.0	276	-1.017	0.30903	insignificant	non-seasonal	-0.00225	-0.00679	0.00204	-12%	0.0000
		Historical	18.0	201	3.387	0.00071	increasing	non-seasonal	0.01281	0.00543	0.02026	70%	0.0003
		Short-term	7.0	75	-1.131	0.25810	insignificant	seasonal	-0.01030	-0.03146	0.00583	-15%	-0.0002
N91	Conductivity	Long-term	25.0	285	-1.241	0.21472	insignificant	non-seasonal	-0.00141	-0.00374	0.00088	-8%	-1.2095
		Historical	18.0	201	1.805	0.07106	insignificant	non-seasonal	0.00350	-0.00028	0.00713	16%	3.3628
		Short-term	7.0	84	2.291	0.02197	increasing	non-seasonal	0.01518	0.00251	0.02990	28%	8.2991
N91	pH	Long-term	25.0	285	2.218	0.02653	increasing	non-seasonal	0.00809	0.00107	0.01496	3%	
		Historical	18.0	201	6.061	0.00000	increasing	non-seasonal	0.03747	0.02638	0.04916	8%	
		Short-term	7.0	84	-3.585	0.00034	decreasing	seasonal	-0.04135	-0.06760	-0.02282	-4%	

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N91	Dissolved oxygen	Long-term	25.0	285	0.922	0.35679	insignificant	seasonal	0.00042	-0.00044	0.00128	2%	0.0085
	DO saturation	Long-term	21.0	250	-0.617	0.53727	insignificant	seasonal	-0.00023	-0.00093	0.00043	-1%	-0.0499
	Temperature	Long-term	25.0	285	1.553	0.12038	insignificant	seasonal	0.00064	-0.00018	0.00164		0.0261
	Turbidity	Long-term	25.0	280	-5.196	0.00000	decreasing	non-seasonal	-0.01121	-0.01524	-0.00697	-48%	-0.0604
N75	Chlorophyll-*a*	Long-term	25.0	295	-1.76	0.07833	insignificant	seasonal	-0.00474	-0.00965	0.00060	-24%	-0.0832
		Historical	16.3	190	0.461	0.64481	insignificant	non-seasonal	0.00255	-0.00922	0.01529	10%	0.0538
		Short-term	8.8	105	-2.583	0.00980	decreasing	seasonal	-0.02427	-0.04072	-0.00672	-39%	-0.4887
N75	Total algal biovolume	Long-term	23.0	145	-1.455	0.14574	insignificant	non-seasonal	-0.00559	-0.01353	0.00188	-26%	-0.0275
		Historical	14.3	94	0.764	0.44468	insignificant	non-seasonal	0.00574	-0.01064	0.02210	21%	0.0359
		Short-term	8.8	51	2.485	0.01294	increasing	non-seasonal	0.03697	0.00863	0.06927	111%	0.1557
N75	Blue-green algal biovolume	Long-term	23.0	145	-0.761	0.44641	insignificant	seasonal	-0.00951	-0.04267	0.01529	-40%	-0.0003
		Historical	14.3	94	-0.587	0.55741	insignificant	seasonal	-0.01583	-0.08714	0.03869	-41%	-0.0005
		Short-term	8.8	51	0.411	0.68084	insignificant	seasonal	0.01855	-0.11354	0.18150	45%	0.0012
N75	Total nitrogen	Long-term	25.0	295	-2.096	0.03612	decreasing	seasonal	-0.00427	-0.00807	-0.00024	-22%	-0.0133
		Historical	16.3	190	7.111	0.00000	increasing	seasonal	0.02129	0.01595	0.02706	122%	0.1140
		Short-term	8.8	105	7.171	0.00000	increasing	seasonal	0.04563	0.03624	0.05556	151%	0.1527
N75	Dissolved inorganic nitrogen	Long-term	25.0	295	-1.887	0.05910	insignificant	seasonal	-0.00492	-0.01008	0.00024	-25%	-0.0113
		Historical	16.3	190	7.002	0.00000	increasing	seasonal	0.02465	0.01769	0.03164	152%	0.1069
		Short-term	8.8	105	7.253	0.00000	increasing	seasonal	0.07840	0.06023	0.09448	386%	0.2235
N75	Total phosphorus	Long-term	25.0	295	-2.893	0.00382	decreasing	non-seasonal	-0.00425	-0.00704	-0.00141	-22%	-0.0002
		Historical	16.8	196	3.364	0.00077	increasing	seasonal	0.01016	0.00433	0.01647	48%	0.0006
		Short-term	8.3	99	-2.297	0.02160	decreasing	seasonal	-0.01047	-0.02007	-0.00189	-18%	-0.0004
N75	Filterable total phosphorus	Long-term	25.0	294	-0.355	0.72261	insignificant	non-seasonal	-0.00063	-0.00419	0.00292	-4%	0.0000
		Historical	16.8	195	6.087	0.00000	increasing	non-seasonal	0.02171	0.01502	0.02854	131%	0.0004
		Short-term	8.3	99	0.617	0.53742	insignificant	non-seasonal	0.00350	-0.00935	0.01672	7%	0.0001
N75	Conductivity	Long-term	25.0	290	-1.131	0.25821	insignificant	non-seasonal	-0.00112	-0.00316	0.00089	-6%	-1.0963
		Historical	16.3	185	6.715	0.00000	increasing	non-seasonal	0.01334	0.00965	0.01724	65%	17.4175
		Short-term	8.8	105	-2.196	0.02811	decreasing	non-seasonal	-0.00867	-0.01669	-0.00070	-16%	-10.8003

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N75	pH	Long-term	25.0	290	0.608	0.54296	insignificant	non-seasonal	0.00177	-0.00421	0.00753	1%	
		Historical	16.3	185	4.376	0.00001	increasing	seasonal	0.02737	0.01538	0.03867	6%	
		Short-term	8.8	105	-4.25	0.00002	decreasing	seasonal	-0.04198	-0.06066	-0.02310	-5%	
N75	Dissolved oxygen	Long-term	25.0	290	1.043	0.29716	insignificant	seasonal	0.00045	-0.00042	0.00135	3%	0.0090
	DO saturation	Long-term	21.0	242	-0.262	0.79319	insignificant	non-seasonal	-0.00016	-0.00119	0.00088	-1%	-0.0358
	Temperature	Long-term	25.0	290	2.118	0.03420	increasing	seasonal	0.00097	0.00008	0.00180		0.0434
	Turbidity	Long-term	25.0	289	-3.974	0.00007	decreasing	non-seasonal	-0.00785	-0.01176	-0.00432	-36%	-0.0791
N67	Chlorophyll-*a*	Long-term	25.0	224	-1.591	0.11164	insignificant	seasonal	-0.00358	-0.00794	0.00091	-19%	-0.0517
		Historical	19.0	152	-0.011	0.99110	insignificant	non-seasonal	-0.00006	-0.00852	0.00827	0%	-0.0010
		Short-term	6.0	72	-3.413	0.00064	decreasing	seasonal	-0.05296	-0.08175	-0.02497	-52%	-0.7680
N67	Total nitrogen	Long-term	25.0	223	-1.053	0.29248	insignificant	seasonal	-0.00141	-0.00401	0.00110	-8%	-0.0025
		Historical	19.0	151	-2.180	0.02929	decreasing	seasonal	-0.00526	-0.00937	-0.00045	-21%	-0.0087
		Short-term	6.0	72	4.322	0.00002	increasing	non-seasonal	0.03980	0.02352	0.05546	73%	0.0807
N67	Dissolved inorganic nitrogen	Long-term	25.0	223	-0.206	0.83659	insignificant	seasonal	-0.00043	-0.00512	0.00407	-2%	-0.0004
		Historical	19.0	151	-2.007	0.04474	decreasing	seasonal	-0.00993	-0.01909	-0.00019	-35%	-0.0070
		Short-term	6.0	72	5.011	0.00000	increasing	seasonal	0.07084	0.04724	0.09215	166%	0.0808
N67	Total phosphorus	Long-term	25.0	223	-1.268	0.20487	insignificant	non-seasonal	-0.00161	-0.00409	0.00092	-9%	-0.0001
		Historical	19.0	151	0.679	0.49716	insignificant	non-seasonal	0.00162	-0.00307	0.00618	7%	0.0001
		Short-term	6.0	72	-0.857	0.39146	insignificant	seasonal	-0.00655	-0.02343	0.00839	-9%	-0.0006
N67	Filterable total phosphorus	Long-term	25.0	223	-0.569	0.56918	insignificant	non-seasonal	-0.00131	-0.00527	0.00316	-7%	0.0000
		Historical	19.0	151	2.008	0.04465	increasing	non-seasonal	0.00815	0.00015	0.01685	43%	0.0001
		Short-term	6.0	72	-1.259	0.20801	insignificant	non-seasonal	-0.00949	-0.02549	0.00638	-12%	-0.0002
N67	Conductivity	Long-term	25.0	221	-0.891	0.37295	insignificant	non-seasonal	-0.00094	-0.00290	0.00110	-5%	-1.0935
		Historical	19.0	149	1.265	0.20571	insignificant	non-seasonal	0.00260	-0.00151	0.00633	12%	3.2938
		Short-term	6.0	72	1.91	0.05607	insignificant	non-seasonal	0.01283	-0.00016	0.02865	19%	7.9453
N67	pH	Long-term	25.0	221	-1.495	0.13485	insignificant	non-seasonal	-0.00413	-0.00914	0.00119	-1%	
		Historical	19.0	149	2.237	0.02526	increasing	seasonal	0.01030	0.00147	0.01932	3%	
		Short-term	6.0	72	-6.344	0.00000	decreasing	non-seasonal	-0.10458	-0.13649	-0.07637	-8%	

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N67	Dissolved oxygen	Long-term	25.0	221	-0.409	0.68218	insignificant	seasonal	-0.00019	-0.00137	0.00095	-1%	-0.0036
	DO saturation	Long-term	21.0	173	-1.648	0.09944	insignificant	non-seasonal	-0.00117	-0.00252	0.00022	-6%	-0.2320
	Temperature	Long-term	25.0	221	1.201	0.22961	insignificant	seasonal	0.00064	-0.00036	0.00169		0.0296
	Turbidity	Long-term	25.0	221	-2.110	0.03482	decreasing	non-seasonal	-0.00351	-0.00700	-0.00028	-18%	-0.0485
N57	Chlorophyll-*a*	Long-term	25.0	298	4.687	0.00000	increasing	non-seasonal	0.00980	0.00574	0.01396	76%	0.0894
		Historical	19.0	226	0.044	0.96490	insignificant	non-seasonal	0.00011	-0.00590	0.00623	0%	0.0008
		Short-term	6.0	72	-1.699	0.08924	insignificant	seasonal	-0.02180	-0.05457	0.00402	-26%	-0.3175
N57	Total algal biovolume	Long-term	25.0	133	5.421	0.00000	increasing	seasonal	0.02437	0.01666	0.03364	307%	0.0647
		Historical	19.0	88	2.382	0.01720	increasing	non-seasonal	0.02686	0.00473	0.04944	224%	0.0621
		Short-term	6.0	45	-0.555	0.57856	insignificant	seasonal	-0.01435	-0.07280	0.03686	-18%	-0.0526
N57	Blue-green algal biovolume	Long-term	25.0	133	1.543	0.12281	insignificant	seasonal	0.01592	-0.00323	0.03670	150%	0.0004
		Historical	19.0	88	2.541	0.01106	increasing	non-seasonal	0.06711	0.01838	0.12622	1787%	0.0055
		Short-term	6.0	45	-0.667	0.50504	insignificant	seasonal	-0.06715	-0.19707	0.10976	-60%	-0.0080
N57	Total nitrogen	Long-term	25.0	298	0.996	0.31924	insignificant	seasonal	0.00103	-0.00112	0.00316	6%	0.0010
		Historical	19.0	226	-2.005	0.04498	decreasing	seasonal	-0.00381	-0.00711	-0.00010	-15%	-0.0034
		Short-term	6.0	72	2.484	0.01300	increasing	seasonal	0.01724	0.00454	0.03048	27%	0.0207
N57	Dissolved inorganic nitrogen	Long-term	25.0	298	-0.725	0.46855	insignificant	seasonal	-0.00243	-0.00875	0.00370	-13%	-0.0010
		Historical	19.0	226	-3.040	0.00236	decreasing	seasonal	-0.01573	-0.02564	-0.00574	-50%	-0.0048
		Short-term	6.0	72	2.251	0.02436	increasing	seasonal	0.04742	0.00520	0.08364	93%	0.0231
N57	Total phosphorus	Long-term	25.0	298	2.098	0.03590	increasing	seasonal	0.00264	0.00014	0.00507	16%	0.0001
		Historical	19.0	226	0.439	0.66080	insignificant	seasonal	0.00077	-0.00268	0.00455	3%	0.0000
		Short-term	6.0	72	-2.270	0.02320	decreasing	non-seasonal	-0.02138	-0.03814	-0.00328	-26%	-0.0009
N57	Filterable total phosphorus	Long-term	25.0	298	2.079	0.03761	increasing	non-seasonal	0.00332	0.00019	0.00670	21%	0.0000
		Historical	19.0	226	1.926	0.05410	insignificant	seasonal	0.00534	-0.00011	0.01091	26%	0.0000
		Short-term	6.0	72	-2.173	0.02978	decreasing	non-seasonal	-0.01940	-0.03512	-0.00209	-24%	-0.0003
N57	Conductivity	Long-term	25.0	298	0.033	0.97401	insignificant	non-seasonal	0.00003	-0.00168	0.00163	0%	0.0173
		Historical	19.0	226	1.621	0.10499	insignificant	non-seasonal	0.00214	-0.00052	0.00485	10%	1.5367
		Short-term	6.0	72	1.525	0.12723	insignificant	seasonal	0.00964	-0.00172	0.01993	14%	5.0650

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N57	pH	Long-term	25.0	298	1.42	0.15557	insignificant	seasonal	0.00523	-0.00206	0.01211	2%	
		Historical	19.0	226	4.601	0.00000	increasing	seasonal	0.02730	0.01573	0.03844	6%	
		Short-term	6.0	72	-2.873	0.00407	decreasing	non-seasonal	-0.07437	-0.11843	-0.02542	-6%	
N57	Dissolved oxygen	Long-term	25.0	298	1.420	0.15557	insignificant	seasonal	0.00086	-0.00030	0.00204	5%	0.0174
	DO saturation	Long-term	21.0	250	1.282	0.19990	insignificant	non-seasonal	0.00090	-0.00051	0.00224	4%	0.1953
	Temperature	Long-term	25.0	298	0.680	0.49673	insignificant	seasonal	0.00028	-0.00055	0.00106		0.0130
	Turbidity	Long-term	25.0	298	-1.678	0.09341	insignificant	non-seasonal	-0.00314	-0.00728	0.00058	-17%	-0.0207
N51	Chlorophyll-*a*	Long-term	9.0	106	1.929	0.05379	insignificant	seasonal	0.01754	-0.00041	0.03857	44%	0.2048
		Historical	3.0	36	.	.	insignificant	non-seasonal	0.00466	.	.	3%	0.0458
		Short-term	6.0	70	-3.526	0.00042	decreasing	seasonal	-0.05739	-0.08976	-0.02549	-55%	-0.5518
N51	Total nitrogen	Long-term	9.0	106	1.636	0.10193	insignificant	seasonal	0.00837	-0.00175	0.01657	19%	0.0140
		Historical	3.0	36	-2.782	0.00540	decreasing	seasonal	-0.08387	-0.12242	-0.01310	-44%	-0.0978
		Short-term	6.0	70	3.798	0.00015	increasing	seasonal	0.03147	0.01571	0.04352	55%	0.0400
N51	Dissolved inorganic nitrogen	Long-term	9.0	106	0.789	0.42993	insignificant	seasonal	0.00899	-0.01313	0.03136	20%	0.0081
		Historical	3.0	36	-2.616	0.00890	decreasing	seasonal	-0.17358	-0.28876	-0.04728	-70%	-0.0832
		Short-term	6.0	70	3.647	0.00027	increasing	seasonal	0.06726	0.03171	0.09883	153%	0.0363
N51	Total phosphorus	Long-term	9.0	106	-0.863	0.38832	insignificant	non-seasonal	-0.00459	-0.01415	0.00575	-9%	-0.0002
		Historical	3.0	36	.	.	insignificant	non-seasonal	0.02247	.	.	17%	0.0012
		Short-term	6.0	70	-3.559	0.00037	decreasing	non-seasonal	-0.02986	-0.04430	-0.01327	-34%	-0.0014
N51	Filterable total phosphorus	Long-term	9.0	106	-2.998	0.00272	decreasing	non-seasonal	-0.01842	-0.03080	-0.00646	-32%	-0.0004
		Historical	3.0	36	-0.208	0.83553	insignificant	seasonal	-0.00334	-0.05702	0.05938	-2%	-0.0001
		Short-term	6.0	70	-0.477	0.63368	insignificant	non-seasonal	-0.00519	-0.02514	0.01612	-7%	-0.0001
N51	Conductivity	Long-term	9.0	106	-1.671	0.09477	insignificant	non-seasonal	-0.00840	-0.01772	0.00139	-16%	-7.0693
		Historical	3.0	36	.	.	decreasing	non-seasonal	-0.10471	.	.	-51%	-68.3460
		Short-term	6.0	70	3.721	0.00020	increasing	non-seasonal	0.02436	0.01239	0.03514	40%	13.4382
N51	pH	Long-term	9.0	106	-3.38	0.00073	decreasing	non-seasonal	-0.03739	-0.05880	-0.01684	-4%	
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.03959	.	.	-2%	
		Short-term	6.0	70	-0.872	0.38322	insignificant	non-seasonal	-0.01708	-0.05107	0.01944	-1%	

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N51	Dissolved oxygen	Long-term	9.0	106	-1.554	0.12014	insignificant	seasonal	-0.00263	-0.00635	0.00088	-5%	-0.0547
	DO saturation	Long-term	9.0	106	0.158	0.87419	insignificant	non-seasonal	0.00042	-0.00293	0.00408	1%	0.0971
	Temperature	Long-term	9.0	106	4.288	0.00002	increasing	seasonal	0.00806	0.00522	0.01155		0.3893
	Turbidity	Long-term	9.0	106	2.932	0.00337	increasing	non-seasonal	0.02816	0.00941	0.04687	79%	0.2735
N48	Chlorophyll-*a*	Long-term	25.0	289	1.138	0.25498	insignificant	non-seasonal	0.00295	-0.00218	0.00780	19%	0.0946
		Historical	19.0	221	-2.909	0.00362	decreasing	seasonal	-0.01086	-0.01879	-0.00377	-38%	-0.2541
		Short-term	6.0	68	-1.487	0.13690	insignificant	non-seasonal	-0.02208	-0.05029	0.00815	-26%	-0.3599
N48	Total nitrogen	Long-term	25.0	289	-6.174	0.00000	decreasing	seasonal	-0.00795	-0.01036	-0.00559	-37%	-0.0134
		Historical	19.0	221	-4.865	0.00000	decreasing	seasonal	-0.00981	-0.01361	-0.00596	-35%	-0.0167
		Short-term	6.0	68	3.984	0.00007	increasing	seasonal	0.03177	0.02001	0.04443	55%	0.0424
N48	Dissolved inorganic nitrogen	Long-term	25.0	289	-6.647	0.00000	decreasing	seasonal	-0.01796	-0.02319	-0.01277	-64%	-0.0125
		Historical	19.0	221	-4.908	0.00000	decreasing	seasonal	-0.01863	-0.02684	-0.01112	-56%	-0.0143
		Short-term	6.0	68	3.480	0.00050	increasing	seasonal	0.06860	0.03380	0.10508	158%	0.0377
N48	Total phosphorus	Long-term	25.0	289	-10.19	0.00000	decreasing	seasonal	-0.01707	-0.02017	-0.01387	-63%	-0.0019
		Historical	19.0	221	-10.62	0.00000	decreasing	non-seasonal	-0.02743	-0.03159	-0.02344	-70%	-0.0028
		Short-term	6.0	68	-2.157	0.03099	decreasing	seasonal	-0.01650	-0.02942	-0.00209	-20%	-0.0009
N48	Filterable total phosphorus	Long-term	25.0	289	-11.95	0.00000	decreasing	seasonal	-0.02550	-0.02869	-0.02215	-77%	-0.0013
		Historical	19.0	221	-10.37	0.00000	decreasing	seasonal	-0.03427	-0.03924	-0.02880	-78%	-0.0017
		Short-term	6.0	68	-0.132	0.89472	insignificant	non-seasonal	-0.00169	-0.02189	0.02100	-2%	0.0000
N48	Conductivity	Long-term	25.0	286	-2.076	0.03788	decreasing	non-seasonal	-0.00175	-0.00330	-0.00010	-10%	-1.3399
		Historical	19.0	218	2.398	0.01647	increasing	non-seasonal	0.00296	0.00056	0.00521	14%	2.5409
		Short-term	6.0	68	2.504	0.01229	increasing	non-seasonal	0.01671	0.00383	0.02850	26%	9.3109
N48	pH	Long-term	25.0	286	-0.375	0.70754	insignificant	seasonal	-0.00181	-0.01021	0.00679	-1%	
		Historical	19.0	218	1.395	0.16311	insignificant	seasonal	0.01018	-0.00440	0.02365	2%	
		Short-term	6.0	68	-1.36	0.17370	insignificant	non-seasonal	-0.03018	-0.06911	0.01431	-2%	
N48	Dissolved oxygen	Long-term	25.0	286	0.752	0.45195	insignificant	seasonal	0.00041	-0.00066	0.00137	2%	0.0088
	DO saturation	Long-term	21.0	238	0.515	0.60671	insignificant	non-seasonal	0.00029	-0.00078	0.00136	1%	0.0663
	Temperature	Long-term	25.0	286	2.452	0.01419	increasing	seasonal	0.00103	0.00021	0.00184		0.0473

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
	Turbidity	Long-term	25.0	286	-1.652	0.09858	insignificant	non-seasonal	-0.00305	-0.00688	0.00055	-16%	-0.0301
N464	Chlorophyll-a	Long-term	25.0	220	-5.02	0	decreasing	non-seasonal	-0.01766	-0.02454	-0.01113	-64%	-0.3974
		Historical	18.4	196	-6.625	0.00000	decreasing	non-seasonal	-0.02858	-0.03643	-0.02140	-70%	-0.5937
		Short-term	6.0	24	Insufficient data								
N464	Total algal biovolume	Long-term	21.0	47	2.128	0.03337	increasing	non-seasonal	0.01128	0.001056	0.021013	73%	0.0459
		Historical	14.4	33	.	.	insignificant	non-seasonal	0.00541	.	.	20%	0.0181
		Short-term	6.0	14	Insufficient data								
N464	Blue-green algal biovolume	Long-term	21.0	47	-0.618	0.53652	insignificant	seasonal	-0.01226	-0.04043	0.022171	-45%	-0.0014
		Historical	14.4	33	-0.334	0.73866	insignificant	seasonal	-0.01213	-0.09555	0.08847	-33%	-0.0015
		Short-term	6.0	14	Insufficient data								
N464	Total nitrogen	Long-term	25.0	220	0.295	0.7677	insignificant	seasonal	0.00050	-0.00277	0.004074	3%	0.0022
		Historical	18.4	196	3.770	0.00016	increasing	seasonal	0.00709	0.00337	0.01093	35%	0.0367
		Short-term	6.0	24	Insufficient data								
N464	Dissolved inorganic nitrogen	Long-term	25.0	220	1.417	0.15656	insignificant	seasonal	0.00341	-0.00133	0.007883	22%	0.0119
		Historical	18.4	196	4.953	0.00000	increasing	seasonal	0.01201	0.00704	0.01660	66%	0.0493
		Short-term	6.0	24	Insufficient data								
N464	Total phosphorus	Long-term	25.0	220	-4.496	0.00001	decreasing	seasonal	-0.01116	-0.01544	-0.00638	-47%	-0.0020
		Historical	18.4	196	-1.216	0.22415	insignificant	seasonal	-0.00307	-0.00872	0.00204	-12%	-0.0007
		Short-term	6.0	24	Insufficient data								
N464	Filterable total phosphorus	Long-term	25.0	195	-6.409	0	decreasing	seasonal	-0.02202	-0.0274	-0.01593	-72%	-0.0015
		Historical	18.4	171	-3.272	0.00107	decreasing	seasonal	-0.01248	-0.02045	-0.00482	-41%	-0.0012
		Short-term	6.0	24	Insufficient data								
N464	Conductivity	Long-term	25.0	219	1.445	0.14854	insignificant	non-seasonal	0.00118	-0.00042	0.002907	7%	1.0289
		Historical	18.4	195	3.578	0.00035	increasing	non-seasonal	0.00378	0.00176	0.00586	17%	3.4647
		Short-term	6.0	24	Insufficient data								
N464	pH	Long-term	25.0	219	0.658	0.51051	insignificant	seasonal	0.00361	-0.0066	0.012976	1%	
		Historical	18.4	195	1.496	0.13453	insignificant	seasonal	0.01109	-0.00395	0.02557	3%	
		Short-term	6.0	24	Insufficient data								
N464	Dissolved oxygen	Long-term	25.0	219	0.79	0.42941	insignificant	seasonal	0.00069	-0.00112	0.002503	4%	0.0142

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
	DO saturation	Long-term	21.0	190	1.13	0.2586	insignificant	seasonal	0.00091	-0.00064	0.002512	5%	0.2000
	Temperature	Long-term	25.0	219	2.299	0.0215	increasing	seasonal	0.00124	0.000171	0.002207		0.0574
	Turbidity	Long-term	25.0	214	-3.391	0.0007	decreasing	seasonal	-0.00783	-0.01209	-0.00312	-36%	-0.0650
N44	Chlorophyll-a	Long-term	25.0	222	-0.076	0.93947	insignificant	non-seasonal	-0.00018	-0.00495	0.00474	-1%	-0.0050
		Historical	19.0	150	-6.874	0.00000	decreasing	non-seasonal	-0.02388	-0.03023	-0.01748	-65%	-0.4175
		Short-term	6.0	72	-2.803	0.00506	decreasing	seasonal	-0.06459	-0.09217	-0.02114	-59%	-0.8458
N44	Total nitrogen	Long-term	25.0	221	-3.582	0.00034	decreasing	seasonal	-0.00349	-0.00545	-0.00174	-18%	-0.0070
		Historical	19.0	149	-0.054	0.95710	insignificant	seasonal	-0.00009	-0.00356	0.00376	0%	-0.0002
		Short-term	6.0	72	2.571	0.01014	increasing	seasonal	0.01694	0.00524	0.02948	26%	0.0253
N44	Dissolved inorganic nitrogen	Long-term	25.0	221	-3.571	0.00036	decreasing	seasonal	-0.00669	-0.01021	-0.00307	-32%	-0.0070
		Historical	19.0	149	1.814	0.06965	insignificant	seasonal	0.00558	-0.00024	0.01173	28%	0.0080
		Short-term	6.0	72	2.513	0.01198	increasing	seasonal	0.03320	0.00800	0.05920	58%	0.0246
N44	Total phosphorus	Long-term	25.0	221	-5.369	0.00000	decreasing	seasonal	-0.00672	-0.00920	-0.00452	-32%	-0.0006
		Historical	19.0	149	-7.408	0.00000	decreasing	seasonal	-0.01502	-0.01854	-0.01186	-48%	-0.0011
		Short-term	6.0	72	-3.145	0.00166	decreasing	non-seasonal	-0.03452	-0.05220	-0.01367	-38%	-0.0018
N44	Filterable total phosphorus	Long-term	25.0	221	-6.352	0.00000	decreasing	seasonal	-0.01071	-0.01366	-0.00762	-46%	-0.0003
		Historical	19.0	149	-1.257	0.20886	insignificant	seasonal	-0.00293	-0.00794	0.00216	-12%	-0.0001
		Short-term	6.0	72	-3.563	0.00037	decreasing	non-seasonal	-0.03205	-0.04976	-0.01544	-36%	-0.0006
N44	Conductivity	Long-term	25.0	219	-1.806	0.07087	insignificant	non-seasonal	-0.00139	-0.00291	0.00010	-8%	-1.0875
		Historical	19.0	147	0.804	0.42145	insignificant	non-seasonal	0.00109	-0.00180	0.00413	5%	0.9048
		Short-term	6.0	72	2.231	0.02566	increasing	non-seasonal	0.01242	0.00144	0.02368	19%	6.9181
N44	pH	Long-term	25.0	220	2.645	0.00816	increasing	non-seasonal	0.00877	0.00242	0.01461	3%	
		Historical	19.0	148	2.993	0.00277	increasing	non-seasonal	0.01920	0.00730	0.03048	5%	
		Short-term	6.0	72	-1.92	0.05483	insignificant	non-seasonal	-0.04167	-0.07940	0.00092	-3%	
N44	Dissolved oxygen	Long-term	25.0	219	3.083	0.00205	increasing	seasonal	0.00182	0.00070	0.00293	11%	0.0334
	DO saturation	Long-term	21.0	171	1.976	0.04812	increasing	seasonal	0.00113	0.00003	0.00237	6%	0.2319
	Temperature	Long-term	25.0	219	3.342	0.00083	increasing	seasonal	0.00131	0.00057	0.00212		0.0596
	Turbidity	Long-term	25.0	219	-2.653	0.00797	decreasing	non-seasonal	-0.00497	-0.00864	-0.00132	-25%	-0.0526

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N42	Chlorophyll-a	Long-term	25.0	300	0.123	0.90237	insignificant	non-seasonal	0.00031	-0.00417	0.00481	2%	0.0090
		Historical	19.0	228	-7.111	0.00000	decreasing	non-seasonal	-0.01967	-0.02482	-0.01453	-58%	-0.3854
		Short-term	6.0	72	-1.99	0.04660	decreasing	seasonal	-0.03075	-0.06556	-0.00041	-35%	-0.4773
N42	Total algal biovolume	Long-term	25.0	299	1.955	0.05056	insignificant	non-seasonal	0.00661	-0.00002	0.01323	46%	0.0249
		Historical	19.0	227	-6.141	0.00000	decreasing	non-seasonal	-0.02367	-0.03070	-0.01651	-65%	-0.0456
		Short-term	6.0	72	-0.566	0.57108	insignificant	seasonal	-0.01493	-0.06400	0.03649	-19%	-0.0306
N42	Blue-green algal biovolume	Long-term	25.0	299	1.202	0.22934	insignificant	seasonal	0.00754	-0.00484	0.01996	54%	0.0006
		Historical	19.0	227	-4.513	0.00001	decreasing	seasonal	-0.03728	-0.05255	-0.02117	-80%	-0.0012
		Short-term	6.0	72	-0.508	0.61119	insignificant	seasonal	-0.02393	-0.15536	0.08428	-28%	-0.0026
N42	Total nitrogen	Long-term	25.0	298	-4.153	0.00003	decreasing	seasonal	-0.00356	-0.00515	-0.00190	-19%	-0.0060
		Historical	19.0	226	-5.137	0.00000	decreasing	seasonal	-0.00688	-0.00937	-0.00435	-26%	-0.0111
		Short-term	6.0	72	2.455	0.01410	increasing	seasonal	0.01285	0.00223	0.02296	19%	0.0159
N42	Dissolved inorganic nitrogen	Long-term	25.0	298	-3.138	0.00170	decreasing	seasonal	-0.00545	-0.00893	-0.00219	-27%	-0.0044
		Historical	19.0	226	-0.428	0.66843	insignificant	seasonal	-0.00133	-0.00643	0.00409	-6%	-0.0012
		Short-term	6.0	72	2.629	0.00856	increasing	seasonal	0.03166	0.00948	0.05306	55%	0.0184
N42	Total phosphorus	Long-term	25.0	298	-5.366	0.00000	decreasing	seasonal	-0.00747	-0.01009	-0.00489	-35%	-0.0005
		Historical	19.0	226	-10.44	0.00000	decreasing	seasonal	-0.01929	-0.02233	-0.01633	-57%	-0.0010
		Short-term	6.0	72	-2.620	0.00879	decreasing	non-seasonal	-0.02850	-0.04506	-0.00885	-33%	-0.0013
N42	Filterable total phosphorus	Long-term	25.0	298	-6.051	0.00000	decreasing	seasonal	-0.00803	-0.01030	-0.00564	-37%	-0.0001
		Historical	19.0	226	-5.599	0.00000	decreasing	seasonal	-0.01132	-0.01476	-0.00779	-39%	-0.0002
		Short-term	6.0	72	-2.270	0.02320	decreasing	non-seasonal	-0.01950	-0.03953	-0.00309	-24%	-0.0003
N42	Conductivity	Long-term	25.0	298	1.494	0.13521	insignificant	non-seasonal	0.00100	-0.00032	0.00228	6%	0.5928
		Historical	19.0	226	1.966	0.04928	increasing	non-seasonal	0.00215	0.00001	0.00427	10%	1.3027
		Short-term	6.0	72	3.904	0.00009	increasing	non-seasonal	0.01809	0.00922	0.02711	28%	8.5150
N42	pH	Long-term	25.0	298	-0.86	0.38955	insignificant	seasonal	-0.00262	-0.00843	0.00344	-1%	
		Historical	19.0	226	1.942	0.05216	insignificant	seasonal	0.00970	-0.00014	0.01925	2%	
		Short-term	6.0	72	-3.427	0.00061	decreasing	non-seasonal	-0.06038	-0.09683	-0.02861	-5%	
N42	Dissolved oxygen	Long-term	25.0	298	1.079	0.28039	insignificant	seasonal	0.00040	-0.00036	0.00137	2%	0.0080

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
	DO saturation	Long-term	21.0	250	-0.929	0.35277	insignificant	non-seasonal	-0.00043	-0.00129	0.00047	-2%	-0.0917
	Temperature	Long-term	25.0	300	0.996	0.31902	insignificant	seasonal	0.00040	-0.00041	0.00125		0.0181
	Turbidity	Long-term	25.0	298	-1.307	0.1914	insignificant	non-seasonal	-0.00253	-0.00652	0.00133	14%	-0.0253
N39	Chlorophyll-a	Long-term	21.5	249	0.736	0.46165	insignificant	non-seasonal	0.00212	-0.00372	0.00842	11%	0.0403
		Historical	15.5	177	-4.211	0.00003	decreasing	non-seasonal	-0.01770	-0.02567	-0.00971	-47%	-0.2361
		Short-term	6.0	72	-1.794	0.07285	insignificant	non-seasonal	-0.03598	-0.08538	0.00315	-39%	-0.4761
N39	Total nitrogen	Long-term	21.5	249	-2.707	0.00678	decreasing	seasonal	-0.00323	-0.00574	-0.00095	-15%	-0.0047
		Historical	15.5	177	-4.022	0.00006	decreasing	seasonal	-0.00854	-0.01255	-0.00451	-26%	-0.0116
		Short-term	6.0	72	2.455	0.01410	increasing	seasonal	0.01481	0.00351	0.02420	23%	0.0189
N39	Dissolved inorganic nitrogen	Long-term	21.5	249	-3.448	0.00056	decreasing	seasonal	-0.00917	-0.01402	-0.00424	-37%	-0.0060
		Historical	15.5	177	-2.516	0.01186	decreasing	seasonal	-0.01123	-0.01997	-0.00296	-33%	-0.0075
		Short-term	6.0	72	1.554	0.12015	insignificant	seasonal	0.02225	-0.00429	0.04332	36%	0.0133
N39	Total phosphorus	Long-term	21.5	249	-2.235	0.02545	decreasing	seasonal	-0.00435	-0.00794	-0.00054	-19%	-0.0002
		Historical	15.5	177	-6.690	0.00000	decreasing	non-seasonal	-0.01847	-0.02347	-0.01368	-48%	-0.0008
		Short-term	6.0	72	-1.162	0.24530	insignificant	non-seasonal	-0.01660	-0.03844	0.00985	-21%	-0.0008
N39	Filterable total phosphorus	Long-term	21.5	249	-3.817	0.00014	decreasing	seasonal	-0.00602	-0.00906	-0.00300	-26%	-0.0001
		Historical	15.5	177	-4.567	0.00000	decreasing	seasonal	-0.01303	-0.01844	-0.00735	-37%	-0.0002
		Short-term	6.0	72	-1.298	0.19430	insignificant	non-seasonal	-0.00908	-0.02399	0.00579	-12%	-0.0002
N39	Conductivity	Long-term	21.5	243	-1.093	0.27450	insignificant	non-seasonal	-0.00118	-0.00310	0.00085	-6%	-0.6978
		Historical	15.5	171	0.192	0.84746	insignificant	non-seasonal	0.00031	-0.00314	0.00399	1%	0.1924
		Short-term	6.0	72	3.165	0.00155	increasing	non-seasonal	0.01796	0.00786	0.02936	28%	8.4735
N39	pH	Long-term	21.5	244	0.466	0.64129	insignificant	seasonal	0.00221	-0.00694	0.01139	1%	
		Historical	15.5	172	4.948	0.00000	increasing	seasonal	0.04215	0.02570	0.05938	9%	
		Short-term	6.0	72	-0.744	0.45702	insignificant	non-seasonal	-0.02360	-0.07527	0.03102	-2%	
N39	Dissolved oxygen	Long-term	21.5	243	1.785	0.07429	insignificant	seasonal	0.00119	-0.00012	0.00252	6%	0.0251
	DO saturation	Long-term	21.0	237	0.866	0.38628	insignificant	non-seasonal	0.00057	-0.00072	0.00188	3%	0.1408
	Temperature	Long-term	21.5	244	0.653	0.51363	insignificant	seasonal	0.00031	-0.00067	0.00137		0.0148
	Turbidity	Long-term	21.5	238	-0.122	0.90276	insignificant	non-seasonal	-0.00039	-0.00626	0.00561	-2%	-0.0074

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
NS04	Chlorophyll-*a*	Long-term	25.0	196	-0.377	0.70619	insignificant	seasonal	-0.00116	-0.00595	0.00446	-6%	-0.0284
		Historical	19.0	124	-2.496	0.01254	decreasing	seasonal	-0.01013	-0.01853	-0.00240	-36%	-0.2071
		Short-term	6.0	72	-1.409	0.15886	insignificant	seasonal	-0.02979	-0.07579	0.01576	-34%	-0.4988
NS04	Total algal biovolume	Long-term	20.5	100	4.506	0.00001	increasing	non-seasonal	0.02678	0.01506	0.03783	254%	0.0477
		Historical	14.5	55	2.396	0.01659	increasing	non-seasonal	0.02762	0.00545	0.04808	152%	0.0402
		Short-term	6.0	45	-0.851	0.39474	insignificant	non-seasonal	-0.02795	-0.11536	0.05270	-32%	-0.0824
NS04	Blue-green algal biovolume	Long-term	20.5	100	-0.628	0.52975	insignificant	non-seasonal	-0.01177	-0.06365	0.02187	-43%	-0.0002
		Historical	14.5	55	-2.933	0.00336	decreasing	non-seasonal	-0.18546	-0.24959	-0.04865	-100%	-0.0006
		Short-term	6.0	45	0.695	0.48734	insignificant	non-seasonal	0.03560	-0.06690	0.20778	64%	0.0006
NS04	Total nitrogen	Long-term	25.0	197	-11.63	0.00000	decreasing	seasonal	-0.02245	-0.02527	-0.01983	-73%	-0.2933
		Historical	19.0	125	-11.47	0.00000	decreasing	seasonal	-0.03694	-0.04105	-0.03297	-80%	-0.4263
		Short-term	6.0	72	0.596	0.55150	insignificant	seasonal	0.00326	-0.00808	0.02107	5%	0.0187
NS04	Dissolved inorganic nitrogen	Long-term	25.0	197	-11.82	0.00000	decreasing	seasonal	-0.02710	-0.03043	-0.02400	-79%	-0.2766
		Historical	19.0	125	-11.33	0.00000	decreasing	seasonal	-0.04265	-0.04780	-0.03781	-85%	-0.3894
		Short-term	6.0	72	1.147	0.25119	insignificant	seasonal	0.01282	-0.00593	0.03258	19%	0.0503
NS04	Total phosphorus	Long-term	25.0	197	-8.346	0.00000	decreasing	non-seasonal	-0.01552	-0.01862	-0.01237	-59%	-0.0093
		Historical	19.0	125	-10.05	0.00000	decreasing	non-seasonal	-0.03003	-0.03468	-0.02551	-73%	-0.0152
		Short-term	6.0	72	0.647	0.51793	insignificant	non-seasonal	0.00771	-0.01702	0.02816	11%	0.0037
NS04	Filterable total phosphorus	Long-term	25.0	196	-9.444	0.00000	decreasing	non-seasonal	-0.02407	-0.02795	-0.02007	-75%	-0.0056
		Historical	19.0	124	-9.890	0.00000	decreasing	non-seasonal	-0.04058	-0.04667	-0.03485	-83%	-0.0081
		Short-term	6.0	72	1.424	0.15435	insignificant	non-seasonal	0.01762	-0.00866	0.04305	28%	0.0039
NS04	Conductivity	Long-term	25.0	159	4.661	0.00000	increasing	seasonal	0.00395	0.00238	0.00547	26%	7.8262
		Historical	19.0	87	2.55	0.01076	increasing	seasonal	0.00309	0.00075	0.00487	14%	5.8390
		Short-term	6.0	72	-1.089	0.27599	insignificant	seasonal	-0.00662	-0.01873	0.00711	-9%	-13.0261
NS04	pH	Long-term	25.0	159	0.613	0.54011	insignificant	seasonal	0.00129	-0.00319	0.00547	0%	
		Historical	19.0	87	3.902	0.00010	increasing	seasonal	0.01393	0.00746	0.02237	4%	
		Short-term	6.0	72	-3.646	0.00027	decreasing	seasonal	-0.04008	-0.06452	-0.01914	-3%	
NS04	Dissolved oxygen	Long-term	25.0	159	2.912	0.00359	increasing	seasonal	0.00289	0.00100	0.00478	18%	0.0324

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
	DO saturation	Long-term	17.0	120	-0.494	0.62165	insignificant	seasonal	-0.00076	-0.00377	0.00271	-3%	-0.1103
	Temperature	Long-term	25.0	159	0.284	0.77631	insignificant	seasonal	0.00015	-0.00089	0.00118		0.0067
	Turbidity	Long-term	25.0	159	-2.335	0.01953	decreasing	seasonal	-0.00591	-0.01043	-0.00145	-29%	-1.5719
N35	Chlorophyll-*a*	Long-term	25.0	292	-0.763	0.44536	insignificant	seasonal	-0.00144	-0.00490	0.00235	-8%	-0.0896
		Historical	19.0	221	-4.126	0.00004	decreasing	seasonal	-0.01130	-0.01672	-0.00580	-39%	-0.5789
		Short-term	6.0	71	-0.578	0.56329	insignificant	seasonal	-0.01192	-0.03494	0.02377	-15%	-0.2792
N35	Total algal biovolume	Long-term	25.0	192	6.97	0.00000	increasing	non-seasonal	0.02778	0.02076	0.03497	395%	0.1296
		Historical	19.0	130	1.892	0.05852	insignificant	non-seasonal	0.01203	-0.00034	0.02243	69%	0.0299
		Short-term	6.0	62	1.105	0.26895	insignificant	non-seasonal	0.02579	-0.02818	0.08059	43%	0.1372
N35	Blue-green algal biovolume	Long-term	25.0	192	-0.066	0.94718	insignificant	seasonal	-0.00063	-0.01767	0.01481	-4%	-0.0007
		Historical	19.0	130	-1.222	0.22182	insignificant	seasonal	-0.01792	-0.04708	0.01121	-54%	-0.0151
		Short-term	6.0	62	-1.156	0.24757	insignificant	seasonal	-0.06287	-0.18762	0.03491	-58%	-0.0032
N35	Total nitrogen	Long-term	25.0	292	-12.73	0.00000	decreasing	seasonal	-0.01890	-0.02132	-0.01647	-66%	-0.0699
		Historical	19.0	221	-11.72	0.00000	decreasing	seasonal	-0.02575	-0.02903	-0.02273	-68%	-0.0937
		Short-term	6.0	71	1.971	0.04872	increasing	seasonal	0.01597	0.00009	0.03126	25%	0.0305
N35	Dissolved inorganic nitrogen	Long-term	25.0	292	-13.12	0.00000	decreasing	seasonal	-0.03079	-0.03436	-0.02703	-83%	-0.0707
		Historical	19.0	221	-11.51	0.00000	decreasing	seasonal	-0.03713	-0.04232	-0.03187	-80%	-0.0901
		Short-term	6.0	71	1.536	0.12691	insignificant	seasonal	0.02605	-0.00650	0.05641	43%	0.0267
N35	Total phosphorus	Long-term	25.0	292	-8.757	0.00000	decreasing	seasonal	-0.01139	-0.01383	-0.00897	-48%	-0.0017
		Historical	19.0	221	-9.303	0.00000	decreasing	seasonal	-0.01843	-0.02165	-0.01519	-55%	-0.0026
		Short-term	6.0	71	-0.252	0.80109	insignificant	seasonal	-0.00212	-0.01766	0.01221	-3%	-0.0003
N35	Filterable total phosphorus	Long-term	25.0	292	-7.499	0.00000	decreasing	seasonal	-0.01446	-0.01803	-0.01081	-57%	-0.0005
		Historical	19.0	221	-6.734	0.00000	decreasing	seasonal	-0.02047	-0.02603	-0.01500	-59%	-0.0007
		Short-term	6.0	71	0.667	0.50485	insignificant	seasonal	0.00924	-0.01282	0.03209	14%	0.0005
N35	Conductivity	Long-term	25.0	291	-1.201	0.22984	insignificant	non-seasonal	-0.00106	-0.00280	0.00064	-6%	-0.9355
		Historical	19.0	220	1.593	0.11107	insignificant	non-seasonal	0.00202	-0.00055	0.00450	9%	1.9164
		Short-term	6.0	71	0.815	0.41503	insignificant	seasonal	0.00566	-0.00756	0.01809	8%	3.9920
N35	pH	Long-term	25.0	292	-1.136	0.25604	insignificant	seasonal	-0.00264	-0.00743	0.00190	-1%	

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
		Historical	19.0	221	2.023	0.04306	increasing	non-seasonal	0.00745	0.00022	0.01439	2%	
		Short-term	6.0	71	-0.637	0.52397	insignificant	seasonal	-0.01169	-0.04326	0.01634	-1%	
N35	Dissolved oxygen	Long-term	25.0	292	0.226	0.82141	insignificant	seasonal	0.00012	-0.00101	0.00128	1%	0.0020
	DO saturation	Long-term	21.0	248	-2.708	0.00677	decreasing	seasonal	-0.00179	-0.00308	-0.00045	-8%	-0.3590
	Temperature	Long-term	25.0	292	1.867	0.06194	insignificant	seasonal	0.00074	-0.00005	0.00154		0.0342
	Turbidity	Long-term	25.0	285	4.613	0.00000	decreasing	seasonal	-0.00646	-0.00947	-0.00365	-31%	-0.3256
NC11	Chlorophyll-*a*	Long-term	9.0	108	-0.91	0.36261	insignificant	seasonal	-0.01095	-0.03401	0.01171	-20%	-0.2166
		Historical	3.0	36	0	1.00000	insignificant	seasonal	0.00150	-0.14078	0.09711	1%	0.0333
		Short-term	6.0	72	-2.019	0.04349	decreasing	seasonal	-0.03850	-0.08219	-0.00121	-41%	-0.3440
NC11	Total algal biovolume	Long-term	9.0	65	3.367	0.00076	increasing	seasonal	0.04418	0.02173	0.07217	150%	0.1727
		Historical	3.0	23	Insufficient data								
		Short-term	6.0	42	1.562	0.11829	insignificant	seasonal	0.04980	-0.00810	0.11620	99%	0.1442
NC11	Blue-green algal biovolume	Long-term	9.0	65	0.171	0.86449	insignificant	seasonal	0.00419	-0.09139	0.14320	9%	0.0009
		Historical	3.0	23	Insufficient data								
		Short-term	6.0	42	-0.029	0.97649	insignificant	seasonal	-0.00817	-0.21354	0.24262	-11%	-0.0002
NC11	Total nitrogen	Long-term	9.0	108	1.164	0.24453	insignificant	seasonal	0.00671	-0.00338	0.01810	15%	0.0291
		Historical	3.0	36	-2.782	0.00540	decreasing	seasonal	-0.07858	-0.12871	-0.02873	-42%	-0.2452
		Short-term	6.0	72	-0.131	0.89599	insignificant	seasonal	-0.00074	-0.01784	0.01687	-1%	-0.0025
NC11	Dissolved inorganic nitrogen	Long-term	9.0	108	0.895	0.37101	insignificant	seasonal	0.00735	-0.00647	0.02481	16%	0.0240
		Historical	3.0	36	-3.114	0.00184	decreasing	seasonal	-0.10329	-0.19270	-0.02987	-51%	-0.2228
		Short-term	6.0	72	0.392	0.69493	insignificant	seasonal	0.00668	-0.02058	0.03096	10%	0.0156
NC11	Total phosphorus	Long-term	9.0	108	0.483	0.62916	insignificant	seasonal	0.00221	-0.00593	0.01171	5%	0.0002
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.01592	.	.	-10%	-0.0016
		Short-term	6.0	72	-1.206	0.22799	insignificant	seasonal	-0.00955	-0.02643	0.00780	-12%	-0.0016
NC11	Filterable total phosphorus	Long-term	9.0	108	0.900	0.36813	insignificant	non-seasonal	0.00522	-0.00685	0.01572	11%	0.0002
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.01603	.	.	-10%	-0.0005
		Short-term	6.0	72	0.452	0.65120	insignificant	non-seasonal	0.00565	-0.02395	0.03006	8%	0.0004

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
NC11	Conductivity	Long-term	9.0	108	-0.625	0.53170	insignificant	seasonal	-0.00206	-0.00857	0.00484	-4%	-2.4608
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.00742	.	.	5%	-8.8402
		Short-term	6.0	72	-0.392	0.69493	insignificant	seasonal	-0.00290	-0.01683	0.01038	-4%	-2.7945
NC11	pH	Long-term	9.0	108	-5.391	0.00000	decreasing	seasonal	-0.04177	-0.05454	-0.02952	-5%	
		Historical	3.0	36	0.457	0.64785	insignificant	seasonal	0.04085	-0.05782	0.09686	2%	
		Short-term	6.0	72	-5.04	0.00000	decreasing	seasonal	-0.07277	-0.09587	-0.04721	-6%	
NC11	Dissolved oxygen	Long-term	9.0	108	-1.401	0.16114	insignificant	seasonal	-0.00646	-0.01424	0.00247	-13%	-0.0841
	DO saturation	Long-term	9.0	108	-1.496	0.13459	insignificant	seasonal	-0.00523	-0.01168	0.00190	-10%	-0.7069
	Temperature	Long-term	9.0	108	2.684	0.00728	increasing	seasonal	0.00569	0.00158	0.00991		0.2478
	Turbidity	Long-term	9.0	108	1.962	0.04977	increasing	non-seasonal	0.01538	0.00002	0.02970	38%	0.9356
N3001	Chlorophyll-a	Long-term	23.0	191	-0.774	0.43920	insignificant	seasonal	-0.00173	-0.00659	0.00304	-9%	-0.1318
		Historical	17.0	120	-1.129	0.25890	insignificant	seasonal	-0.00515	-0.01331	0.00366	-18%	-0.3711
		Short-term	6.0	71	-0.923	0.35588	insignificant	non-seasonal	-0.01658	-0.04691	0.01698	-20%	-0.4453
N3001	Total nitrogen	Long-term	23.0	191	-7.712	0.00000	decreasing	seasonal	-0.01148	-0.01461	-0.00883	-46%	-0.0349
		Historical	17.0	120	-6.105	0.00000	decreasing	seasonal	-0.01500	-0.01956	-0.01060	-44%	-0.0460
		Short-term	6.0	71	0.756	0.44977	insignificant	seasonal	0.00635	-0.01243	0.02547	9%	0.0128
N3001	Dissolved inorganic nitrogen	Long-term	23.0	191	-7.894	0.00000	decreasing	seasonal	-0.02136	-0.02617	-0.01607	-68%	-0.0349
		Historical	17.0	120	-6.186	0.00000	decreasing	seasonal	-0.02426	-0.03350	-0.01766	-61%	-0.0427
		Short-term	6.0	71	0.370	0.71102	insignificant	seasonal	0.00734	-0.03025	0.04737	11%	0.0078
N3001	Total phosphorus	Long-term	23.0	190	-5.133	0.00000	decreasing	seasonal	-0.00759	-0.01005	-0.00479	-33%	-0.0010
		Historical	17.0	119	-5.482	0.00000	decreasing	seasonal	-0.01358	-0.01780	-0.00930	-41%	-0.0018
		Short-term	6.0	71	-0.637	0.52397	insignificant	seasonal	-0.00595	-0.02293	0.01286	-8%	-0.0008
N3001	Filterable total phosphorus	Long-term	23.0	190	-5.235	0.00000	decreasing	seasonal	-0.01247	-0.01668	-0.00762	-48%	-0.0005
		Historical	17.0	119	-3.744	0.00018	decreasing	non-seasonal	-0.01695	-0.02452	-0.00902	-49%	-0.0006
		Short-term	6.0	71	0.430	0.66736	insignificant	seasonal	0.00490	-0.01804	0.03088	7%	0.0002
N3001	Conductivity	Long-term	23.0	189	-0.360	0.71867	insignificant	seasonal	-0.00047	-0.00234	0.00163	-2%	-0.4134
		Historical	17.0	118	1.33	0.18338	insignificant	non-seasonal	0.00241	-0.00107	0.00577	10%	2.2426
		Short-term	6.0	71	0.104	0.91738	insignificant	seasonal	0.00131	-0.01290	0.01682	2%	1.0045

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N3001	pH	Long-term	23.0	189	-1.767	0.07725	insignificant	seasonal	-0.00587	-0.01287	0.00076	-2%	
		Historical	17.0	118	0.595	0.55155	insignificant	non-seasonal	0.00370	-0.00855	0.01456	1%	
		Short-term	6.0	71	-1.378	0.16814	insignificant	seasonal	-0.02274	-0.05492	0.01236	-2%	
N3001	Dissolved oxygen	Long-term	23.0	189	-0.182	0.85572	insignificant	seasonal	-0.00013	-0.00137	0.00122	-1%	-0.0025
	DO saturation	Long-term	21.0	165	-2.248	0.02459	decreasing	seasonal	-0.00165	-0.00314	-0.00024	-8%	-0.3499
	Temperature	Long-term	23.0	189	2.227	0.02598	increasing	seasonal	0.00113	0.00009	0.00201		0.0515
	Turbidity	Long-term	23.0	188	-2.351	0.01871	decreasing	seasonal	-0.00423	-0.00787	-0.00057	-20%	-0.2438
N26	Chlorophyll-*a*	Long-term	23.0	271	-2.939	0.00329	decreasing	seasonal	-0.00726	-0.01229	-0.00237	-32%	-0.6511
		Historical	17.0	200	-1.495	0.13495	insignificant	seasonal	-0.00672	-0.01483	0.00191	-23%	-0.6385
		Short-term	6.0	71	-3.534	0.00041	decreasing	non-seasonal	-0.04400	-0.06873	-0.02015	-46%	-1.7391
N26	Total algal biovolume	Long-term	25.0	266	4.04	0.00005	increasing	non-seasonal	0.01299	0.00665	0.01927	111%	0.2665
		Historical	19.0	201	1.241	0.21467	insignificant	non-seasonal	0.00595	-0.00407	0.01634	30%	0.0937
		Short-term	6.0	65	0.493	0.62234	insignificant	non-seasonal	0.00917	-0.02887	0.05203	14%	0.0504
N26	Blue-green algal biovolume	Long-term	25.0	266	-2.166	0.03030	decreasing	seasonal	-0.01368	-0.02647	-0.00140	-55%	-0.1094
		Historical	19.0	201	0.666	0.50537	insignificant	seasonal	0.00658	-0.01221	0.02370	33%	0.0881
		Short-term	6.0	65	-1.262	0.20677	insignificant	non-seasonal	-0.07441	-0.20213	0.04101	-64%	-0.0172
N26	Total nitrogen	Long-term	23.0	271	-7.671	0.00000	decreasing	seasonal	-0.01225	-0.01502	-0.00937	-48%	-0.0248
		Historical	17.0	200	-6.344	0.00000	decreasing	non-seasonal	-0.01552	-0.02011	-0.01118	-46%	-0.0320
		Short-term	6.0	71	-0.020	0.98416	insignificant	non-seasonal	-0.00040	-0.02249	0.02184	-1%	-0.0007
N26	Dissolved inorganic nitrogen	Long-term	23.0	271	-6.076	0.00000	decreasing	seasonal	-0.02706	-0.03543	-0.01865	-76%	-0.0211
		Historical	17.0	200	-5.746	0.00000	decreasing	seasonal	-0.04421	-0.06028	-0.02978	-82%	-0.0309
		Short-term	6.0	71	-0.459	0.64594	insignificant	seasonal	-0.01111	-0.06616	0.04090	-14%	-0.0086
N26	Total phosphorus	Long-term	23.0	271	-5.872	0.00000	decreasing	seasonal	-0.00863	-0.01155	-0.00581	-37%	-0.0010
		Historical	17.0	200	-5.008	0.00000	decreasing	seasonal	-0.01173	-0.01591	-0.00698	-37%	-0.0014
		Short-term	6.0	71	0.044	0.96454	insignificant	seasonal	0.00013	-0.02092	0.02435	0%	0.0000
N26	Filterable total phosphorus	Long-term	23.0	271	-2.874	0.00405	decreasing	non-seasonal	-0.00743	-0.01246	-0.00252	-33%	-0.0003
		Historical	17.0	200	-4.389	0.00001	decreasing	non-seasonal	-0.01818	-0.02582	-0.01043	-51%	-0.0006
		Short-term	6.0	71	1.171	0.24143	insignificant	non-seasonal	0.01658	-0.01284	0.05527	26%	0.0007

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N26	Conductivity	Long-term	23.0	271	-1.112	0.26622	insignificant	seasonal	-0.00145	-0.00378	0.00103	-7%	-1.2038
		Historical	17.0	200	2.491	0.01272	increasing	seasonal	0.00479	0.00102	0.00840	21%	4.5478
		Short-term	6.0	71	0	1.00000	insignificant	seasonal	0.00015	-0.01465	0.01217	0%	0.1044
N26	pH	Long-term	23.0	271	-4.224	0.00002	decreasing	non-seasonal	-0.01948	-0.02838	-0.01084	-6%	
		Historical	17.0	200	-1.973	0.04850	decreasing	non-seasonal	-0.01582	-0.03119	-0.00010	-3%	
		Short-term	6.0	71	-1.526	0.12691	insignificant	seasonal	-0.02748	-0.07452	0.01601	-2%	
N26	Dissolved oxygen	Long-term	23.0	271	-2.318	0.02046	decreasing	seasonal	-0.00163	-0.00293	-0.00023	-8%	-0.0320
	DO saturation	Long-term	19.0	223	-3.182	0.00146	decreasing	seasonal	-0.00221	-0.00366	-0.00077	-9%	-0.4601
	Temperature	Long-term	23.0	271	1.645	0.10003	insignificant	seasonal	0.00084	-0.00014	0.00182		0.0381
	Turbidity	Long-term	18.0	204	0.370	0.71119	insignificant	seasonal	0.00096	-0.00382	0.00592	4%	0.0361
N2202	Chlorophyll-*a*	Long-term	9.0	108	1.037	0.29970	insignificant	seasonal	0.00769	-0.00791	0.02618	17%	0.0194
		Historical	3.0	36	2.035	0.04189	increasing	seasonal	0.08051	0.00225	0.15206	74%	0.2506
		Short-term	6.0	72	-1.322	0.18625	insignificant	seasonal	-0.02187	-0.05513	0.01244	-26%	-0.0447
N2202	Total nitrogen	Long-term	9.0	108	1.277	0.20161	insignificant	non-seasonal	0.00519	-0.00299	0.01415	11%	0.0028
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.02444	.	.	-16%	-0.0113
		Short-term	6.0	72	-0.520	0.60296	insignificant	non-seasonal	-0.00371	-0.01746	0.00996	-5%	-0.0025
N2202	Dissolved inorganic nitrogen	Long-term	9.0	108	-0.594	0.55268	insignificant	seasonal	-0.00574	-0.02495	0.01260	-11%	-0.0011
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.08546	.	.	-45%	-0.0132
		Short-term	6.0	72	-2.832	0.00462	decreasing	seasonal	-0.04202	-0.07393	-0.01375	-44%	-0.0094
N2202	Total phosphorus	Long-term	9.0	108	-0.451	0.65181	insignificant	seasonal	-0.00245	-0.01342	0.00754	-5%	0.0000
		Historical	3.0	36	0.125	0.90087	insignificant	seasonal	0.00571	-0.04169	0.06286	4%	0.0001
		Short-term	6.0	72	1.235	0.21698	insignificant	seasonal	0.01164	-0.00680	0.02687	17%	0.0004
N2202	Filterable total phosphorus	Long-term	9.0	108	-0.610	0.54214	insignificant	seasonal	-0.00405	-0.01452	0.00763	-8%	0.0000
		Historical	3.0	36	.	.	insignificant	non-seasonal	-0.00765	.	.	-5%	-0.0001
		Short-term	6.0	72	0.915	0.36016	insignificant	seasonal	0.01172	-0.01024	0.02927	18%	0.0002
N2202	Conductivity	Long-term	9.0	108	2.127	0.03346	increasing	non-seasonal	0.00982	0.00086	0.01824	23%	2.7972
		Historical	3.0	36	.	.	insignificant	non-seasonal	0.01255	.	.	9%	3.3680
		Short-term	6.0	72	-1.21	0.22611	insignificant	non-seasonal	-0.01011	-0.03107	0.00719	-13%	-2.8873

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N2202	pH	Long-term	9.0	108	-5.613	0.00000	decreasing	seasonal	-0.08028	-0.10817	-0.05619	-10%	
		Historical	3.0	36	0.54	0.58934	insignificant	seasonal	0.05288	-0.09417	0.17637	2%	
		Short-term	6.0	72	-5.187	0.00000	decreasing	non-seasonal	-0.13441	-0.17813	-0.09455	-11%	
N2202	Dissolved oxygen	Long-term	9.0	108	-2.969	0.00299	decreasing	seasonal	-0.00524	-0.00854	-0.00131	-10%	-0.0978
	DO saturation	Long-term	9.0	107	-3.443	0.00058	decreasing	seasonal	-0.00420	-0.00605	-0.00175	-8%	-0.8183
	Temperature	Long-term	9.0	108	2.557	0.01056	increasing	seasonal	0.00681	0.00192	0.01106		0.2973
	Turbidity	Long-term	9.0	108	1.086	0.27756	insignificant	non-seasonal	0.00818	-0.00664	0.02286	18%	0.0962
N18	Chlorophyll-a	Long-term	21.5	253	3.737	0.00019	increasing	non-seasonal	0.01188	0.00586	0.01832	80%	0.5965
		Historical	15.5	182	2.796	0.00517	increasing	non-seasonal	0.01589	0.00485	0.02633	76%	0.7884
		Short-term	6.0	71	-1.976	0.04821	decreasing	non-seasonal	-0.03153	-0.06245	-0.00039	-35%	-0.9903
N18	Total nitrogen	Long-term	21.5	253	-0.468	0.63949	insignificant	seasonal	-0.00076	-0.00386	0.00216	-4%	-0.0008
		Historical	15.5	182	-1.645	0.09992	insignificant	non-seasonal	-0.00390	-0.00853	0.00084	-13%	-0.0041
		Short-term	6.0	71	2.386	0.01704	increasing	seasonal	0.02266	0.00350	0.04200	37%	0.0327
N18	Dissolved inorganic nitrogen	Long-term	21.5	253	-2.826	0.00471	decreasing	seasonal	-0.01174	-0.02011	-0.00349	-44%	-0.0042
		Historical	15.5	182	-2.897	0.00376	decreasing	seasonal	-0.01988	-0.03281	-0.00656	-51%	-0.0067
		Short-term	6.0	71	1.556	0.11970	insignificant	seasonal	0.03756	-0.00816	0.09019	68%	0.0227
N18	Total phosphorus	Long-term	21.5	253	0.459	0.64651	insignificant	non-seasonal	0.00085	-0.00319	0.00491	4%	0.0001
		Historical	15.5	182	-0.494	0.62127	insignificant	non-seasonal	-0.00174	-0.00834	0.00520	-6%	-0.0001
		Short-term	6.0	71	2.839	0.00452	increasing	non-seasonal	0.03442	0.01090	0.05799	61%	0.0034
N18	Filterable total phosphorus	Long-term	21.5	253	2.326	0.02003	increasing	non-seasonal	0.00692	0.00124	0.01312	41%	0.0002
		Historical	15.5	182	0.684	0.49405	insignificant	non-seasonal	0.00364	-0.00644	0.01409	14%	0.0001
		Short-term	6.0	71	2.819	0.00481	increasing	non-seasonal	0.04430	0.01404	0.07996	85%	0.0016
N18	Conductivity	Long-term	21.5	239	-6.550	0.00000	decreasing	non-seasonal	-0.03873	-0.04931	-0.02772	-85%	-133.478
		Historical	15.5	168	-4.059	0.00005	decreasing	non-seasonal	-0.04445	-0.06240	-0.02281	-80%	-172.654
		Short-term	6.0	71	-0.109	0.91304	insignificant	non-seasonal	-0.00522	-0.05962	0.04601	-7%	-4.1431
N18	pH	Long-term	21.5	253	-2.298	0.02158	decreasing	seasonal	-0.00807	-0.01400	-0.00118	-2%	
		Historical	15.5	182	-0.234	0.81526	insignificant	non-seasonal	-0.00130	-0.01216	0.00826	0%	
		Short-term	6.0	71	-2.119	0.03407	decreasing	seasonal	-0.04186	-0.08488	-0.00495	-3%	

Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
N18	Dissolved oxygen	Long-term	21.5	253	-1.241	0.21462	insignificant	seasonal	-0.00093	-0.00251	0.00056	-4%	-0.0179
	DO saturation	Long-term	21.0	247	-0.886	0.37569	insignificant	seasonal	-0.00055	-0.00181	0.00068	-3%	-0.1129
	Temperature	Long-term	21.5	253	0.992	0.32104	insignificant	seasonal	0.00049	-0.00058	0.00163		0.0228
	Turbidity	Long-term	9.0	107	2.337	0.01946	increasing	non-seasonal	0.02031	0.00363	0.03404	52%	0.5339
NB11	Chlorophyll-*a*	Long-term	22.5	265	2.819	0.00481	increasing	seasonal	0.00623	0.00199	0.01060	38%	0.1405
		Historical	10.5	125	0.935	0.34959	insignificant	seasonal	0.00720	-0.00889	0.02452	19%	0.1720
		Short-term	12.0	140	2.362	0.01819	increasing	non-seasonal	0.01189	0.00232	0.02282	39%	0.2111
NB11	Total algal biovolume	Long-term	20.9	73	0.938	0.34815	insignificant	non-seasonal	0.00911	-0.00861	0.02671	55%	0.2071
		Historical	8.9	12	Insufficient data								
		Short-term	12.0	61	0.965	0.33477	insignificant	non-seasonal	0.01362	-0.01252	0.04294	46%	0.1088
NB11	Blue-green algal biovolume	Long-term	20.9	73	0.076	0.93924	insignificant	non-seasonal	0.00000	-0.00833	0.01230	0%	0.0000
		Historical	8.9	12	Insufficient data								
		Short-term	12.0	61	0.442	0.65851	insignificant	non-seasonal	0.00384	-0.01275	0.03044	11%	0.0000
NB11	Total nitrogen	Long-term	22.5	265	-2.543	0.01099	decreasing	non-seasonal	-0.00317	-0.00582	-0.00077	-15%	-0.0048
		Historical	10.5	125	-4.991	0.00000	decreasing	non-seasonal	-0.02489	-0.03605	-0.01516	-45%	-0.0349
		Short-term	12.0	140	-0.171	0.86411	insignificant	non-seasonal	-0.00043	-0.00583	0.00447	-1%	-0.0003
NB11	Dissolved inorganic nitrogen	Long-term	22.5	265	-8.102	0.00000	decreasing	seasonal	-0.03605	-0.04462	-0.02784	-85%	-0.0115
		Historical	10.5	125	-7.171	0.00000	decreasing	seasonal	-0.10996	-0.13334	-0.08471	-93%	-0.0451
		Short-term	12.0	140	0.000	1.00000	insignificant	seasonal	0.00009	-0.01670	0.01734	0%	0.0000
NB11	Total phosphorus	Long-term	22.5	265	-2.098	0.03587	decreasing	seasonal	-0.00276	-0.00549	-0.00021	-13%	-0.0002
		Historical	10.5	125	-0.872	0.38334	insignificant	seasonal	-0.00345	-0.01210	0.00451	-8%	-0.0003
		Short-term	12.0	140	0.000	1.00000	insignificant	seasonal	0.00000	-0.00599	0.00540	0%	0.0000
NB11	Filterable total phosphorus	Long-term	22.5	265	5.115	0.00000	increasing	non-seasonal	0.01180	0.00732	0.01643	84%	0.0003
		Historical	10.5	125	1.105	0.26897	insignificant	non-seasonal	0.00784	-0.00638	0.02486	21%	0.0002
		Short-term	12.0	140	-0.097	0.92297	insignificant	seasonal	-0.00045	-0.00799	0.00713	-1%	0.0000
NB11	Conductivity	Long-term	21.5	239	-1.726	0.08439	insignificant	seasonal	-0.00144	-0.00313	0.00023	-7%	-130.264
		Historical	9.5	102	1.423	0.15466	insignificant	seasonal	0.00427	-0.00149	0.01137	10%	392.4443
		Short-term	12.0	137	0.055	0.95575	insignificant	seasonal	0.00003	-0.00328	0.00343	0%	2.5660

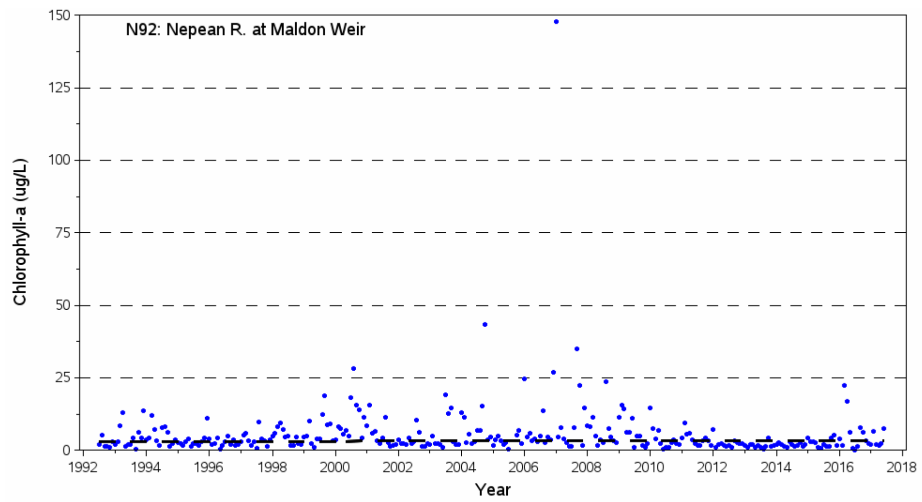
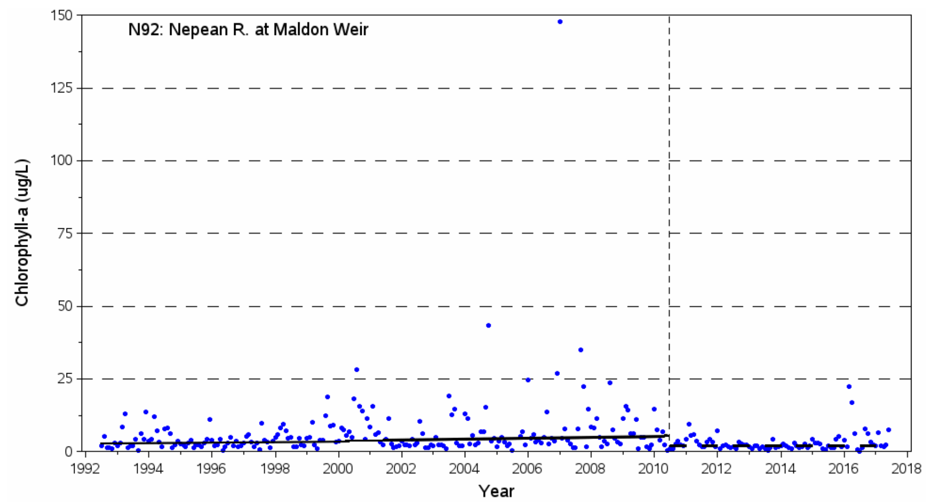
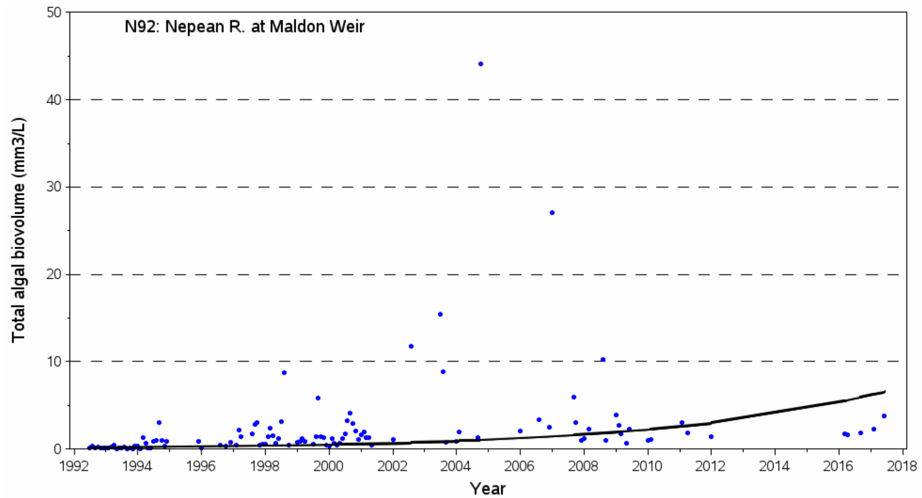
Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
NB11	pH	Long-term	22.5	265	-2.654	0.00796	decreasing	seasonal	-0.00510	-0.00866	-0.00127	-1%	
		Historical	10.5	125	2.324	0.02013	increasing	non-seasonal	0.01567	0.00261	0.02803	2%	
		Short-term	12.0	140	-2.374	0.01758	decreasing	seasonal	-0.00900	-0.01675	-0.00114	-1%	
NB11	Dissolved oxygen	Long-term	22.5	265	-1.949	0.05126	insignificant	seasonal	-0.00123	-0.00256	0.00002	-6%	-0.0196
	DO saturation	Long-term	19.0	223	-0.775	0.43854	insignificant	seasonal	-0.00047	-0.00156	0.00074	-2%	-0.0989
	Temperature	Long-term	22.5	265	3.097	0.00196	increasing	seasonal	0.00155	0.00058	0.00257		0.0706
	Turbidity	Long-term	9.0	107	-0.746	0.45549	insignificant	seasonal	-0.00536	-0.01729	0.00837	-11%	-0.0746
NB13	Chlorophyll-*a*	Long-term	20.5	229	1.033	0.30158	insignificant	seasonal	0.00312	-0.00374	0.00992	16%	0.0851
		Historical	8.5	89	-1.743	0.08140	insignificant	seasonal	-0.02235	-0.04805	0.00257	-35%	-0.4741
		Short-term	12.0	140	3.105	0.00190	increasing	seasonal	0.01997	0.00786	0.03547	74%	0.5752
NB13	Total nitrogen	Long-term	20.5	229	-5.872	0.00000	decreasing	non-seasonal	-0.00914	-0.01196	-0.00628	-35%	-0.0118
		Historical	8.5	89	-5.333	0.00000	decreasing	non-seasonal	-0.03733	-0.04805	-0.02632	-52%	-0.0321
		Short-term	12.0	140	-0.740	0.45904	insignificant	non-seasonal	-0.00158	-0.00606	0.00296	-4%	-0.0015
NB13	Dissolved inorganic nitrogen	Long-term	20.5	229	-8.257	0.00000	decreasing	seasonal	-0.04070	-0.04947	-0.03319	-85%	-0.0146
		Historical	8.5	89	-6.199	0.00000	decreasing	seasonal	-0.10519	-0.12989	-0.08097	-87%	-0.0278
		Short-term	12.0	140	-1.547	0.12186	insignificant	seasonal	-0.01297	-0.02978	0.00348	-30%	-0.0026
NB13	Total phosphorus	Long-term	20.5	229	0.935	0.34970	insignificant	seasonal	0.00197	-0.00198	0.00546	10%	0.0002
		Historical	8.5	89	-0.053	0.95789	insignificant	seasonal	-0.00054	-0.01628	0.01657	-1%	0.0000
		Short-term	12.0	140	2.106	0.03523	increasing	seasonal	0.00786	0.00082	0.01551	24%	0.0008
NB13	Filterable total phosphorus	Long-term	20.5	229	1.715	0.08642	insignificant	non-seasonal	0.00425	-0.00063	0.00909	22%	0.0001
		Historical	8.5	89	0.606	0.54452	insignificant	non-seasonal	0.00566	-0.01190	0.02530	12%	0.0002
		Short-term	12.0	140	0.395	0.69319	insignificant	non-seasonal	0.00210	-0.00848	0.01216	6%	0.0001
NB13	Conductivity	Long-term	17.0	173	-1.801	0.07170	insignificant	seasonal	-0.00192	-0.00517	0.00026	-7%	-141.809
		Historical	5.0	36	2.082	0.03734	increasing	seasonal	0.02484	0.00095	0.04457	33%	2202.121
		Short-term	12.0	137	-0.067	0.94691	insignificant	seasonal	-0.00004	-0.00410	0.00408	0%	-4.0074
NB13	pH	Long-term	17.0	187	-2.367	0.01793	decreasing	seasonal	-0.00829	-0.01542	-0.00172	-2%	
		Historical	5.0	47	-2.311	0.02084	decreasing	non-seasonal	-0.04921	-0.09367	-0.00706	-3%	
		Short-term	12.0	140	-0.032	0.97429	insignificant	seasonal	-0.00023	-0.01124	0.01110	0%	

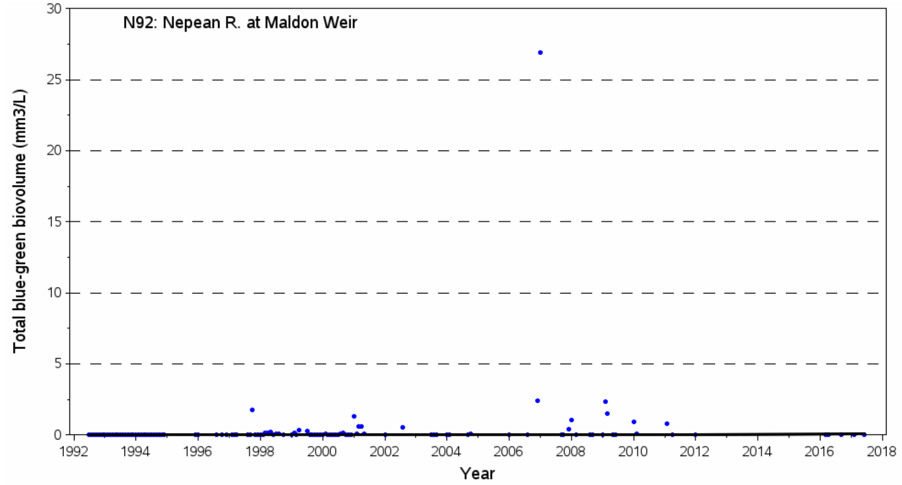
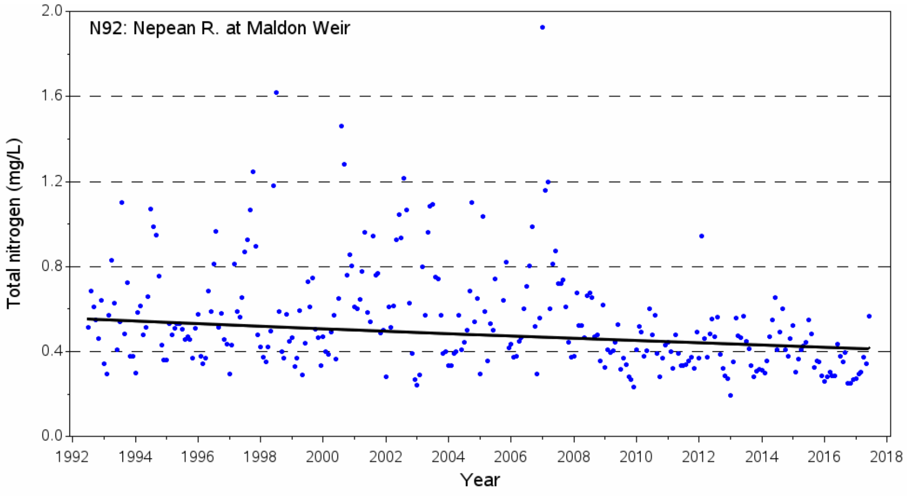
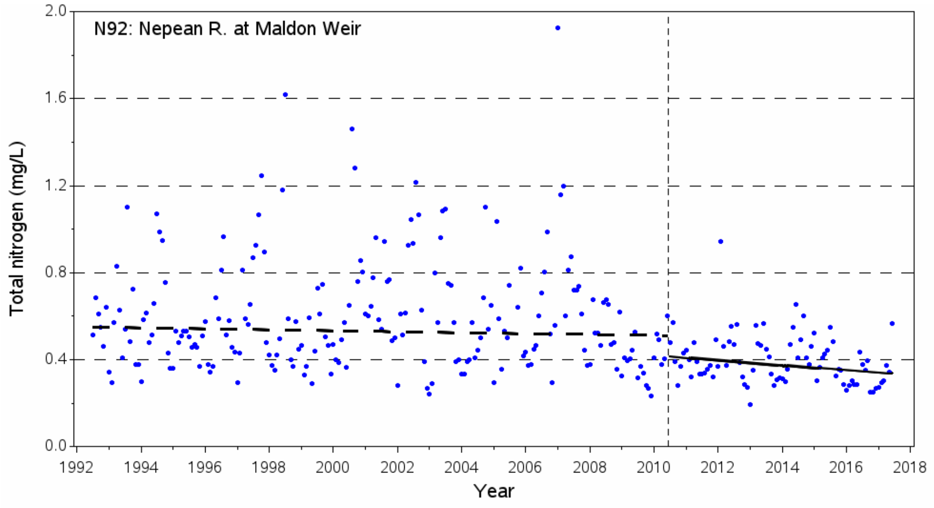
Site	Parameters	Period	No. of years	No. of obs.	Z score	Trend p value	Trend	Method of Kendall test	Sen slope	Low confidence	High confidence	Percent change	Rate per year
NB13	Dissolved oxygen	Long-term	17.0	187	-1.844	0.06516	insignificant	seasonal	-0.00229	-0.00473	0.00024	-9%	-0.0446
	DO saturation	Long-term	17.0	187	-1.302	0.19300	insignificant	non-seasonal	-0.00143	-0.00364	0.00068	-5%	-0.3359
	Temperature	Long-term	17.0	187	2.130	0.03317	increasing	seasonal	0.00188	0.00012	0.00379		0.0908
	Turbidity	Long-term	9.0	107	-0.939	0.34779	insignificant	seasonal	-0.00771	-0.02223	0.00922	-15%	-0.0714

Blue	Significant decreasing trend
Olive	Significant increasing trend

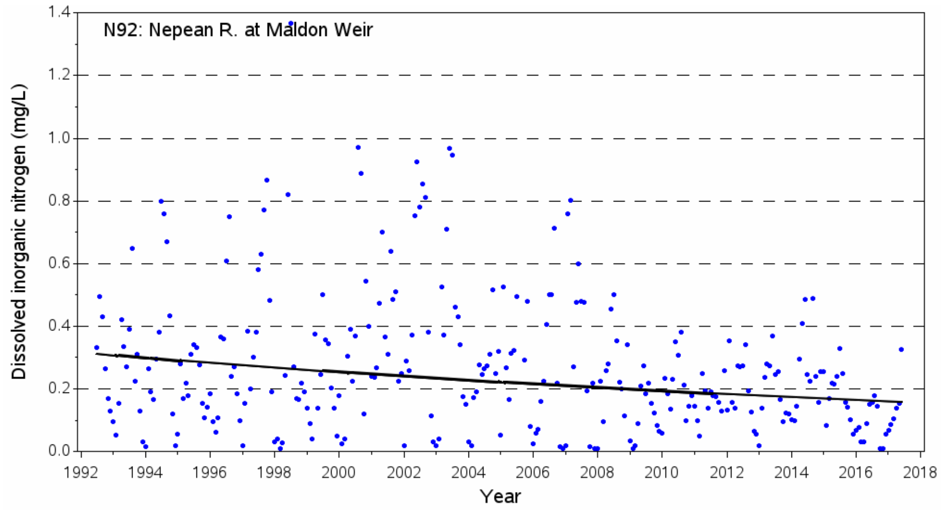
Figure E-2 Temporal trends in water quality: Nepean River at Maldon Weir (N92)

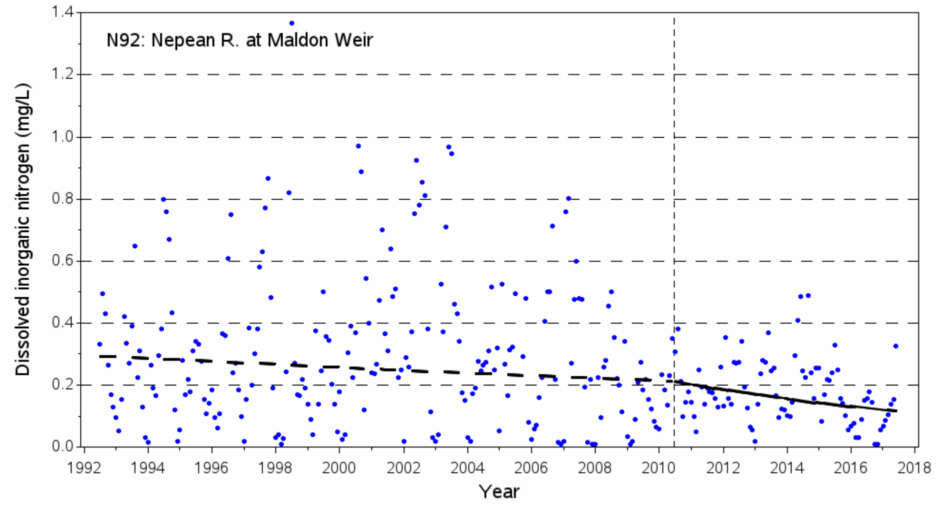
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the commencement of riparian release from the Upper Nepean dams in 2010 (separated by a vertical line)

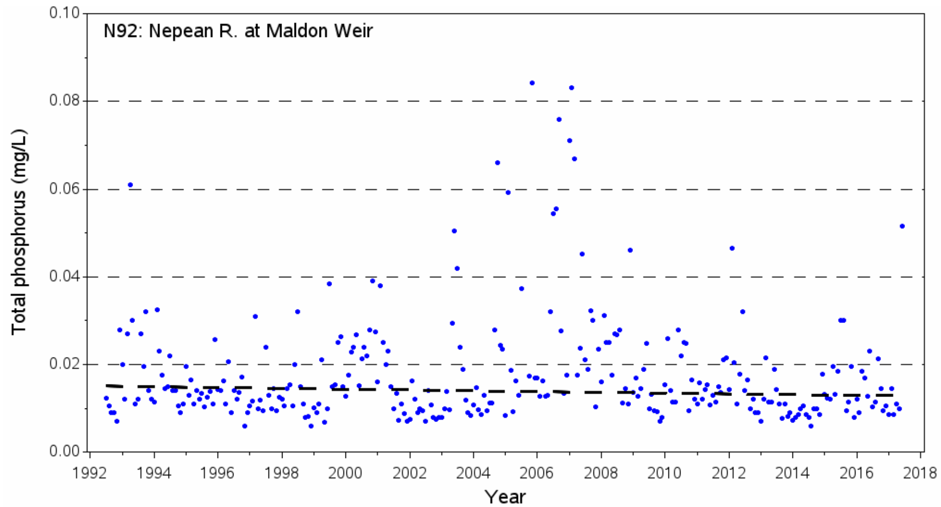
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	In-sufficient algal biovolume data during the Post riparian release period; No step trend fitted

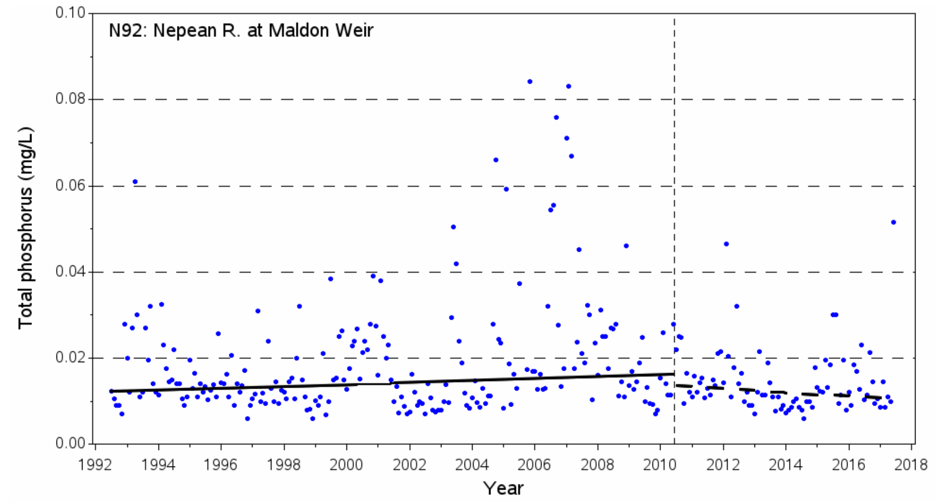
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	In-sufficient Blue-green algal biovolume data during the Post riparian release period; No step trend fitted
	

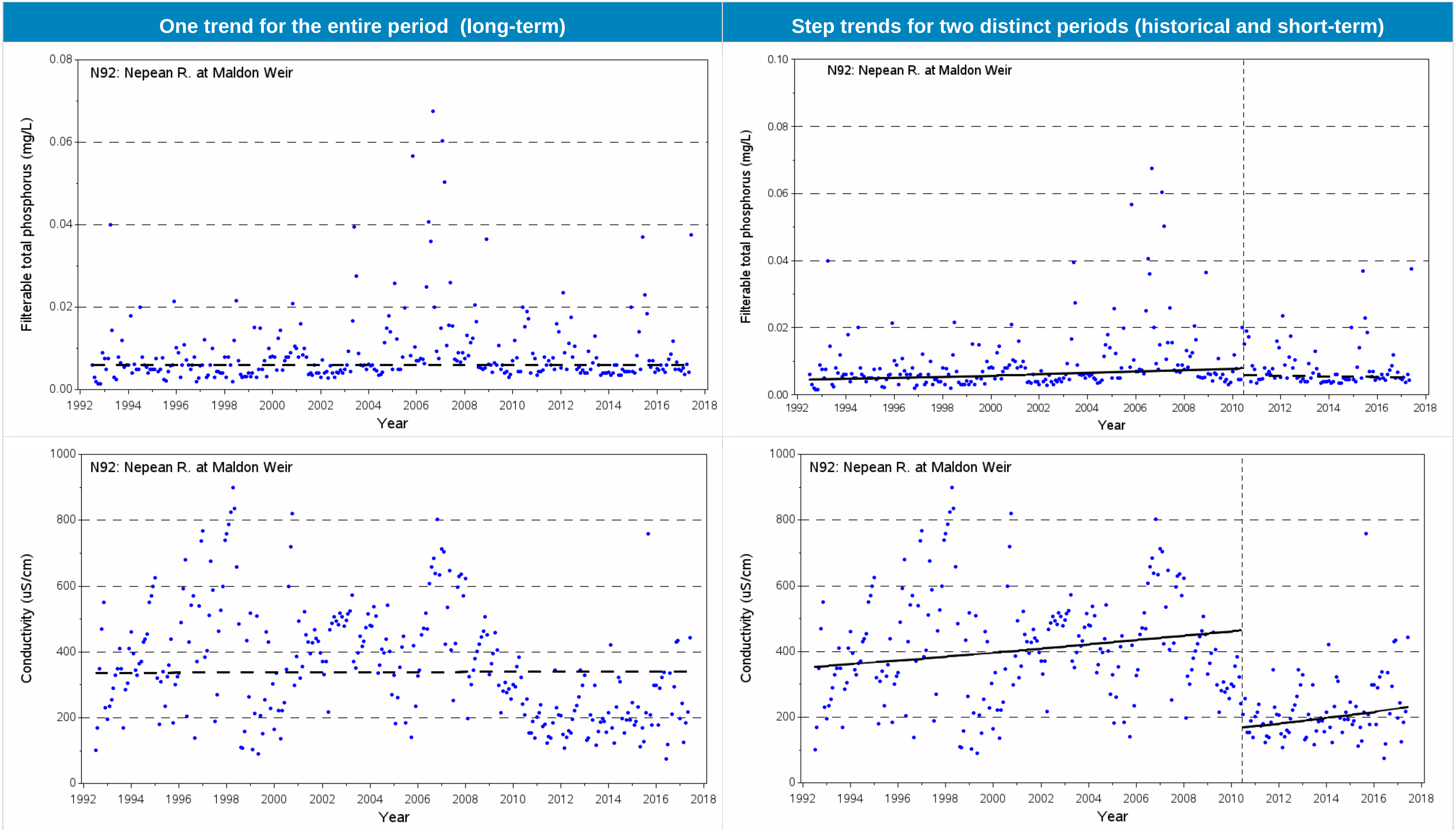
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

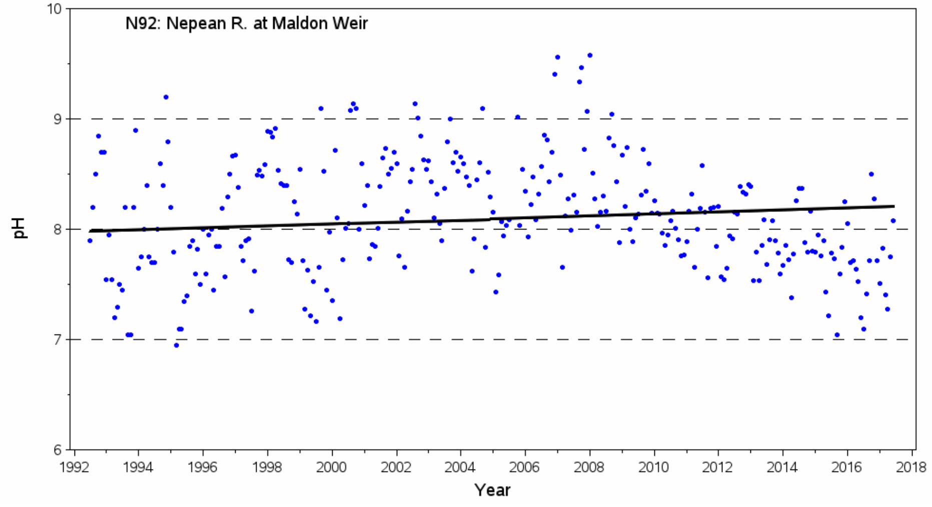
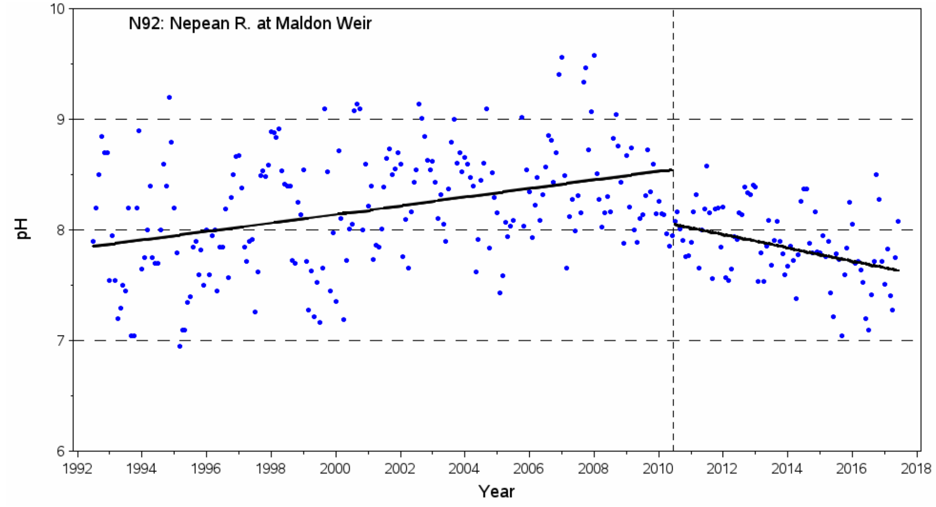


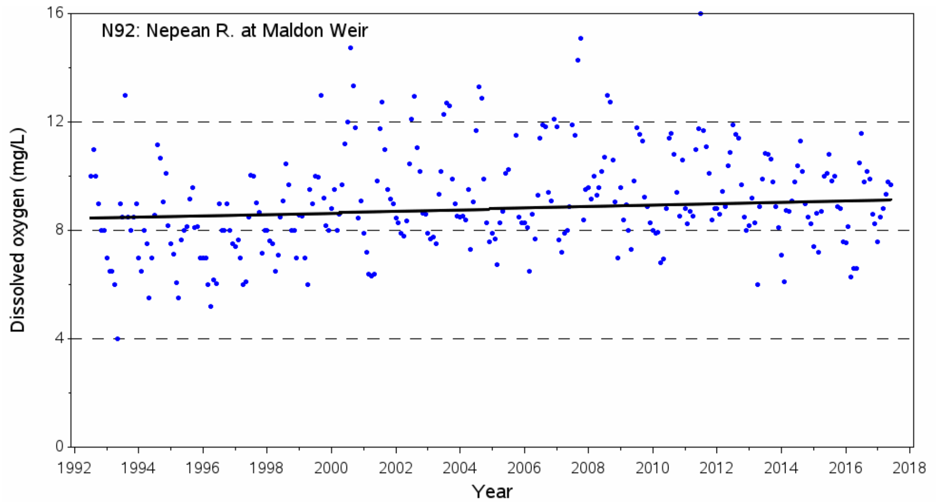


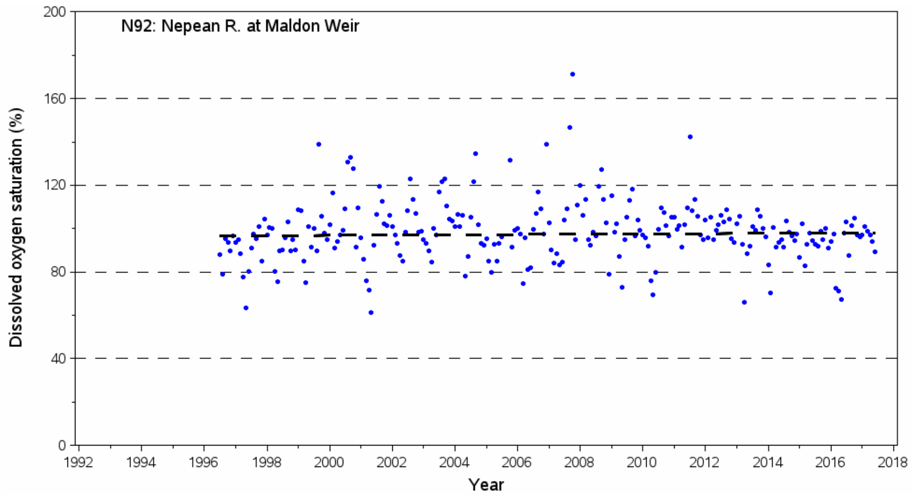
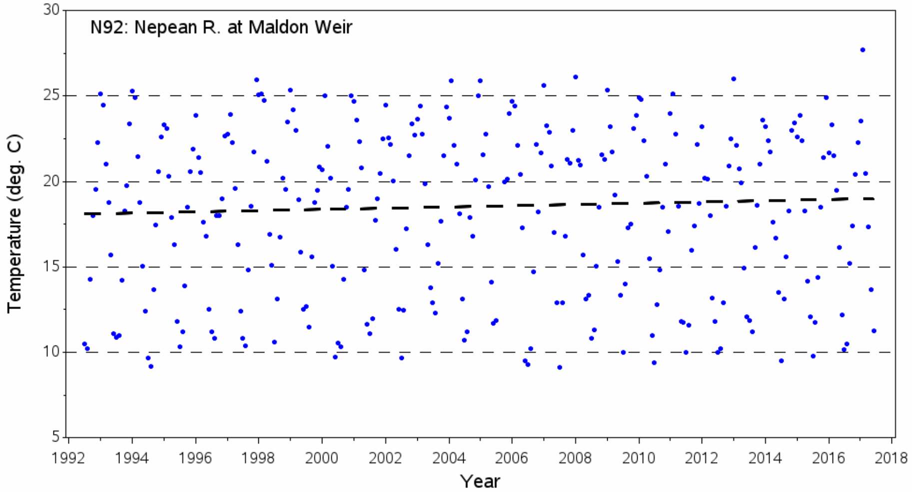





One trend for the entire period (long-term)
Step trends for two distinct periods (historical and short-term)
N92: Nepean R. at Maldon Weir
Filterable total phosphorus (mg/L)
Conductivity (uS/cm)
Year
0.00
0.02
0.04
0.06
0.08
0.10
0
200
400
600
800
1000
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	



One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

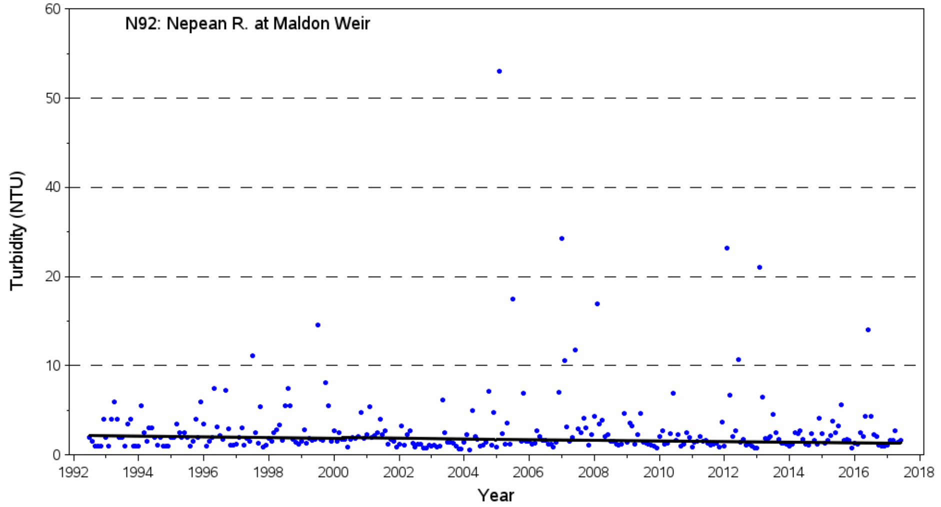
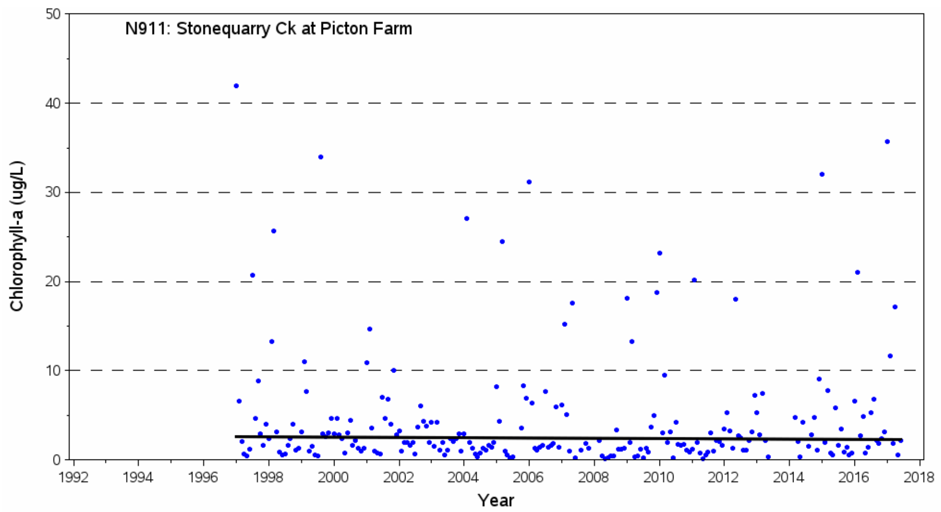
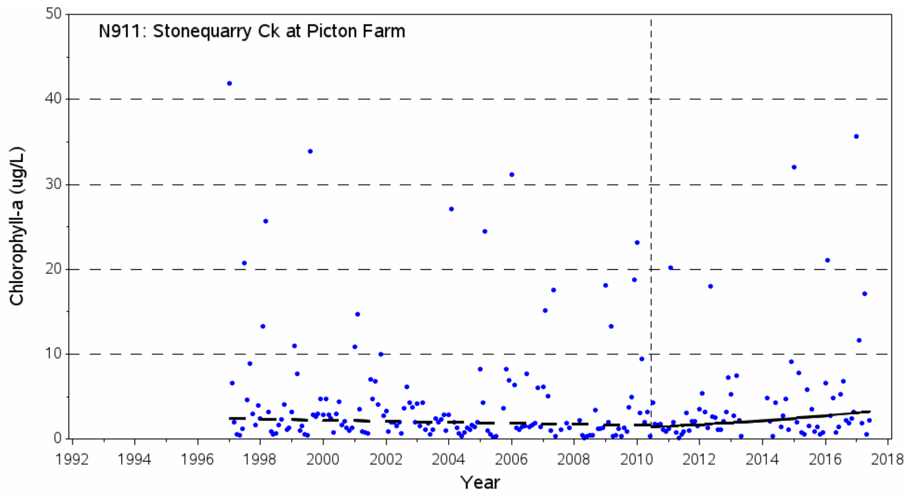
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

Figure E-3 Temporal trends in water quality: Stonequarry Creek at Picton Farm (N911)

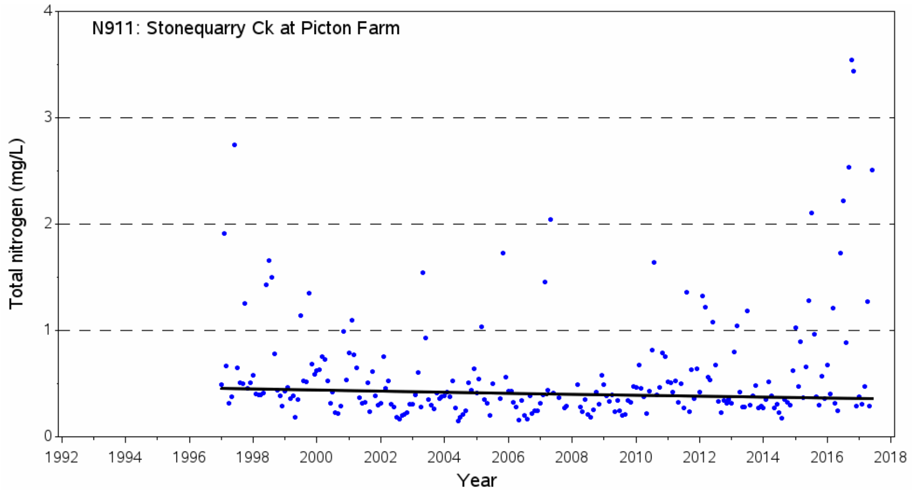
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after intensification of precautionary discharges from Picton WWTP in 2010 (separated by a vertical line)

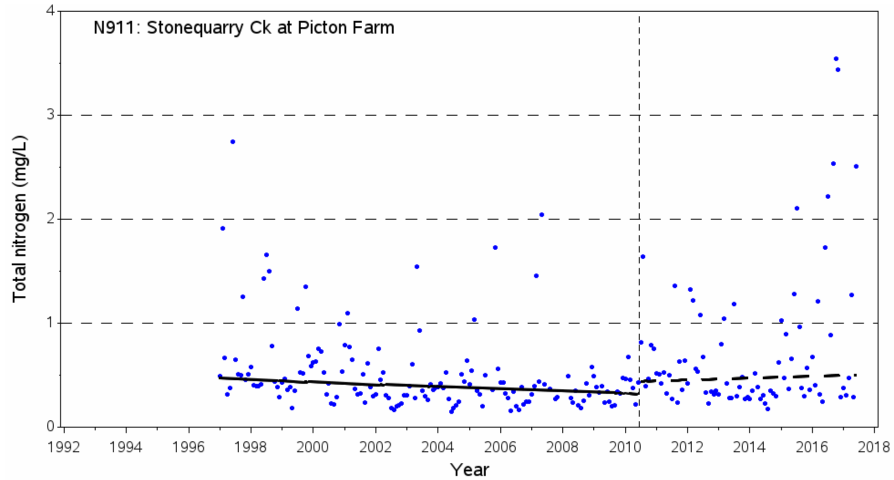
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)



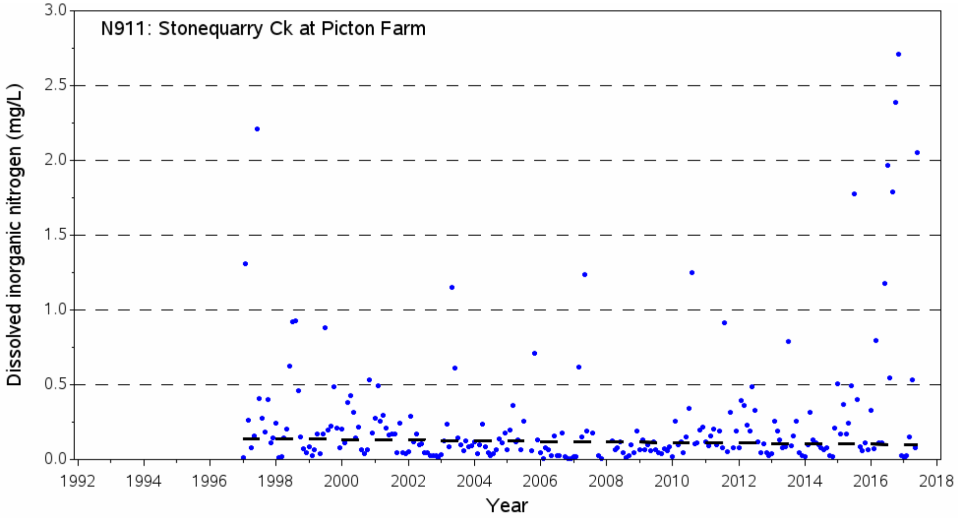


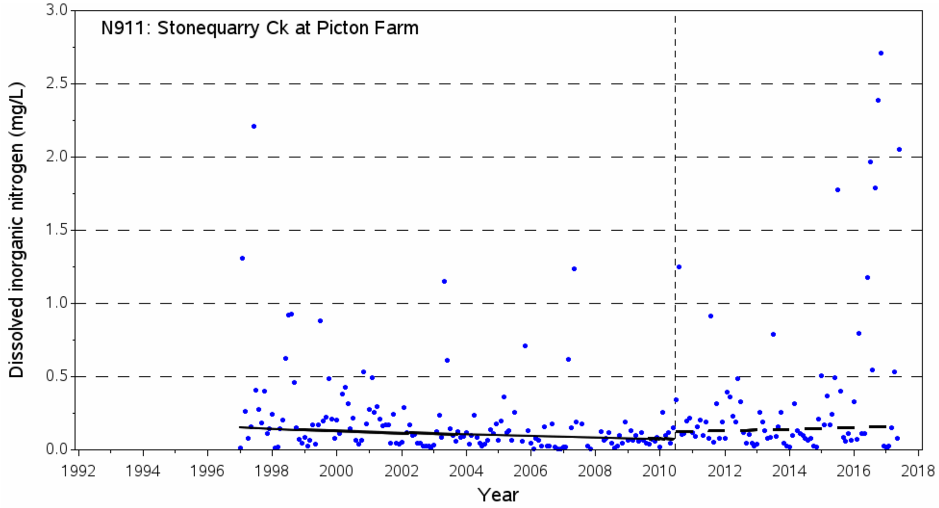
Algal data was very limited (only 28 observations), no plots presented for total algal biovolume and Blue-green algal biovolume

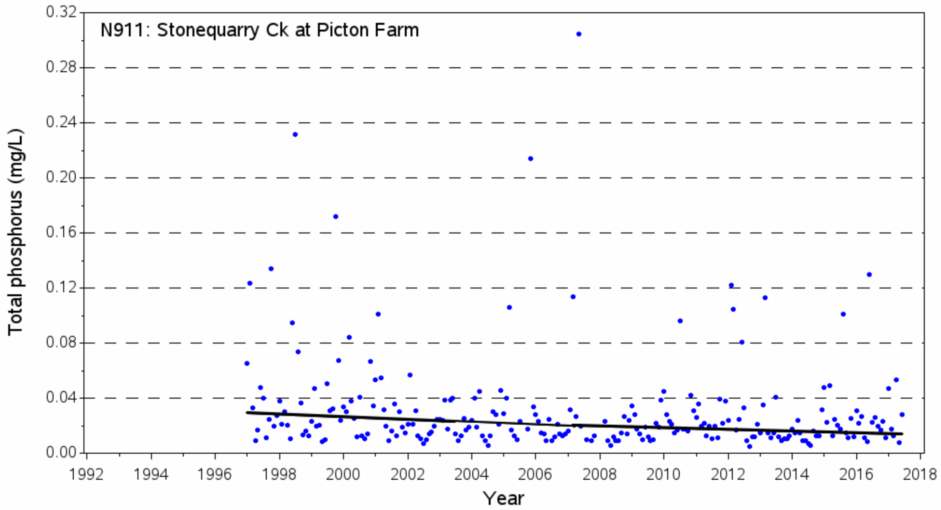


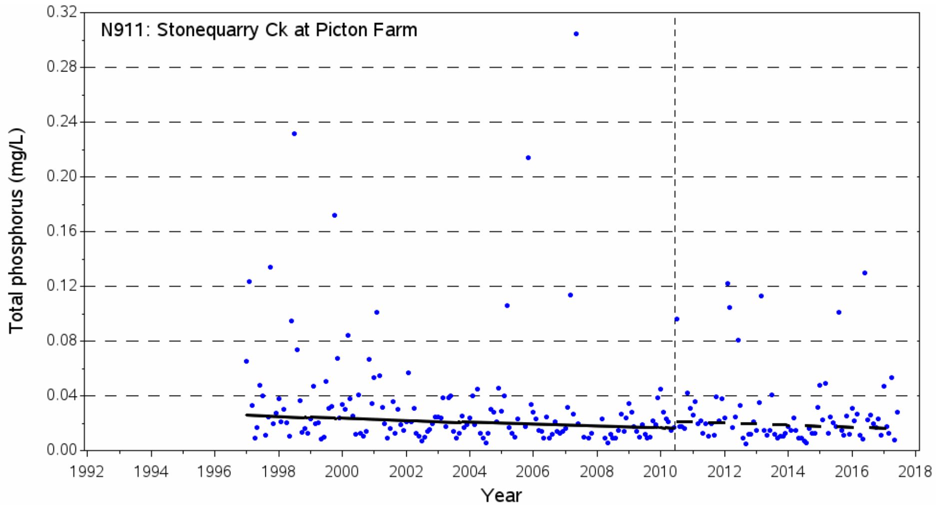


One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

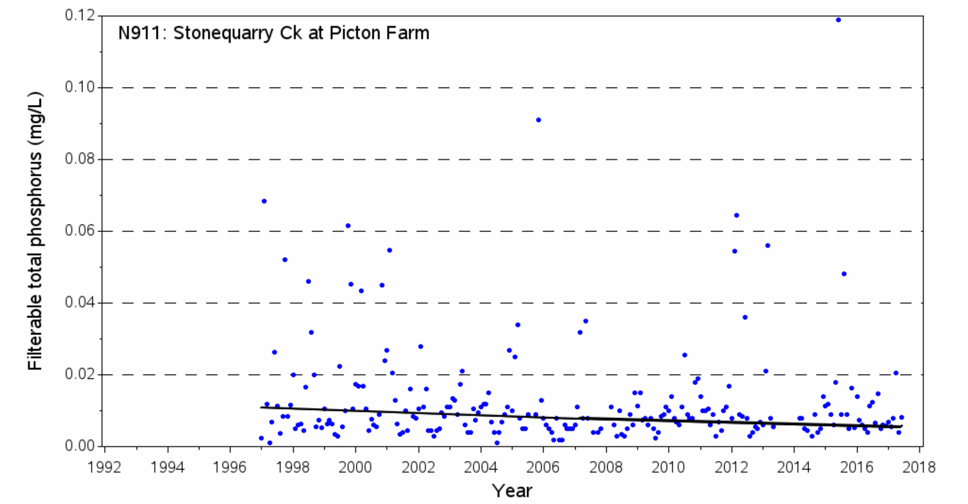


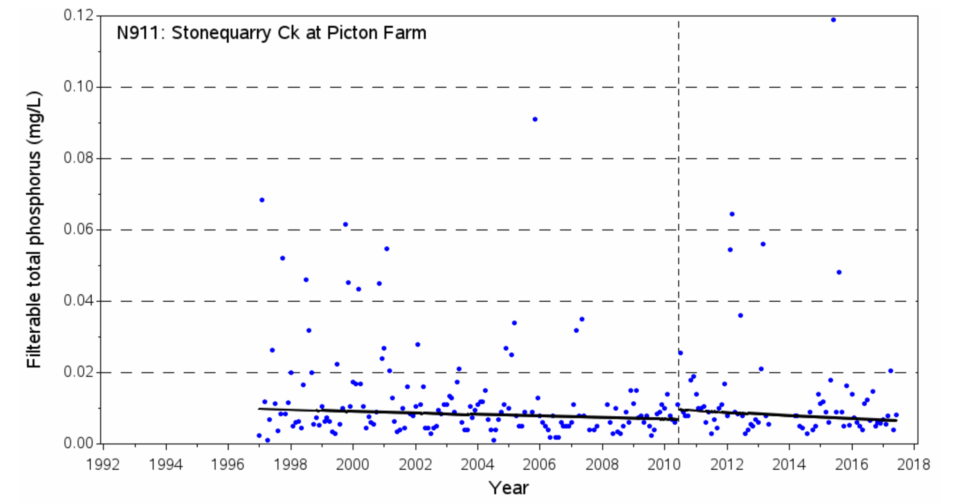


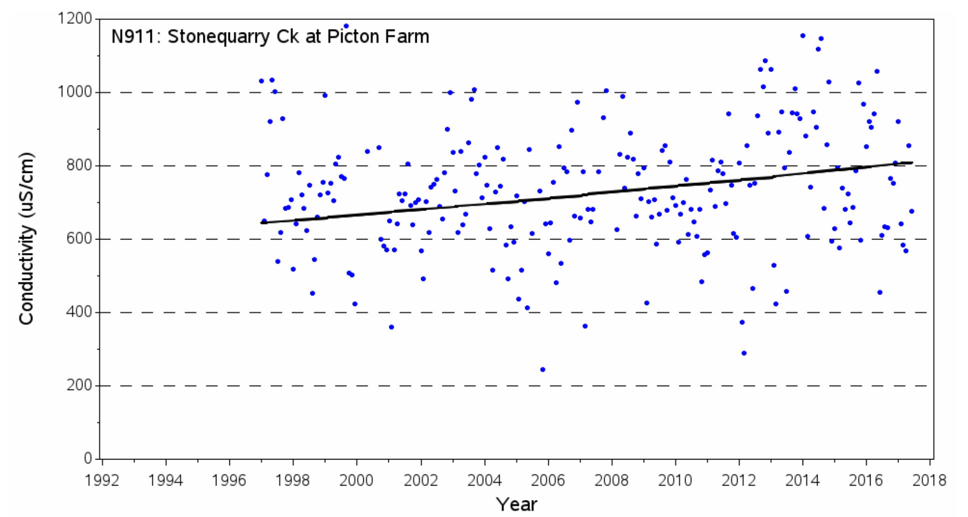


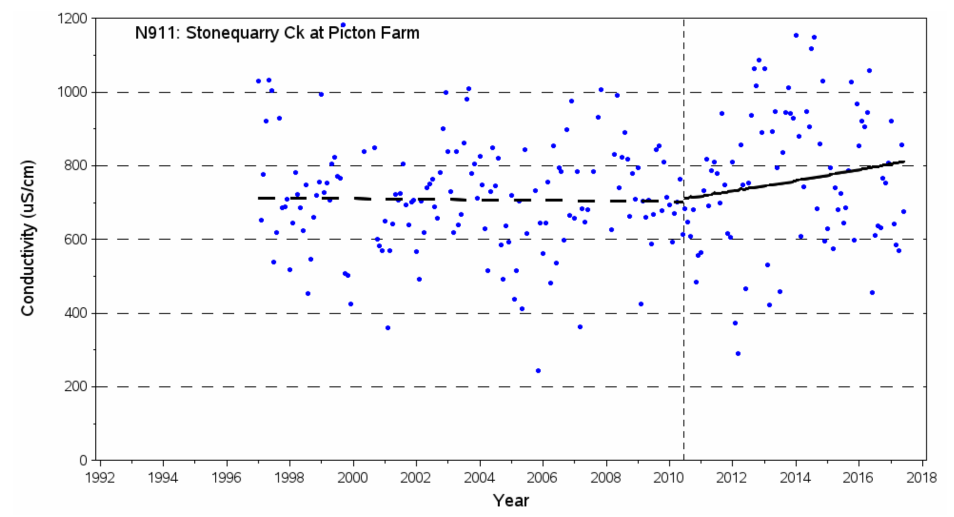


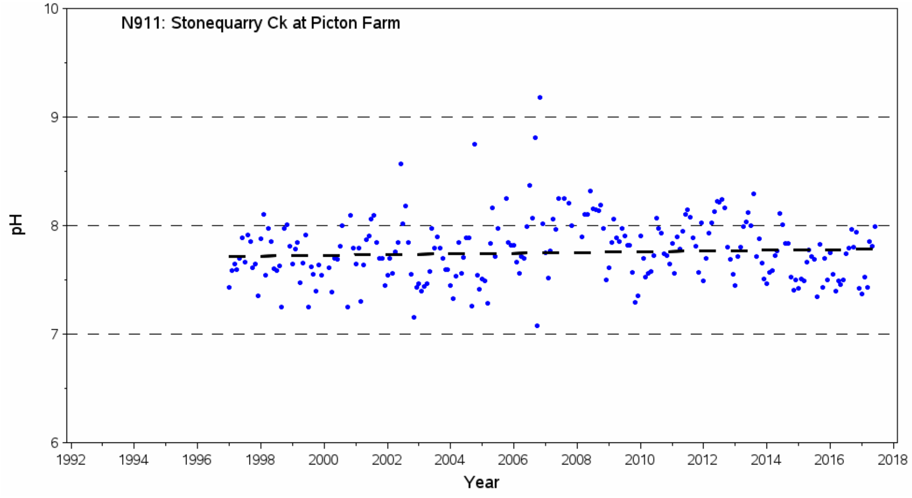
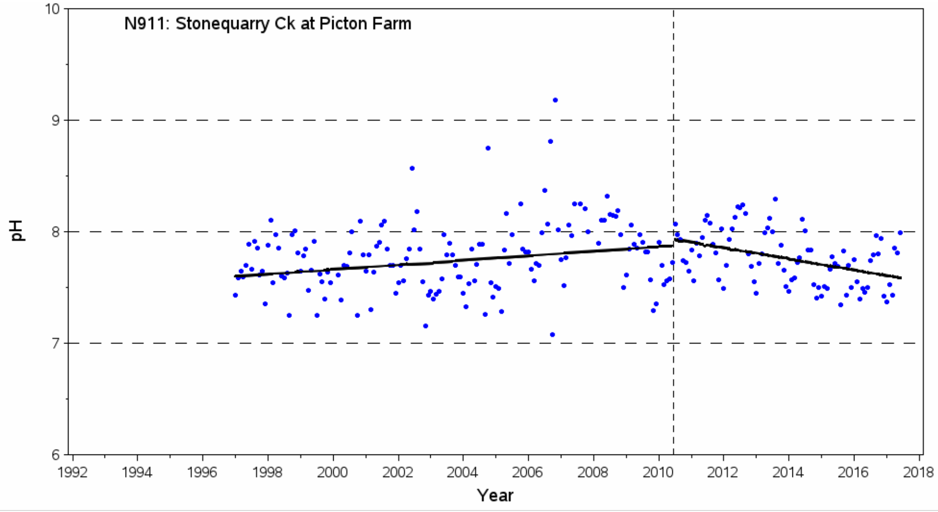
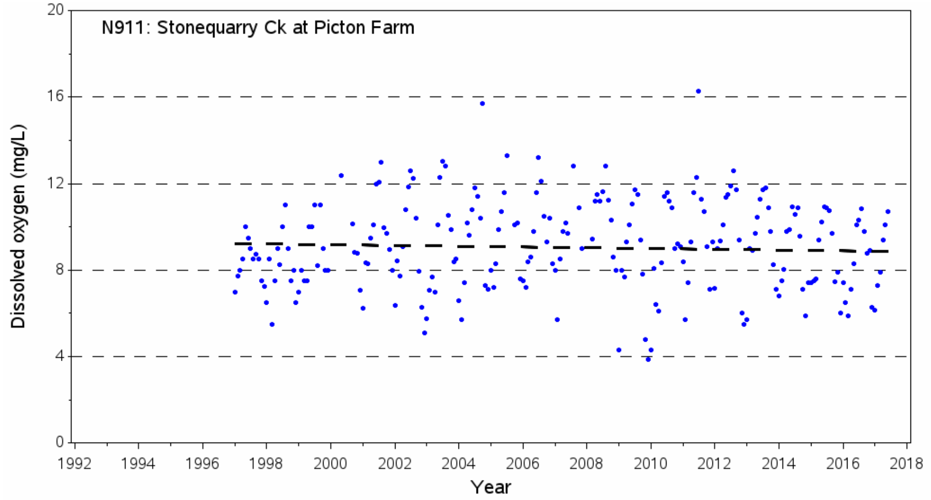
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

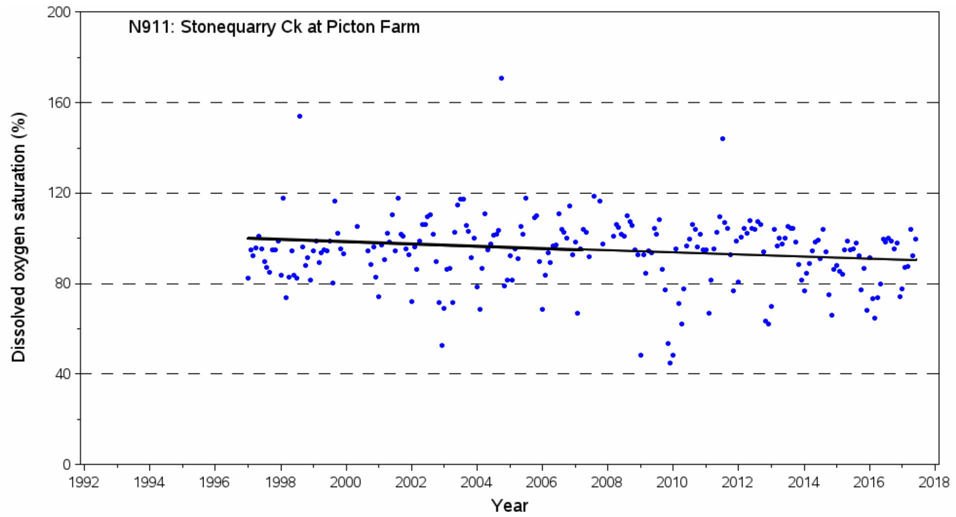
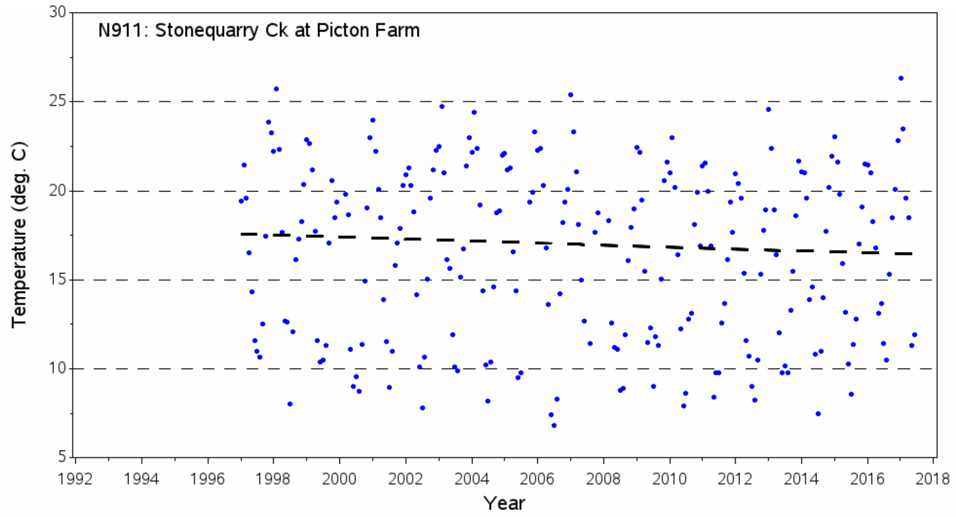








One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

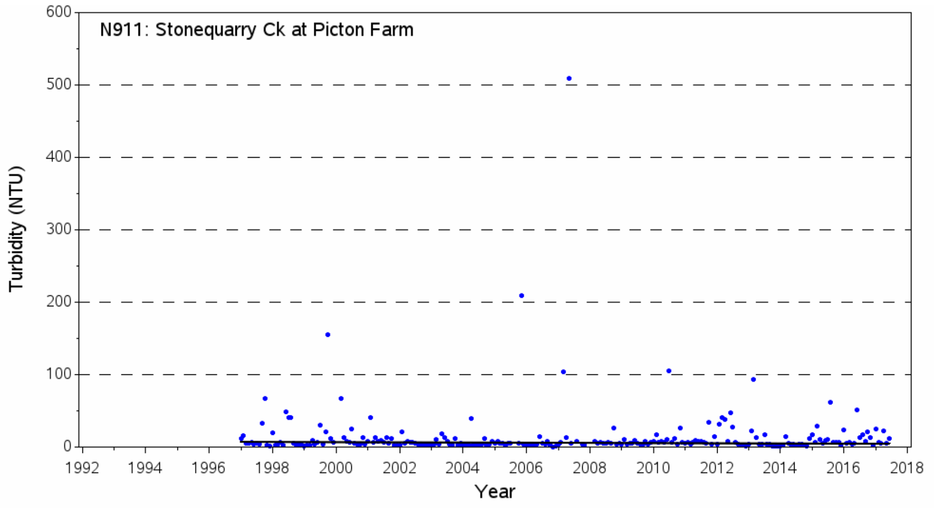
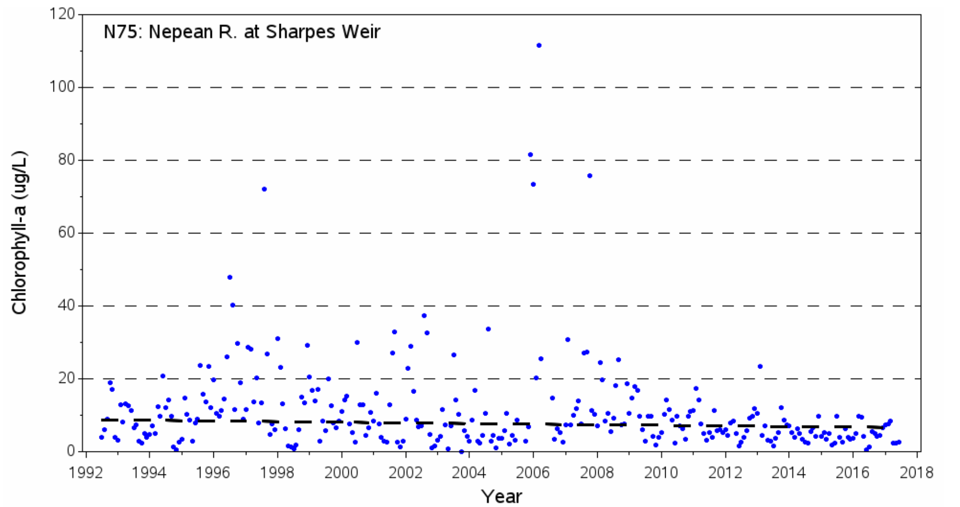
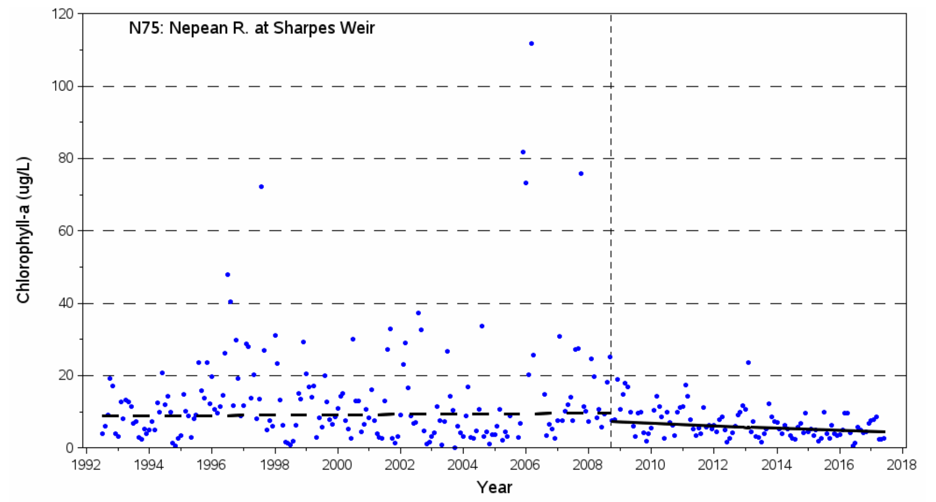
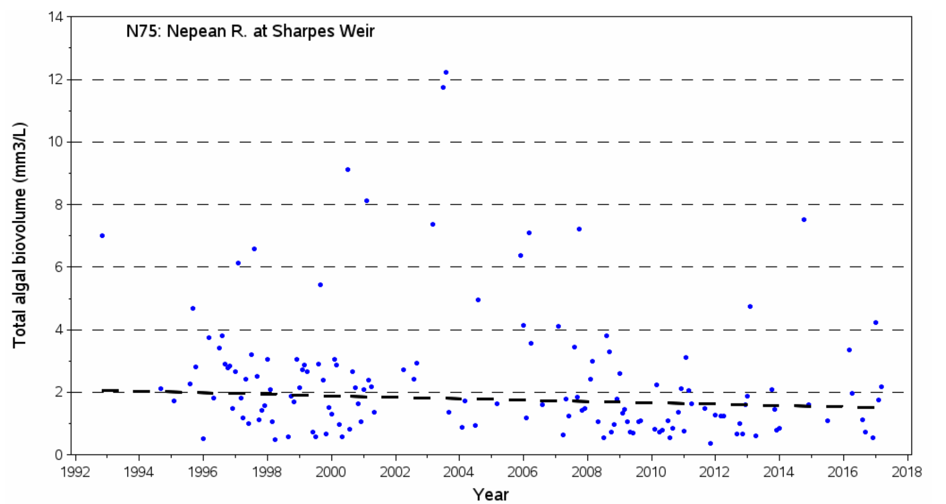
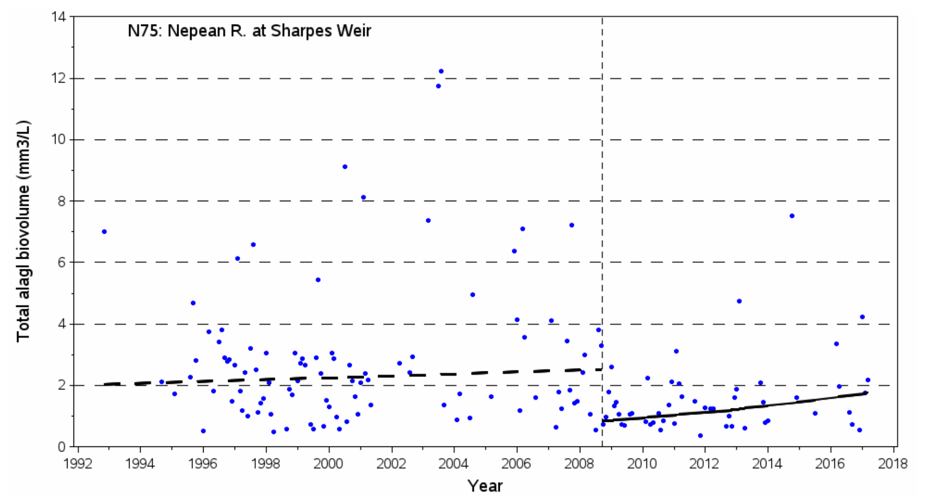
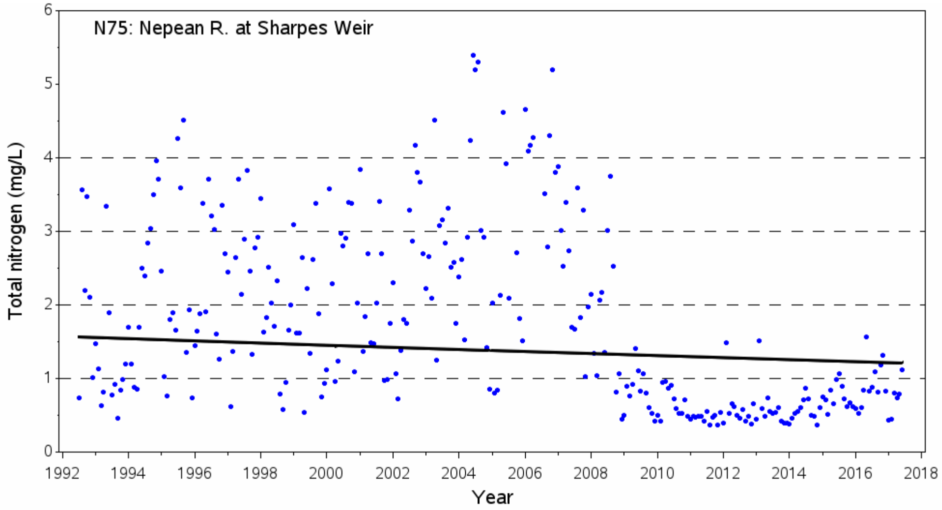
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

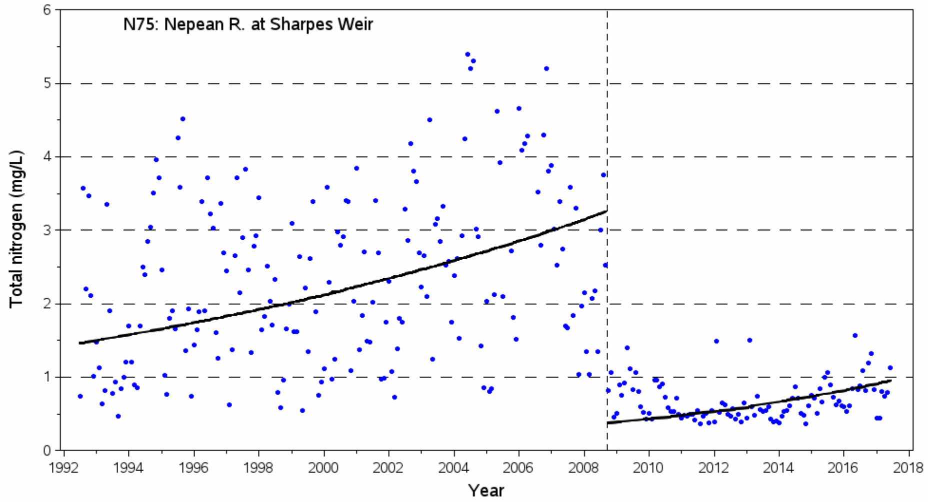
Figure E-4 Temporal trends in water quality: Nepean River at Sharpes Weir (N75)

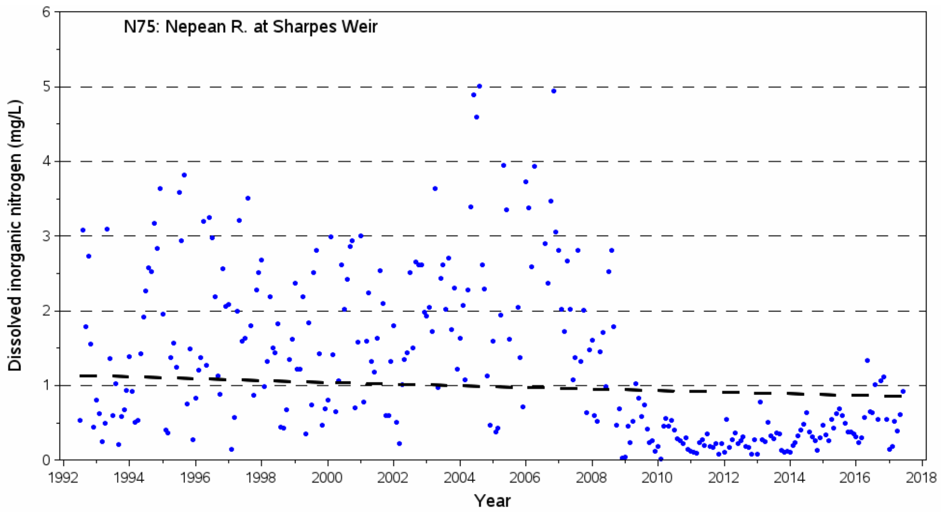
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the upgrade of West Camden WWTP in 2009 (separated by a vertical line)

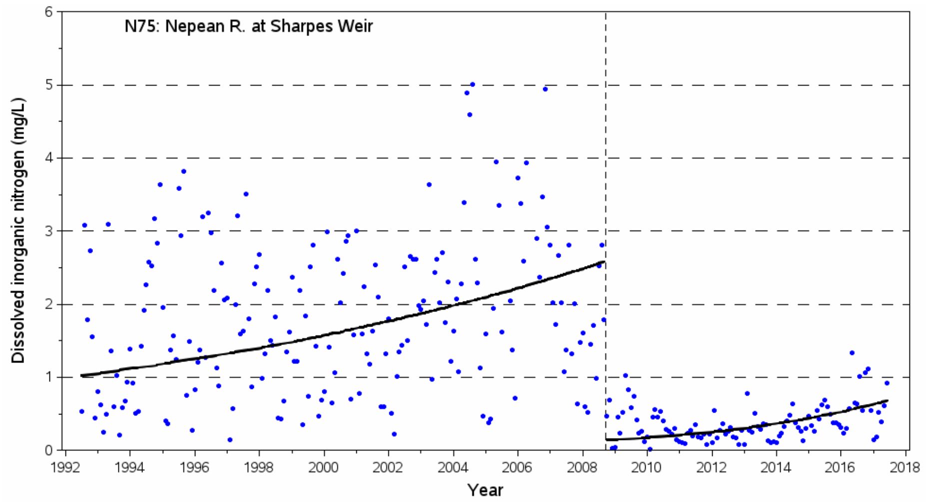
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

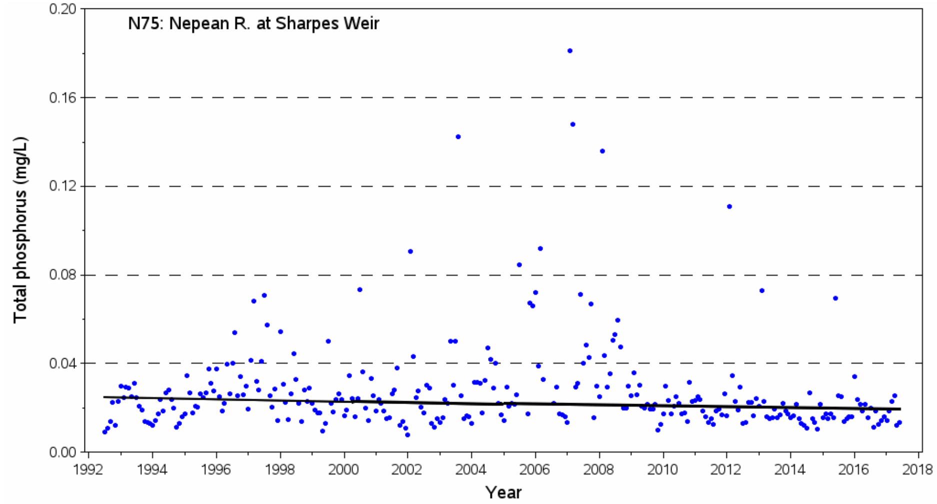
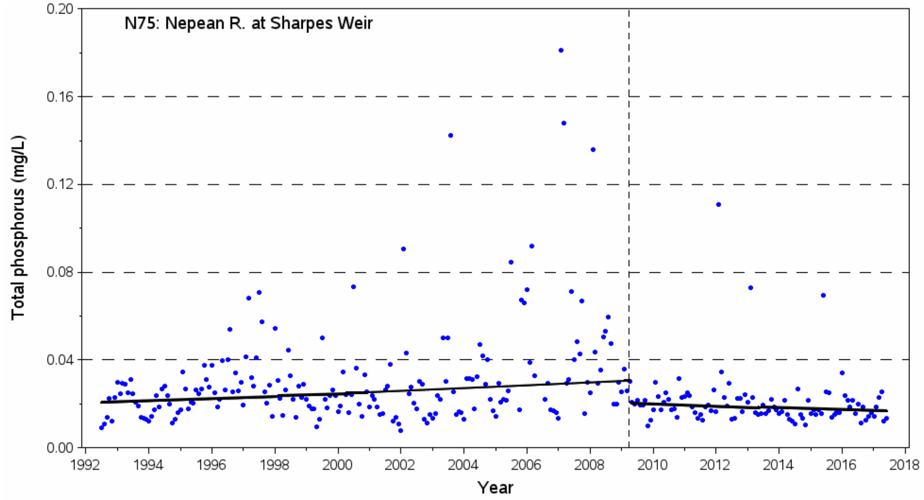
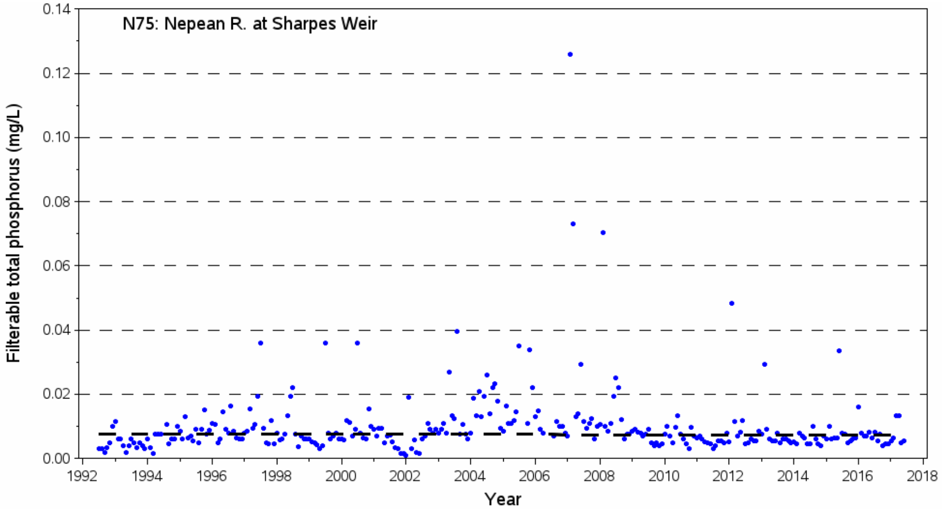
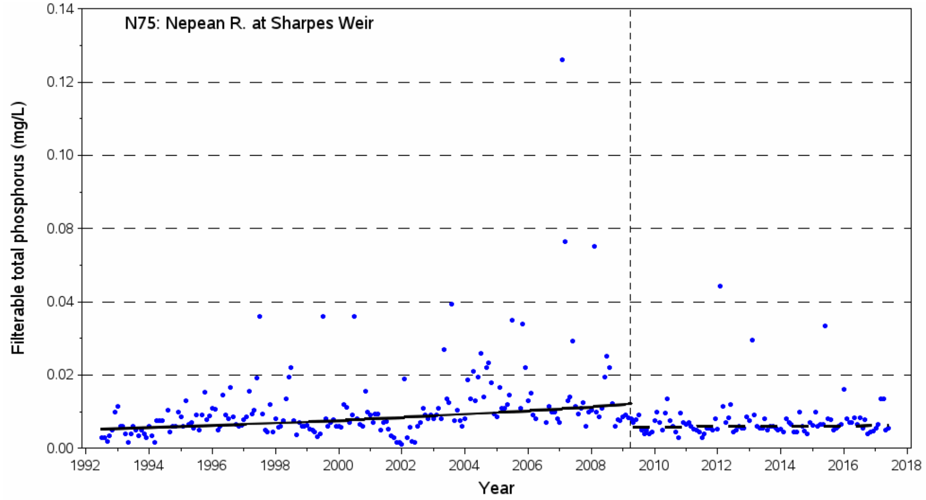
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
• Limited data, no blue-green algal biovolume plots constructed	

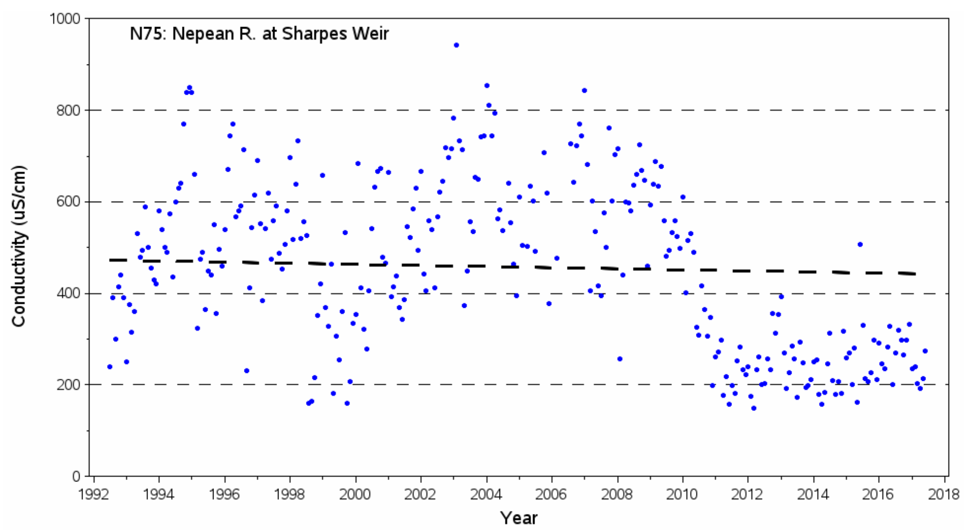
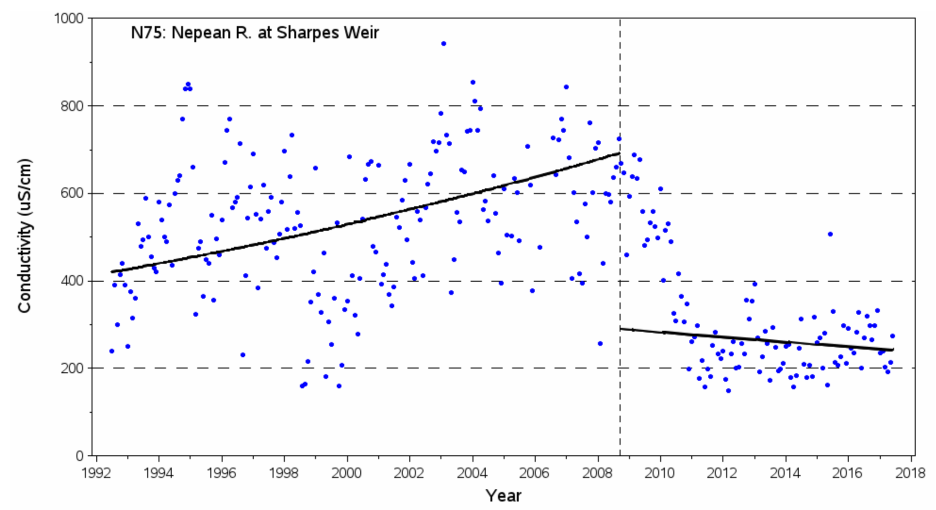
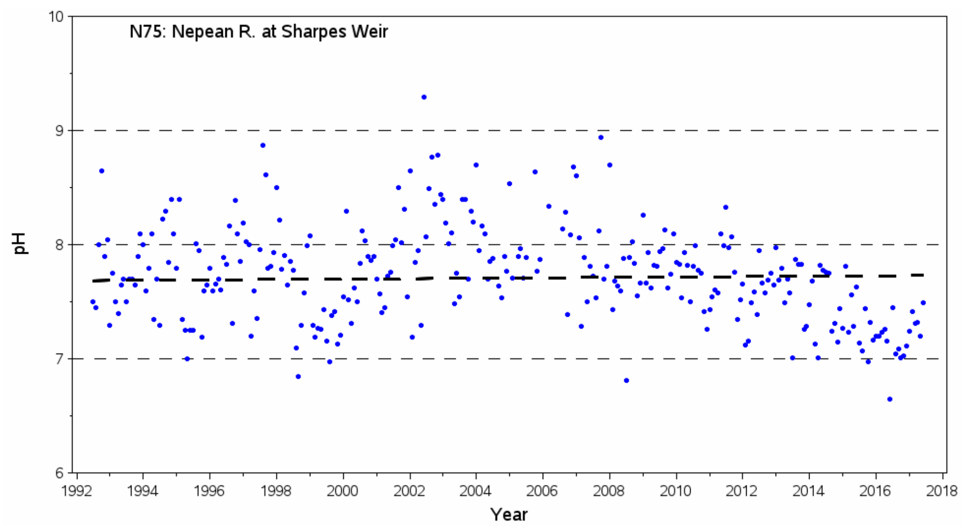
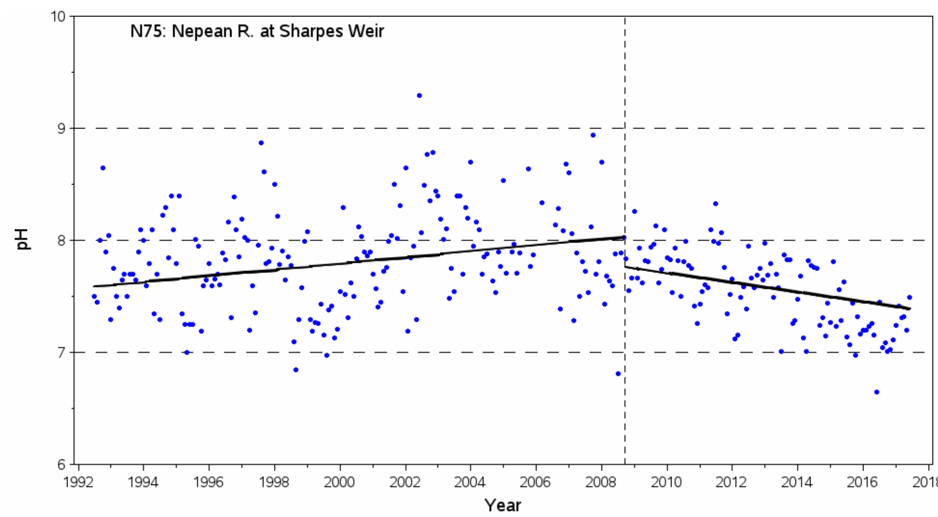


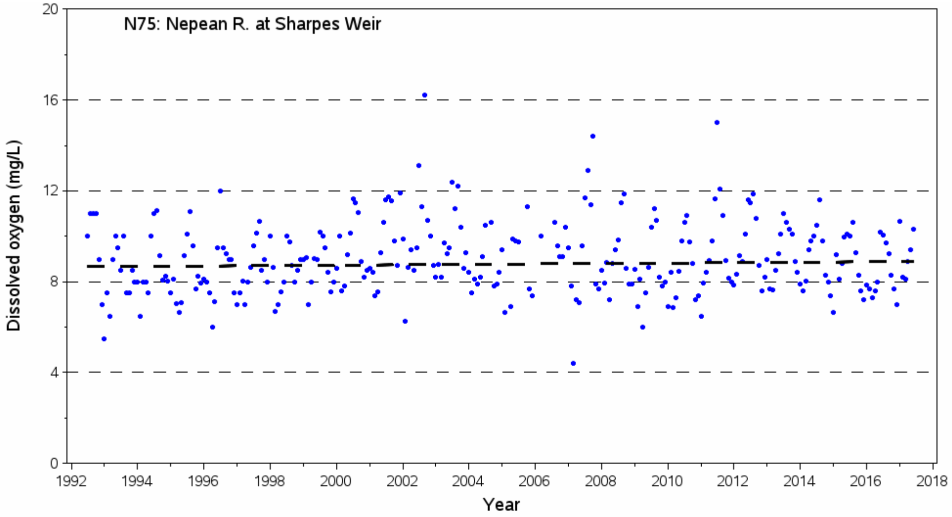
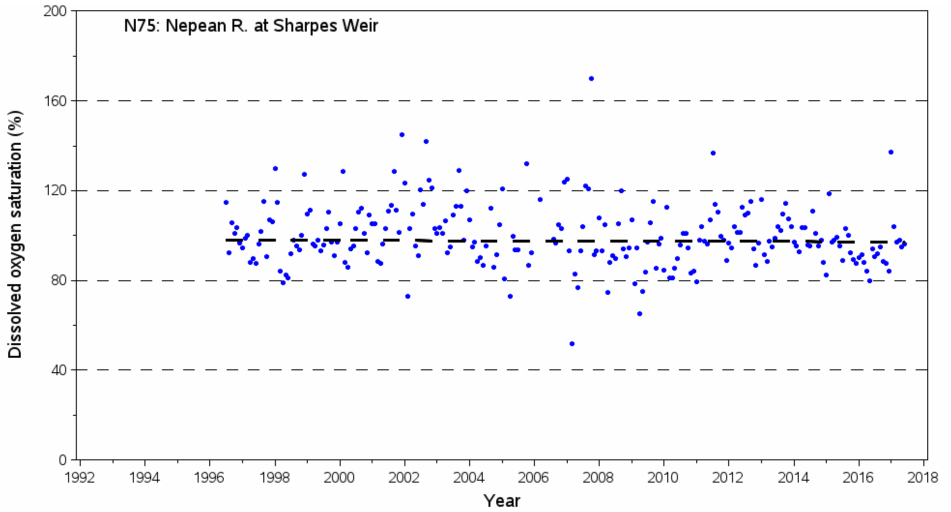






One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

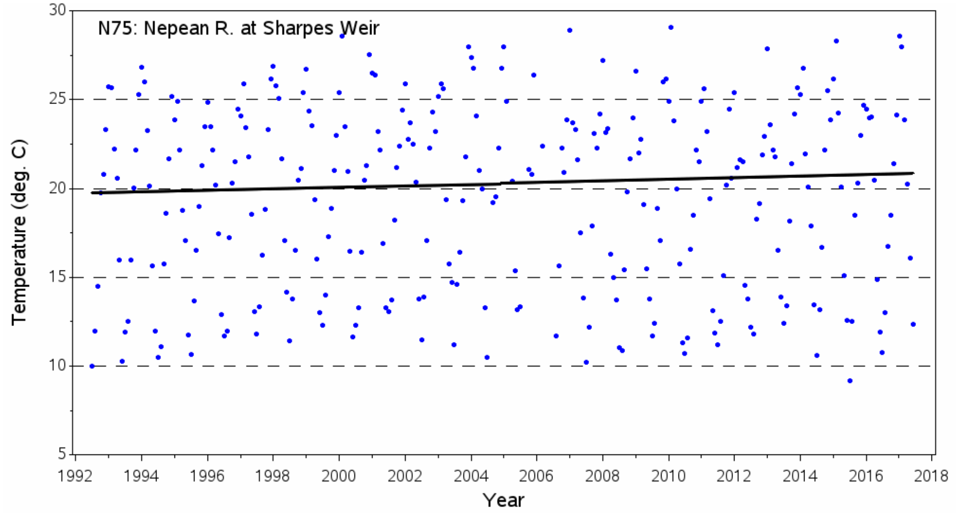
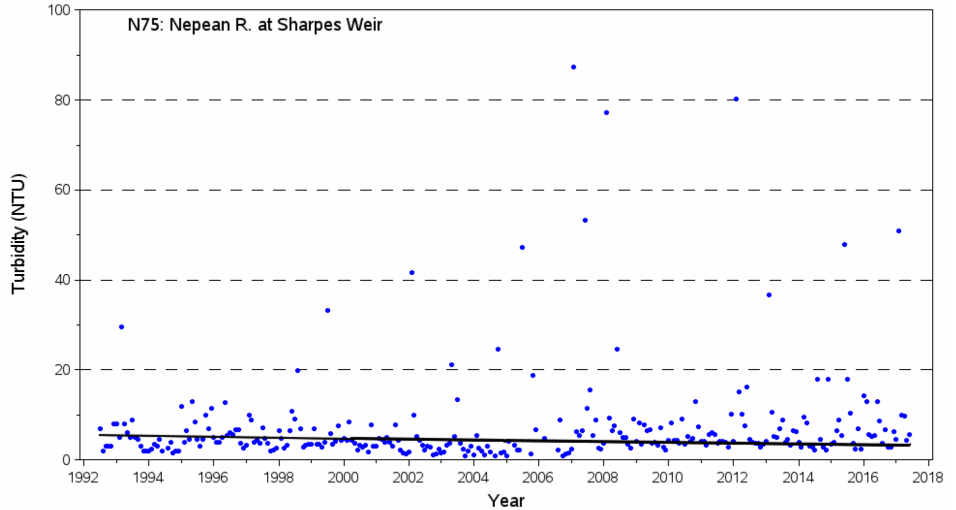
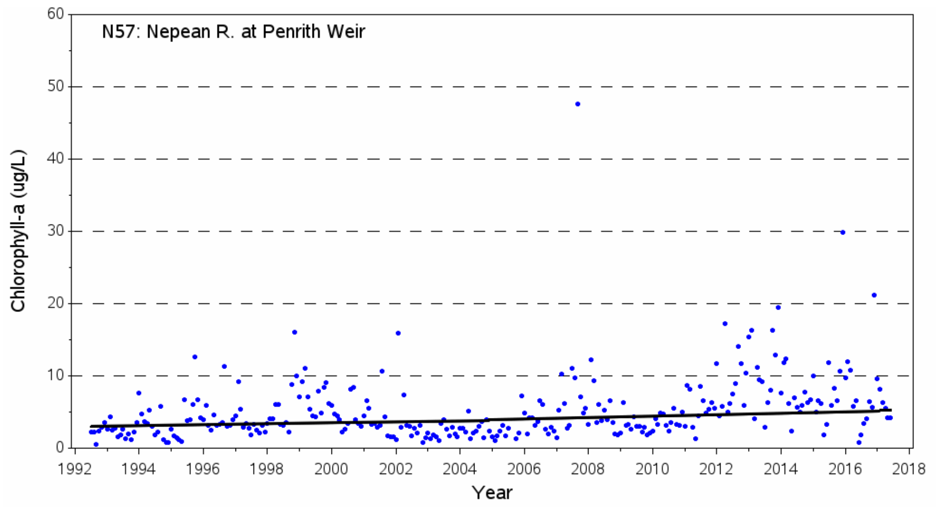
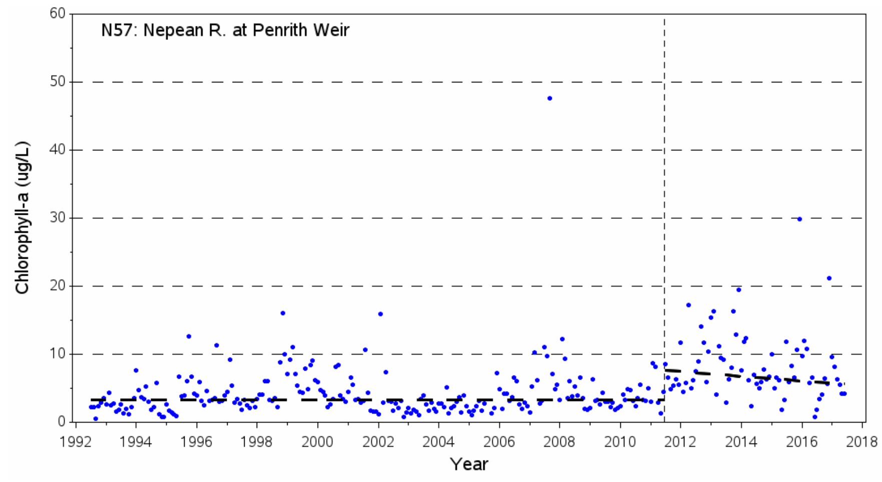
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

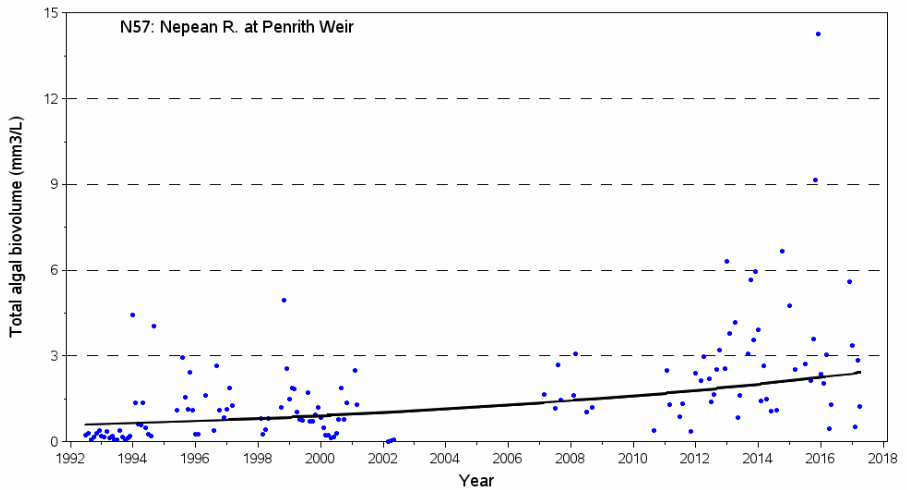
Figure E-5 Temporal trends in water quality: Nepean River at Penrith Weir (N57)

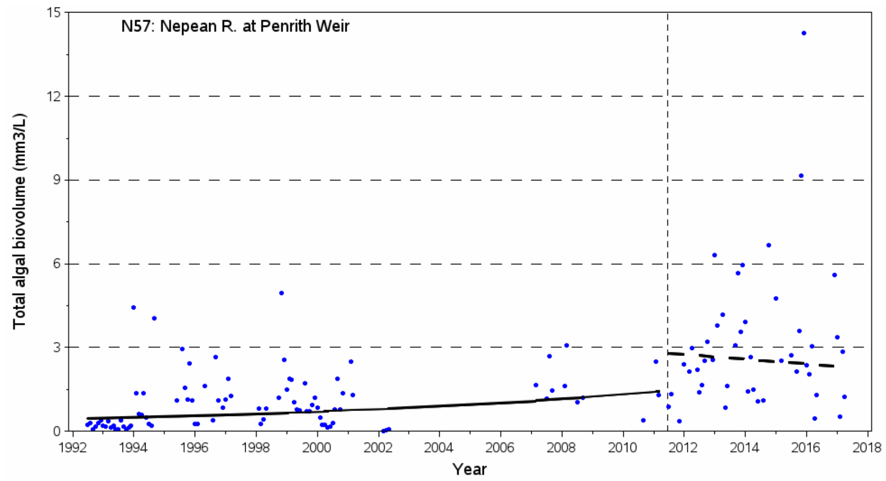
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)



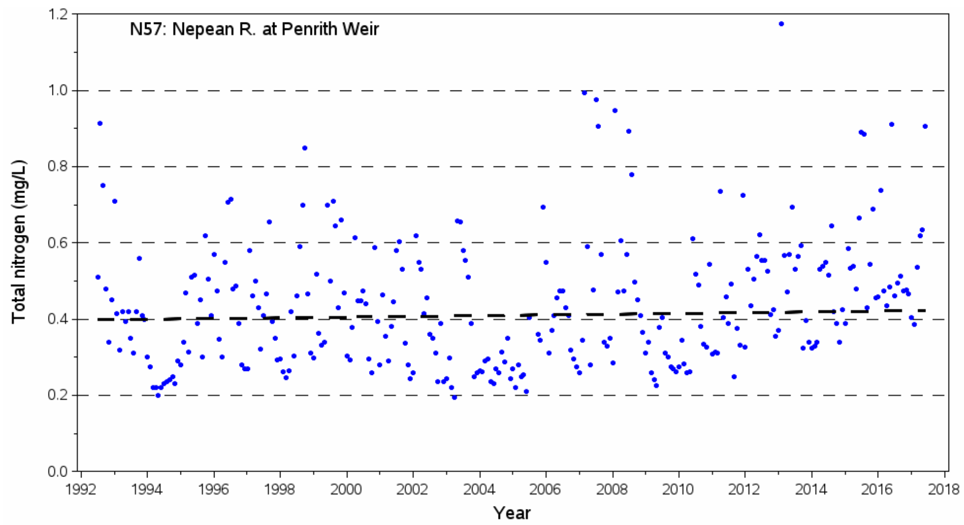


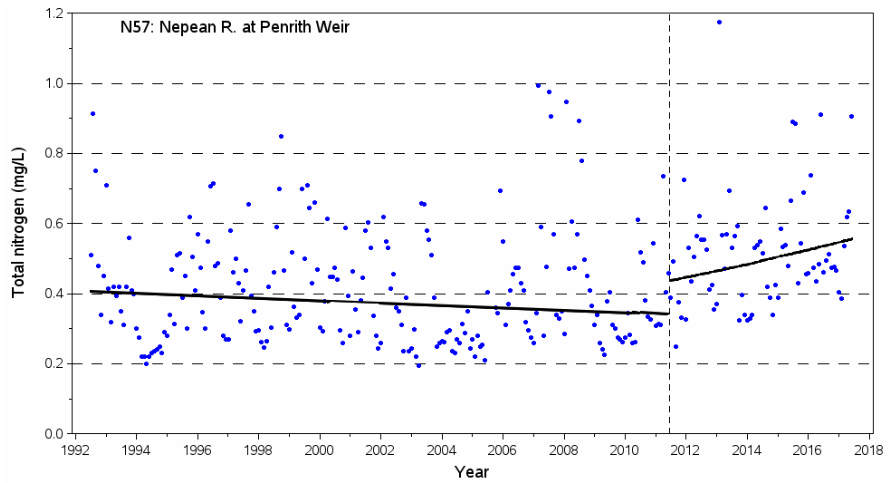


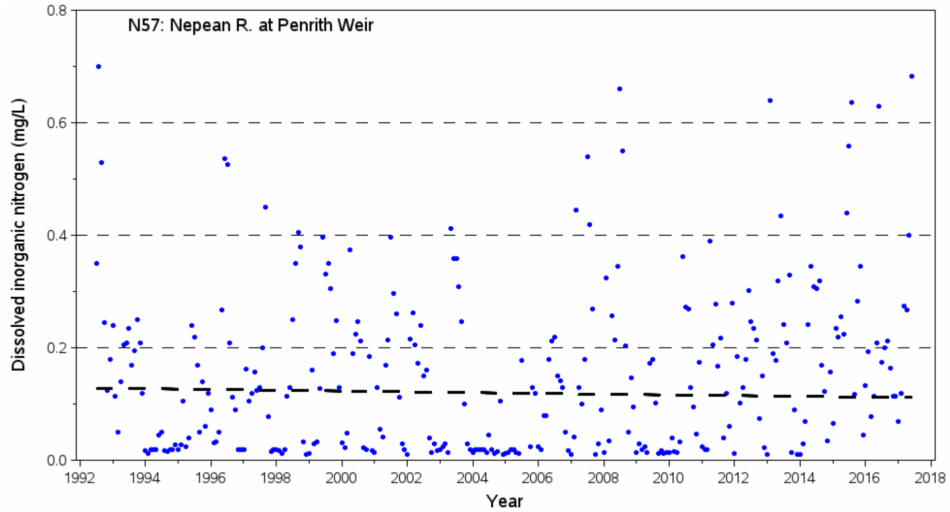


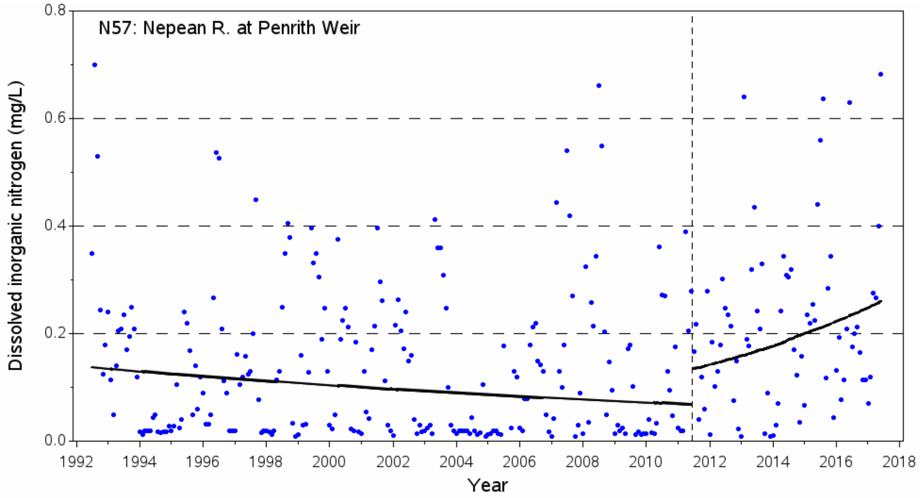
Limited data, no blue-green algal biovolume plots constructed

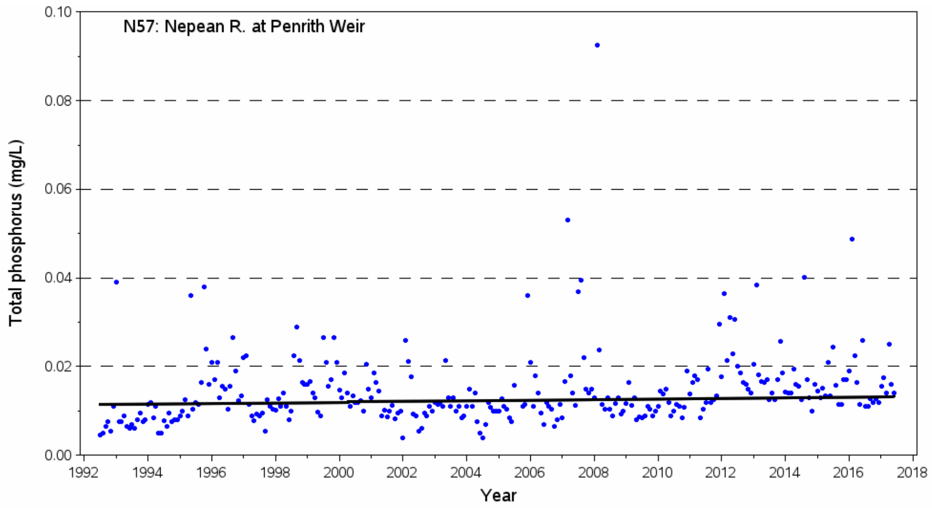
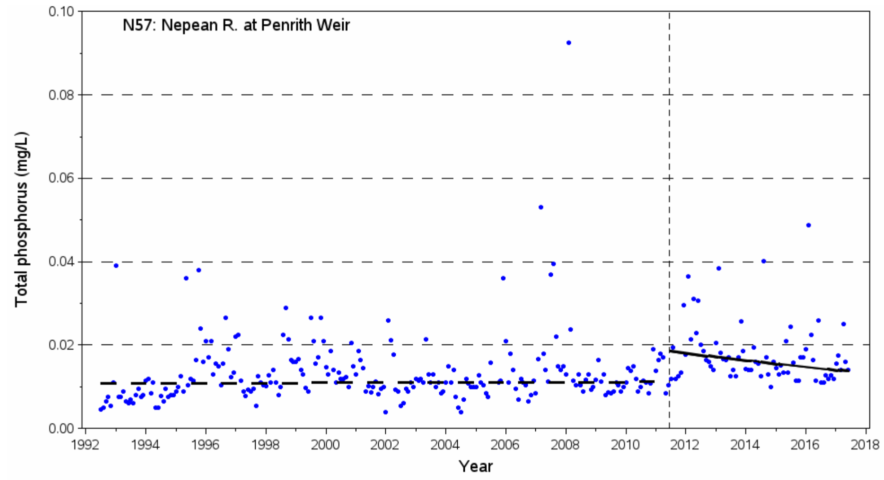
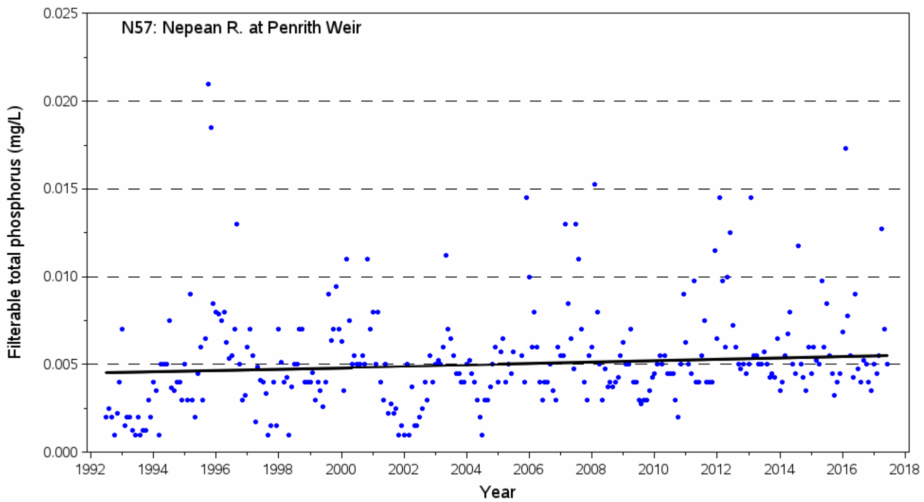
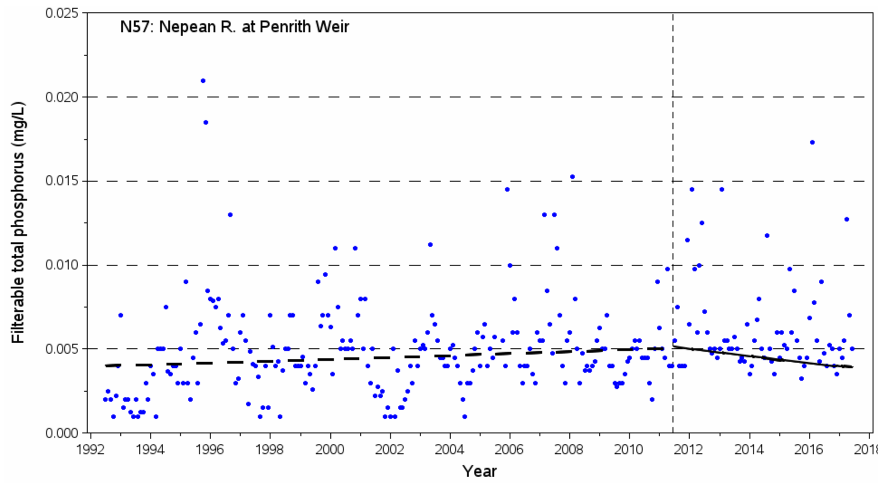
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)



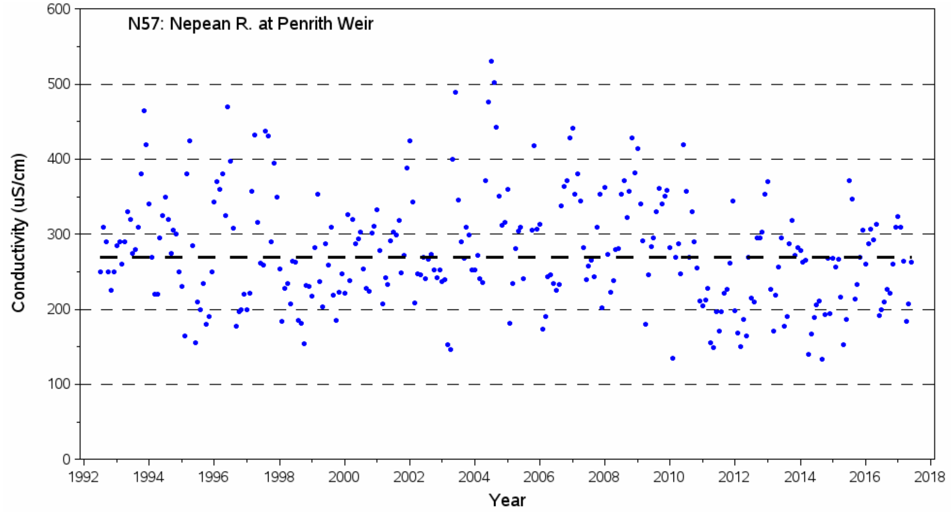


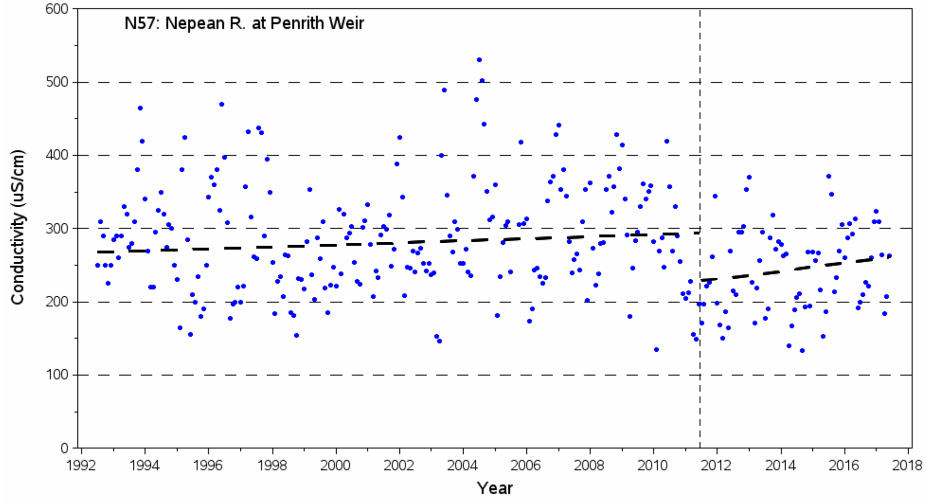


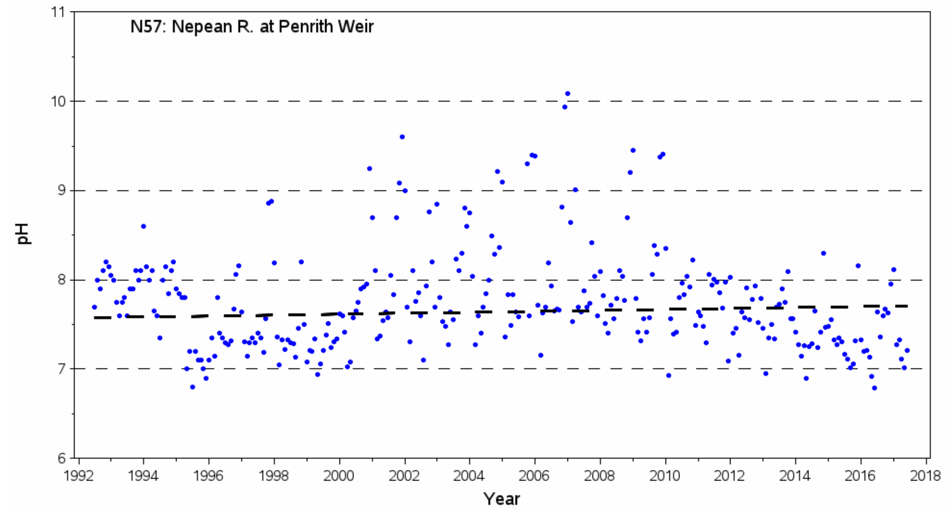


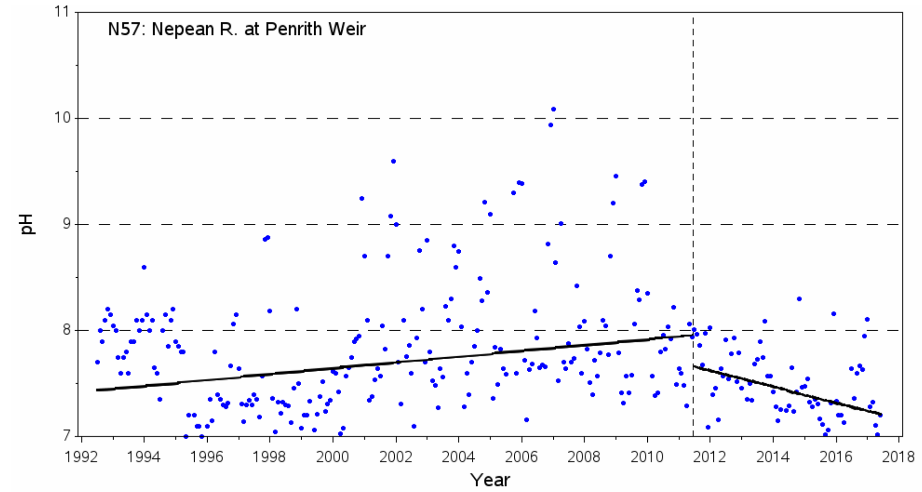
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

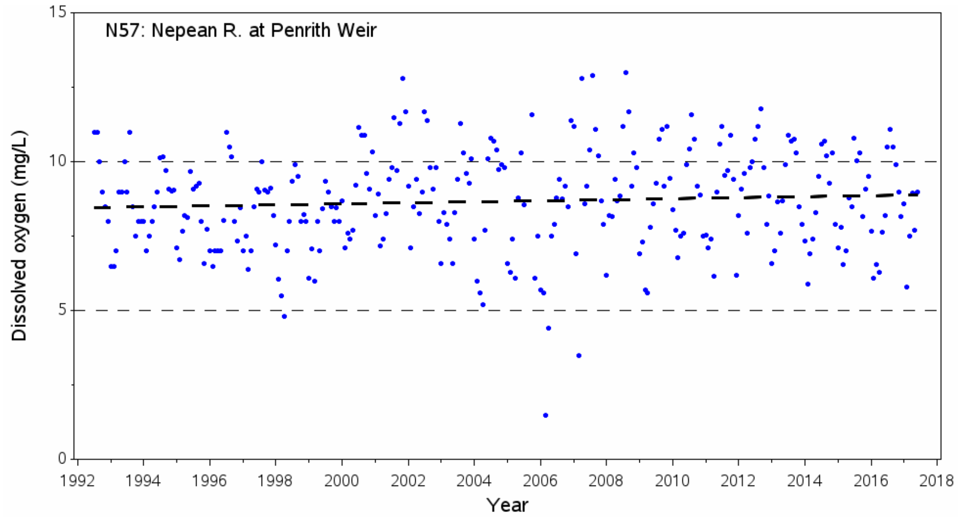
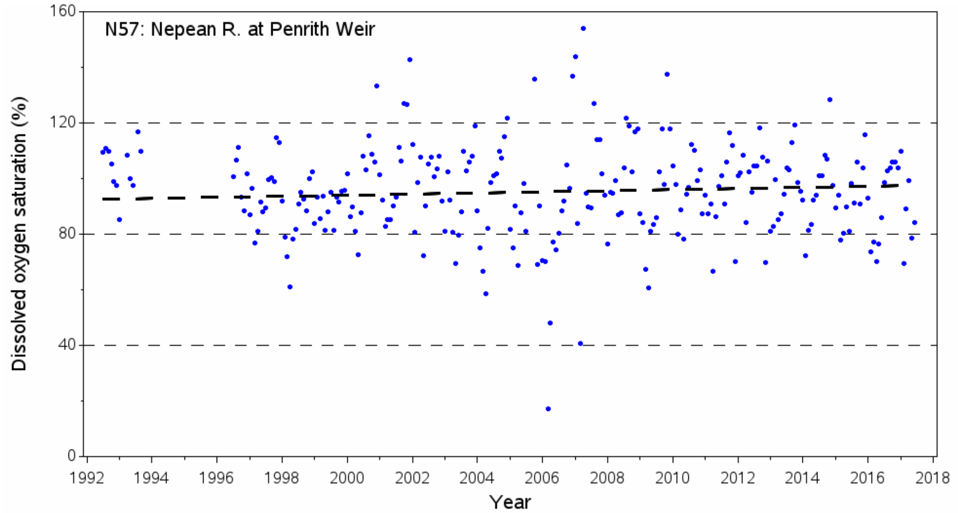
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)









One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

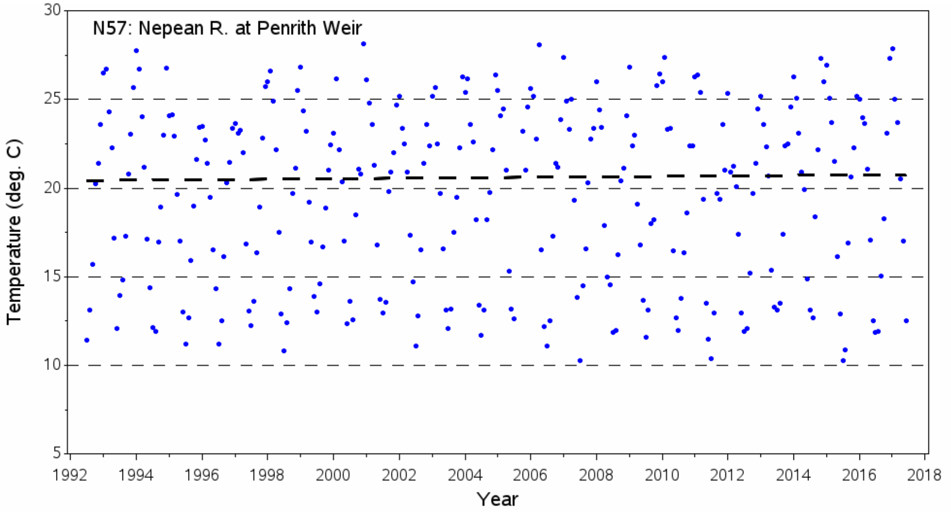
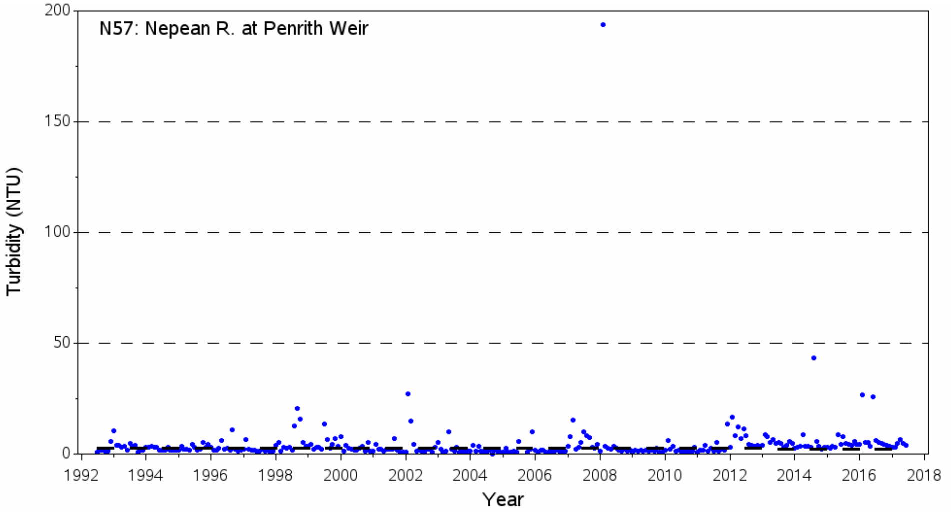
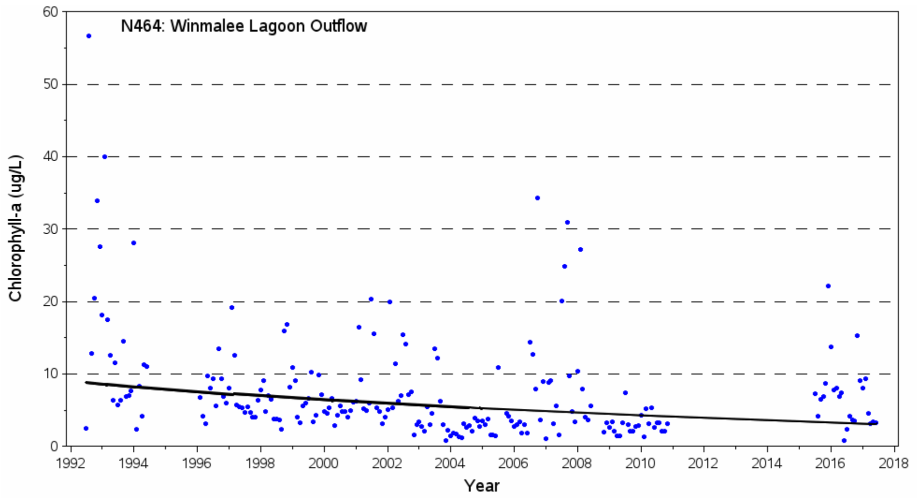
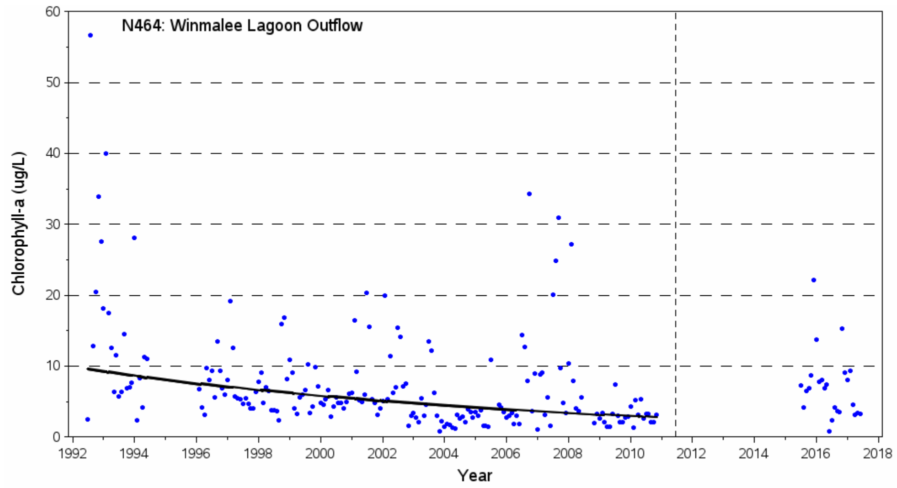
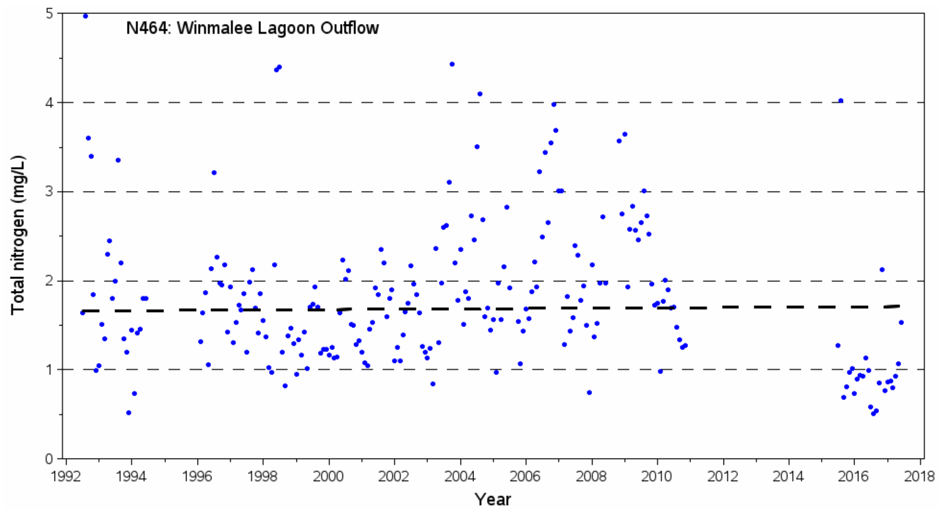
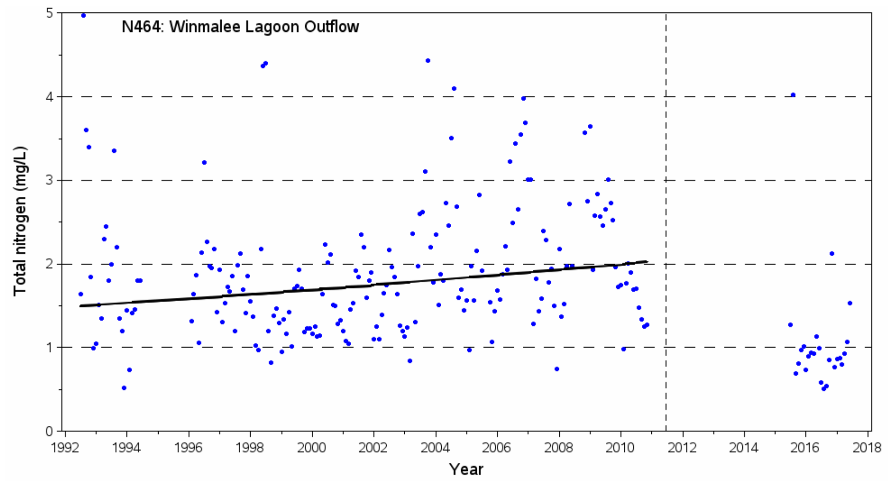
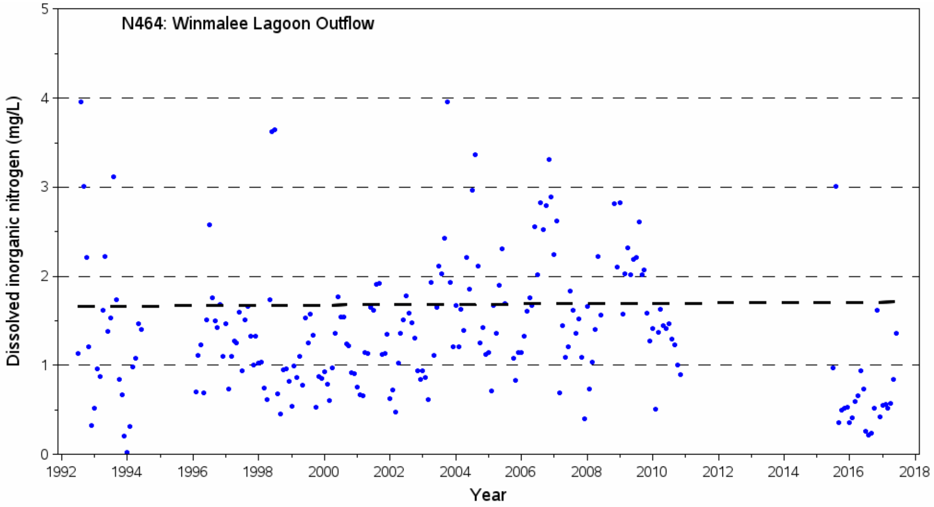
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

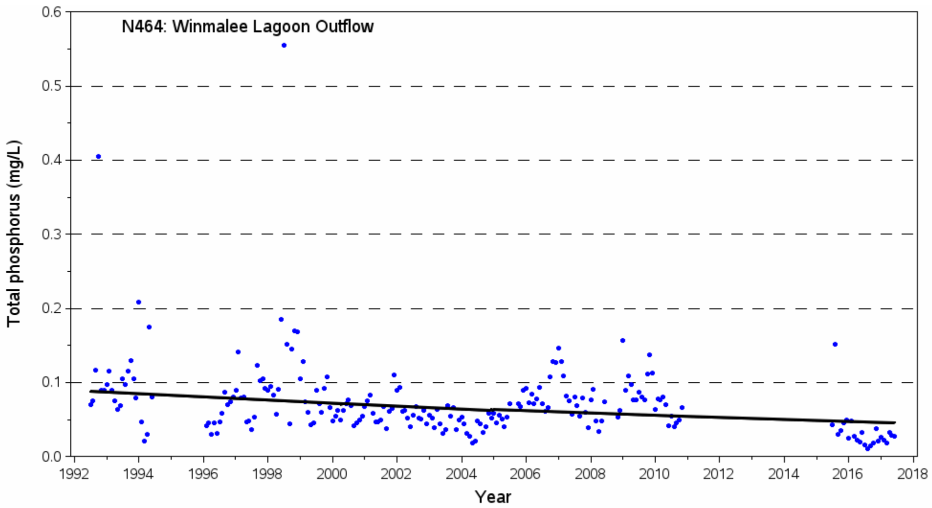
Figure E-6 Temporal trends in water quality: Winmalee Lagoon outflow at Springwood Road (N464)

Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

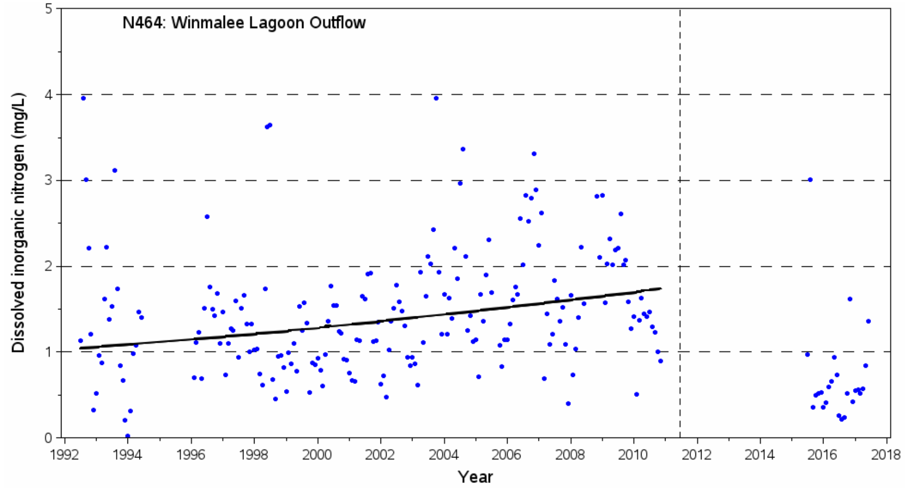
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
Limited algal data, no plots constructed	
	

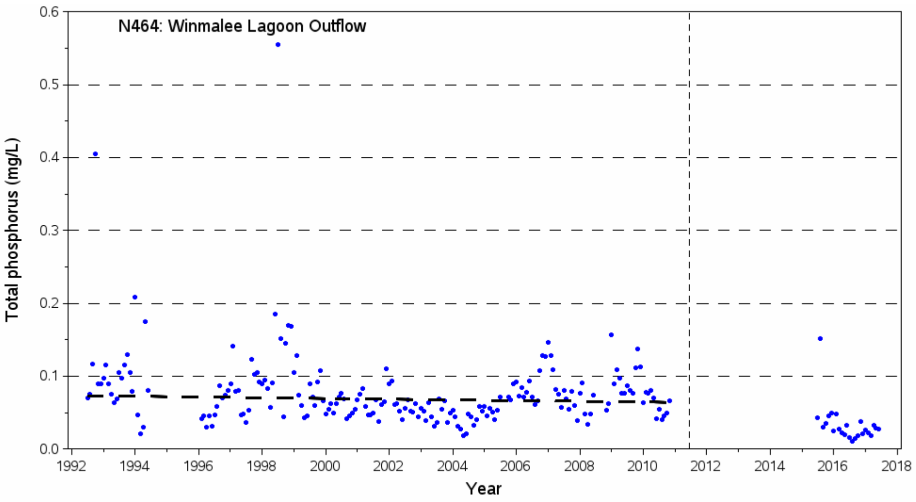
One trend for the entire period (long-term)



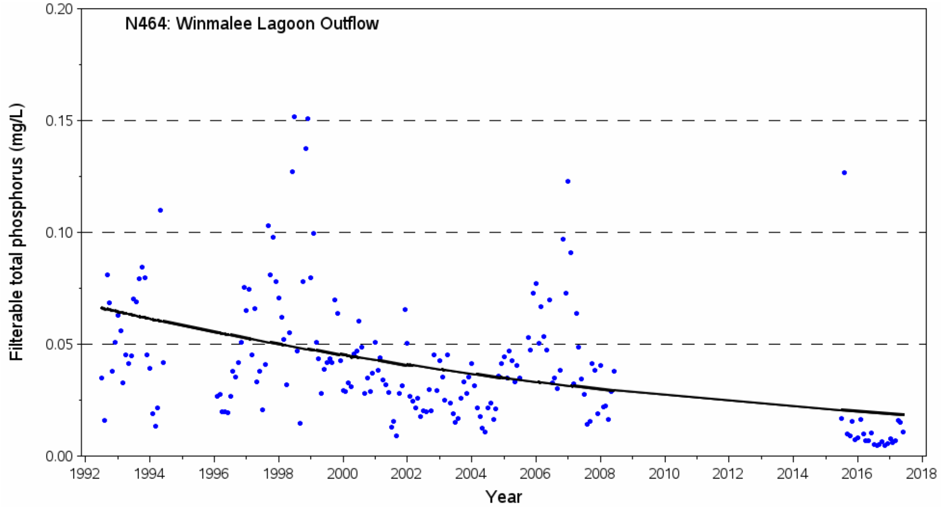


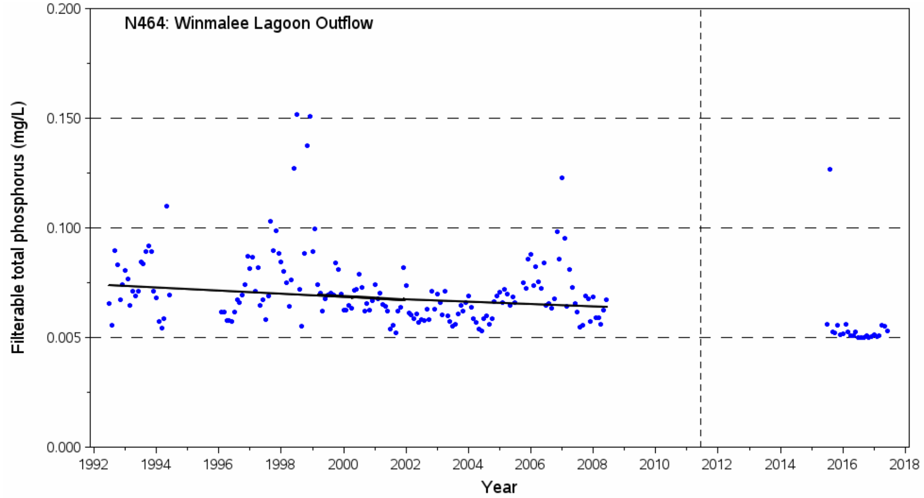
Step trends for two distinct periods (historical and short-term)

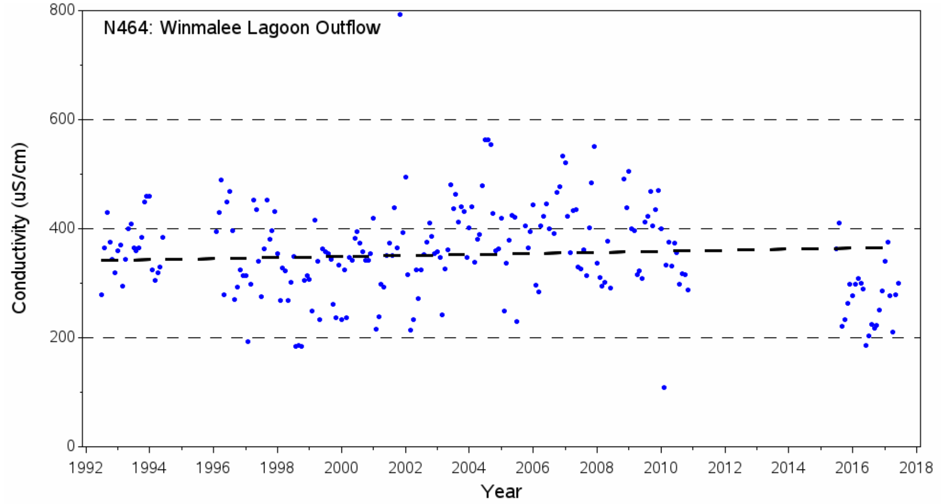


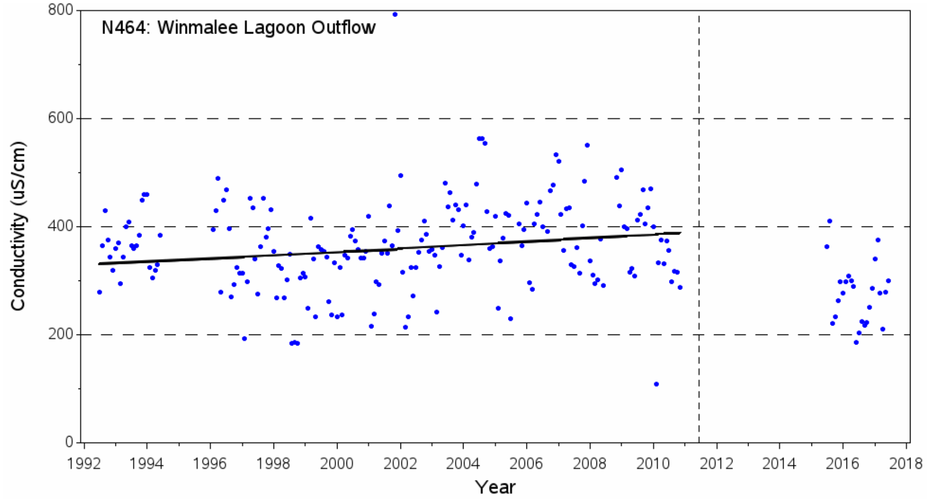


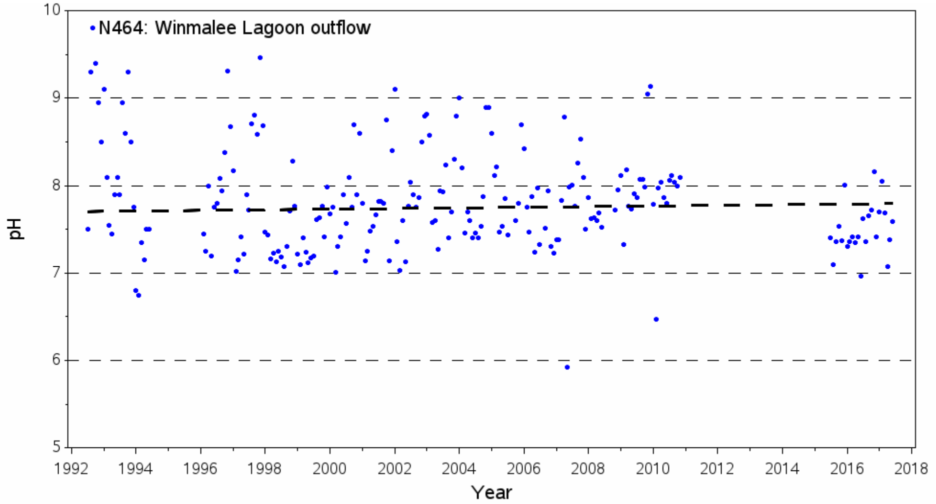
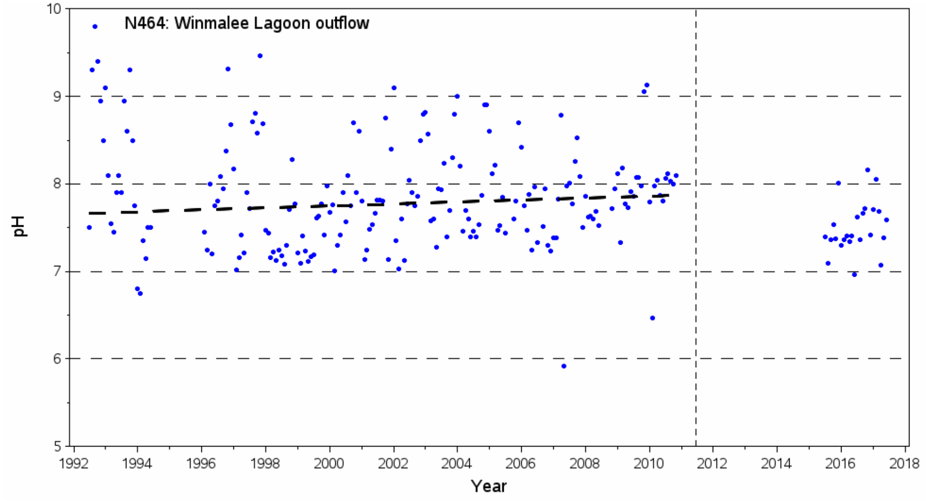
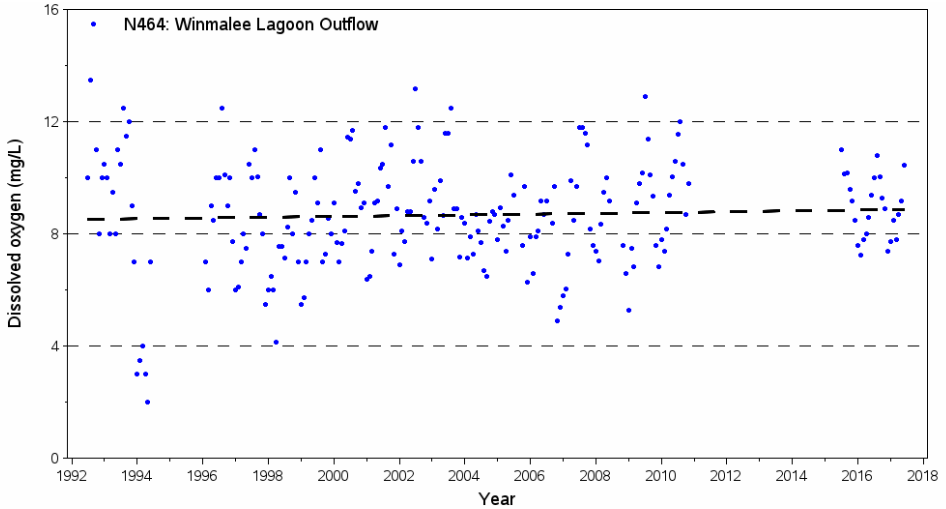
One trend for the entire period (long-term) | **Step trends for two distinct periods (historical and short-term)**

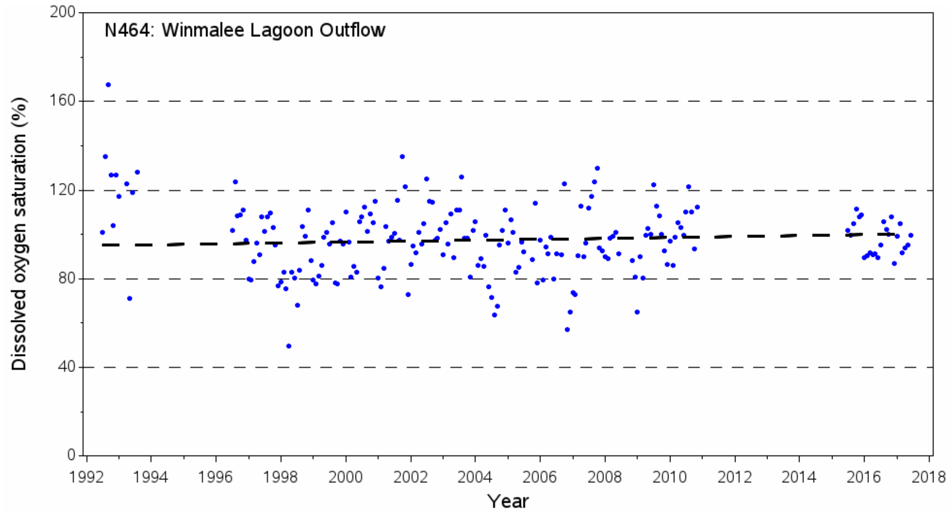
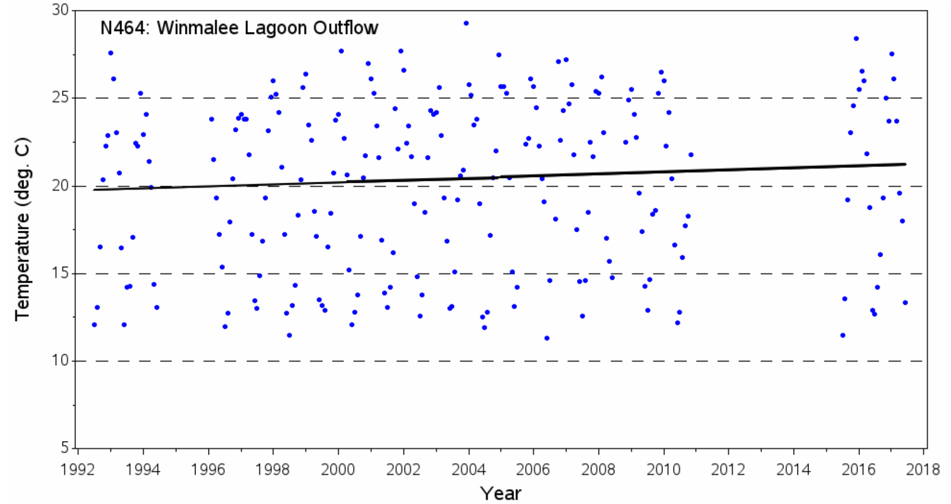








One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

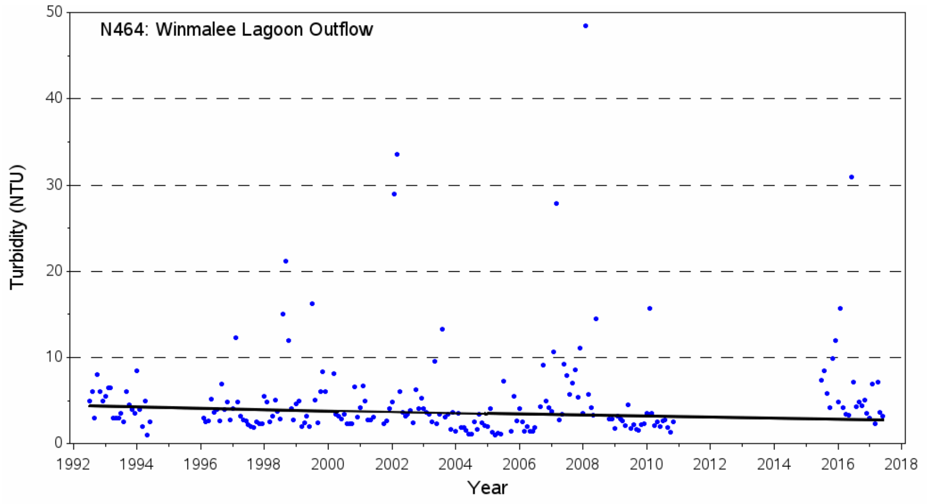
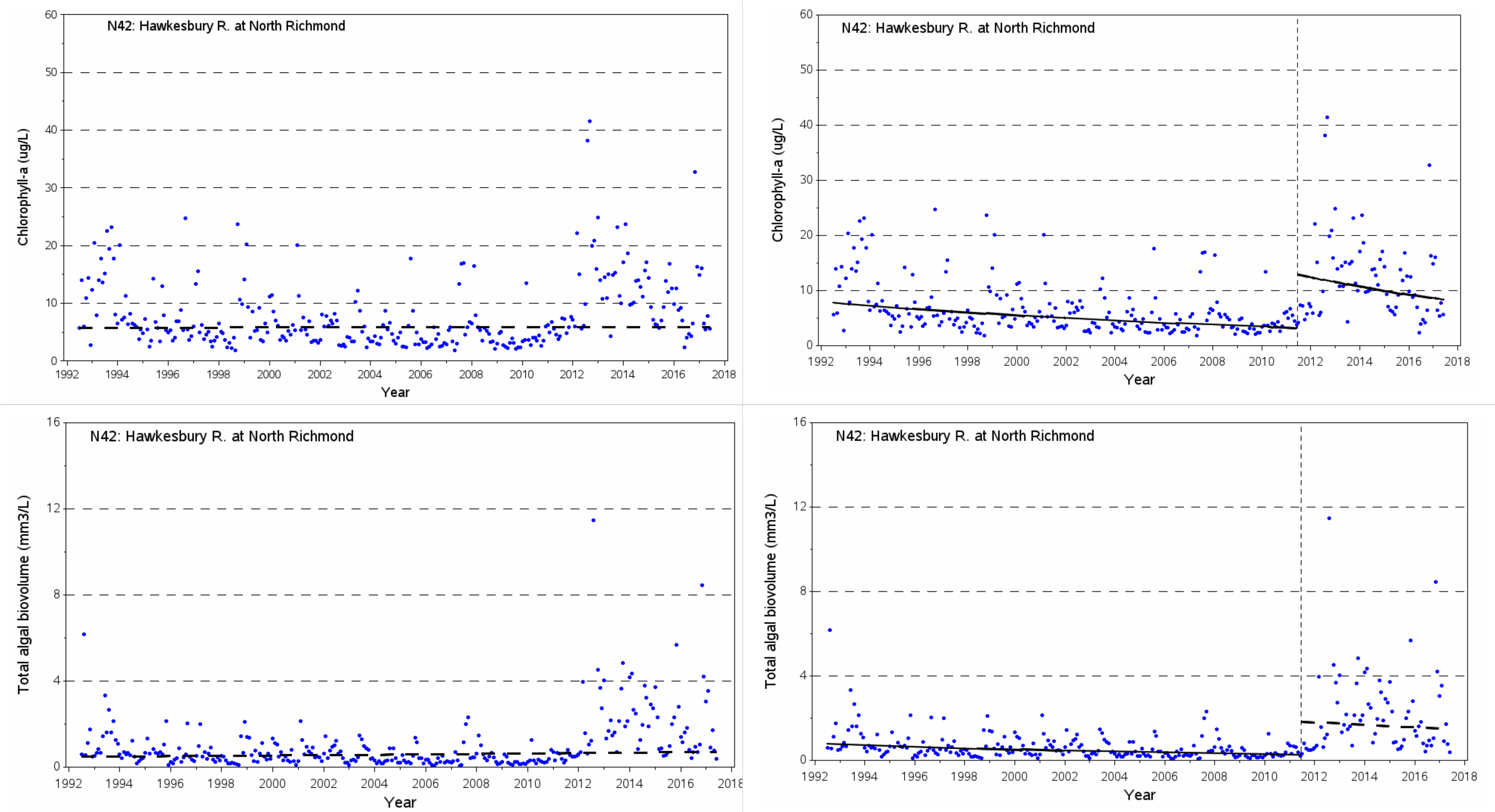
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

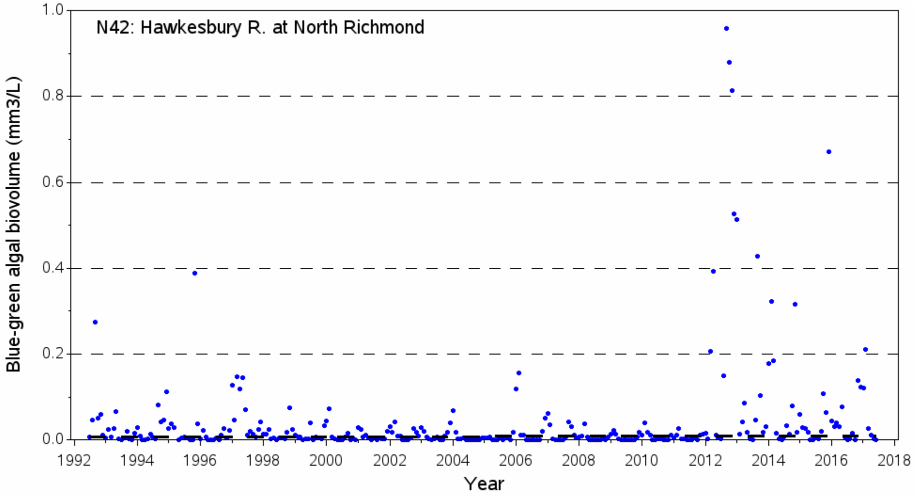
Figure E-7 Temporal trends in water quality: Hawkesbury River at North Richmond (N42)

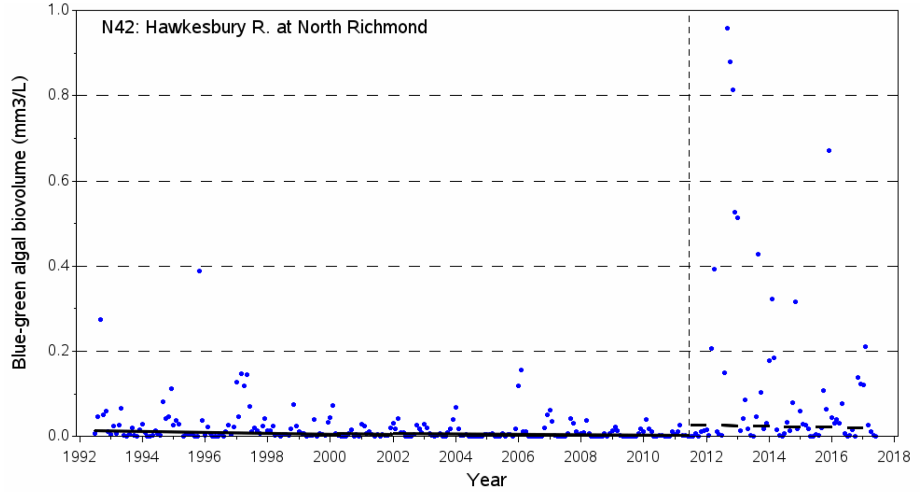
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

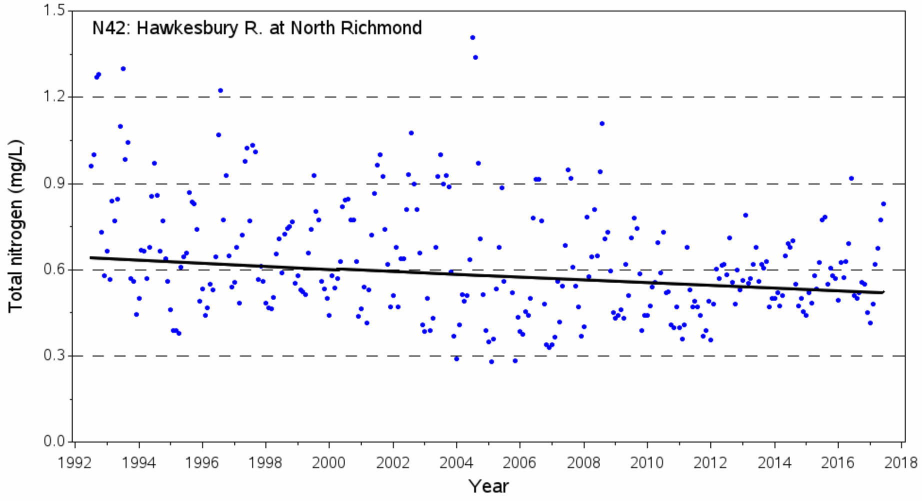
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

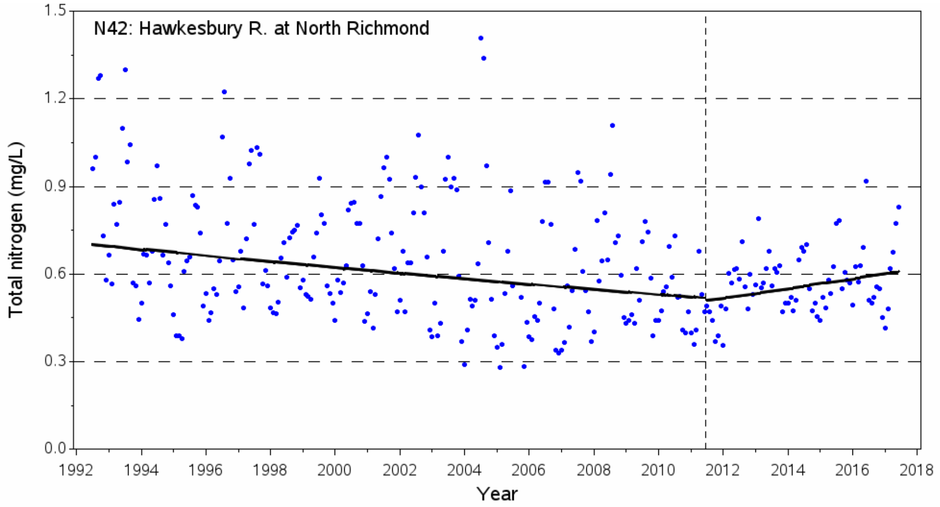


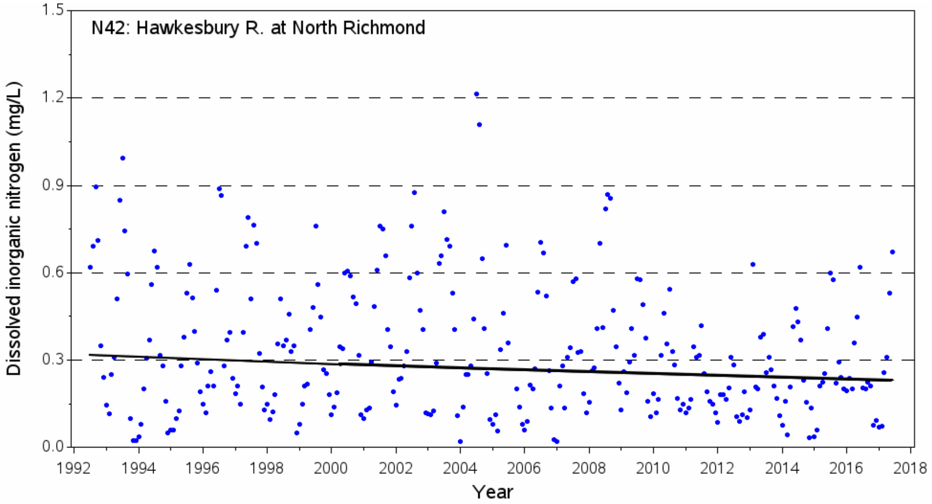
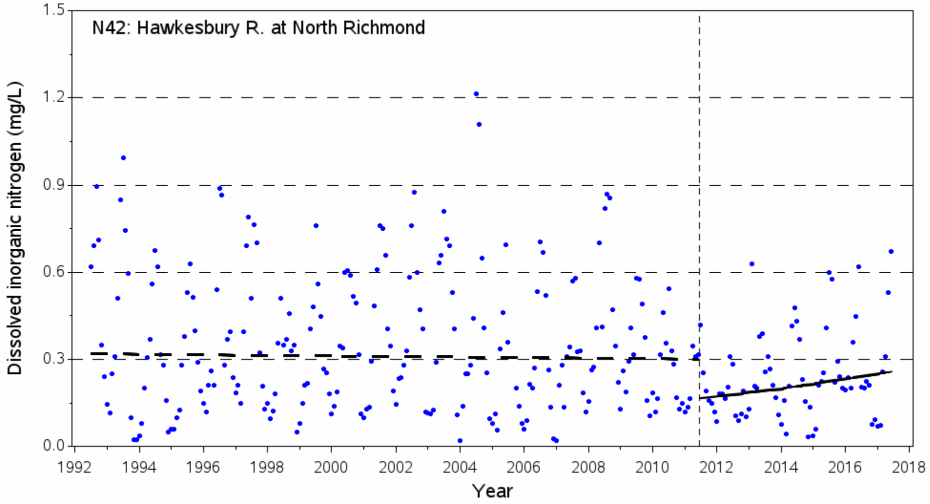
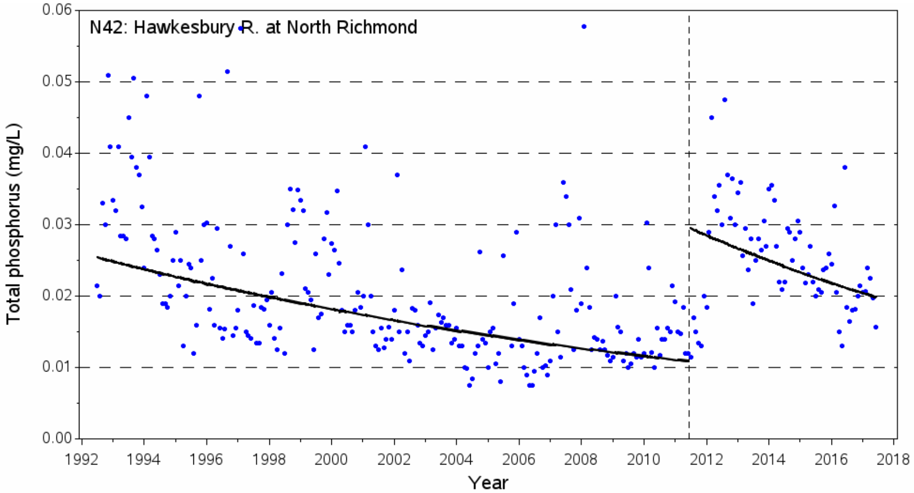
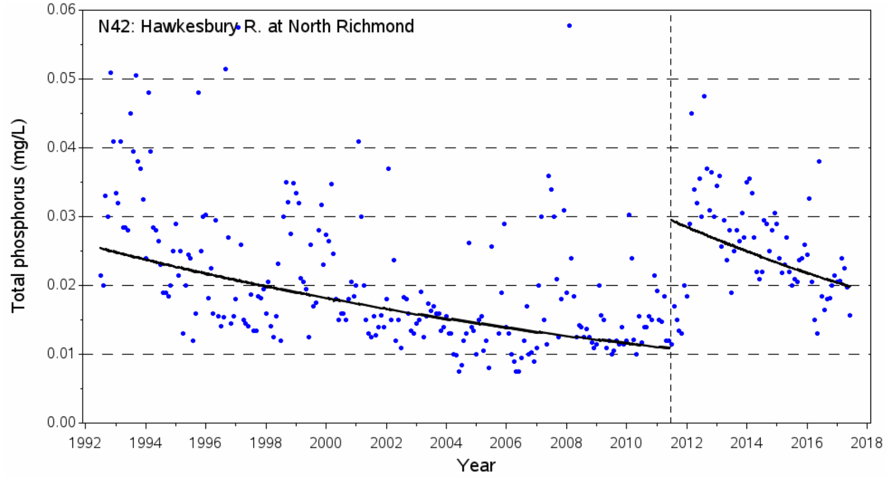
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)



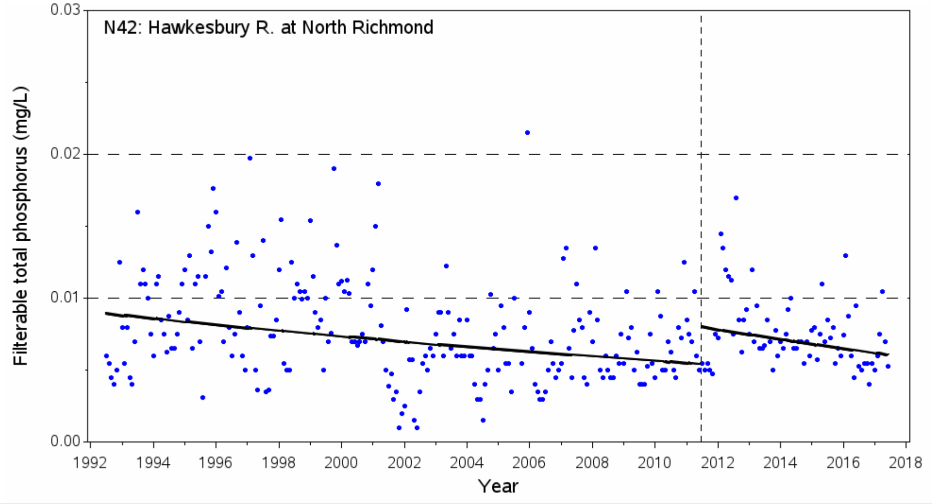


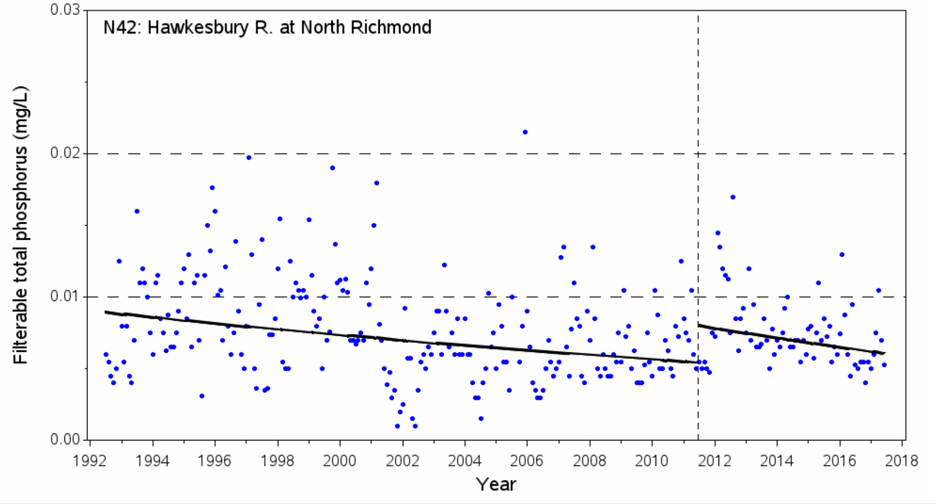


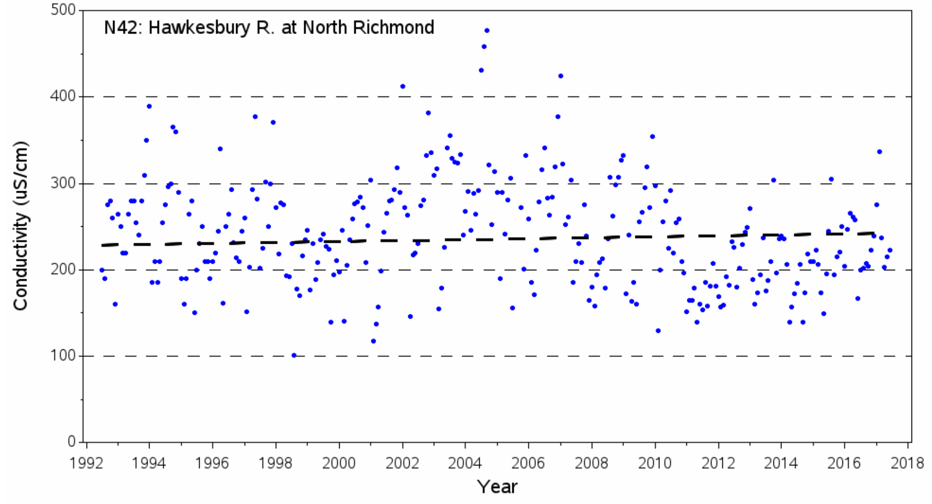


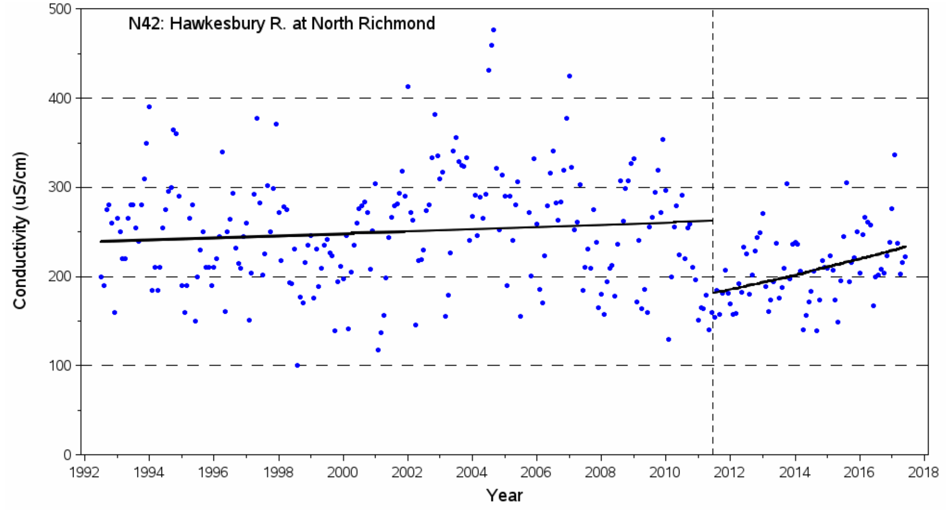
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

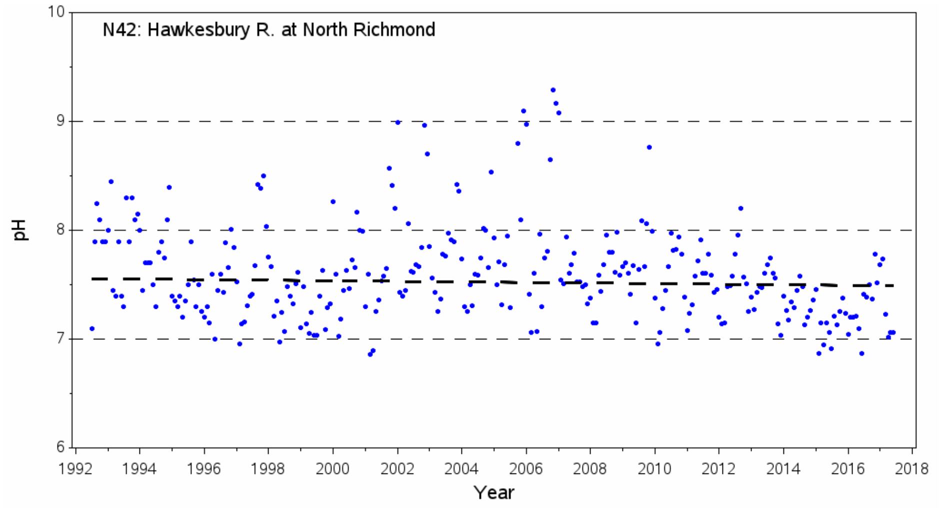
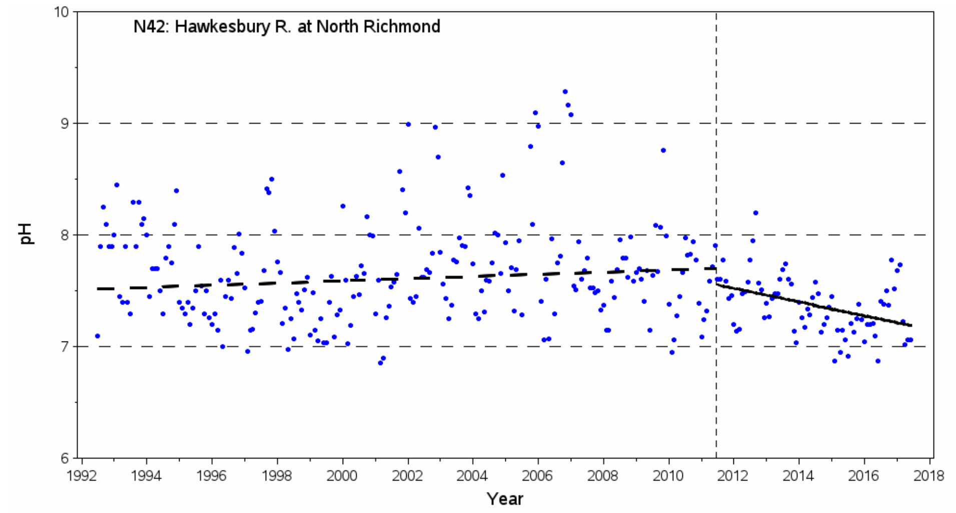
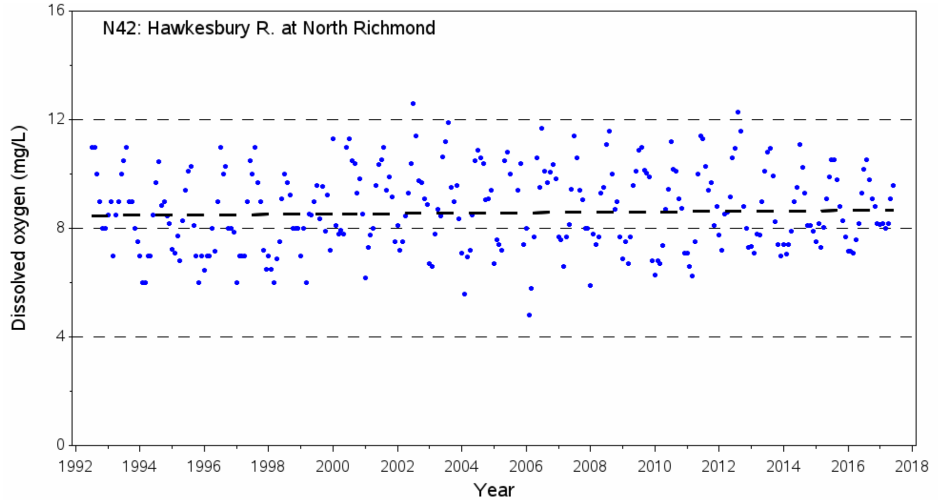
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

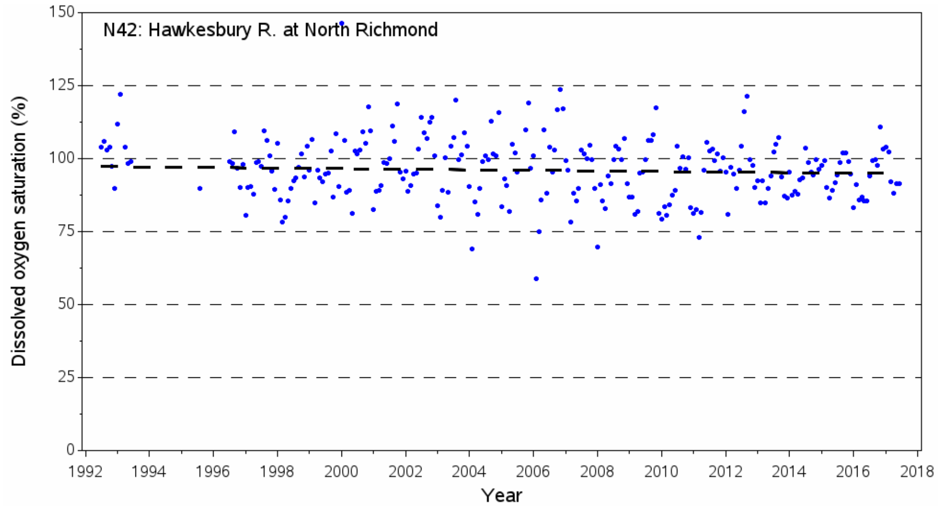
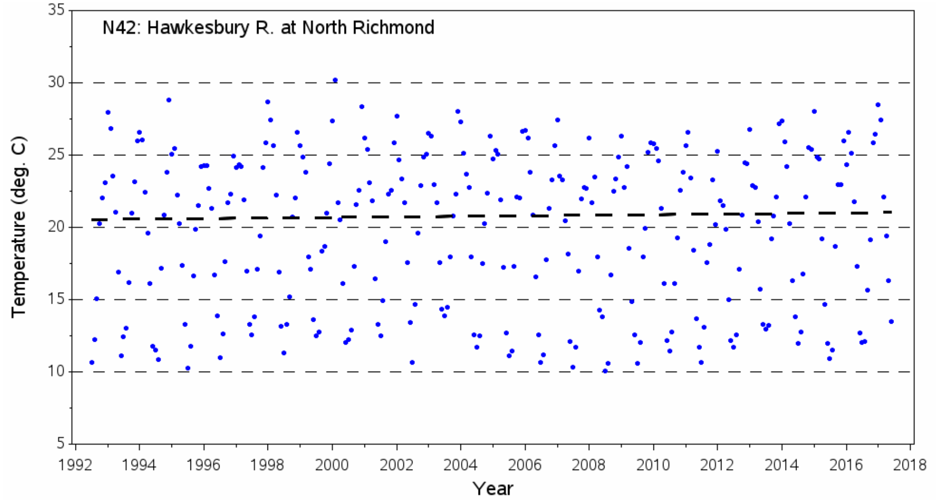








One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

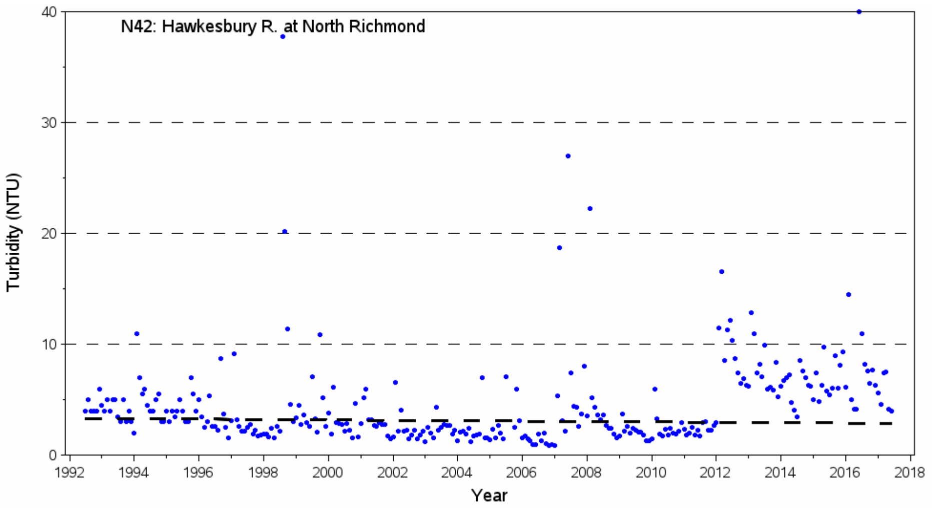
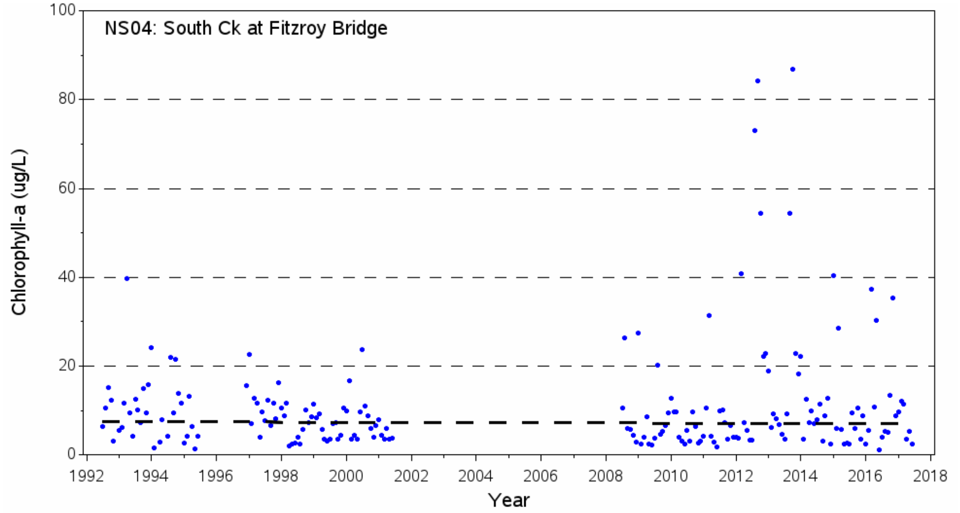
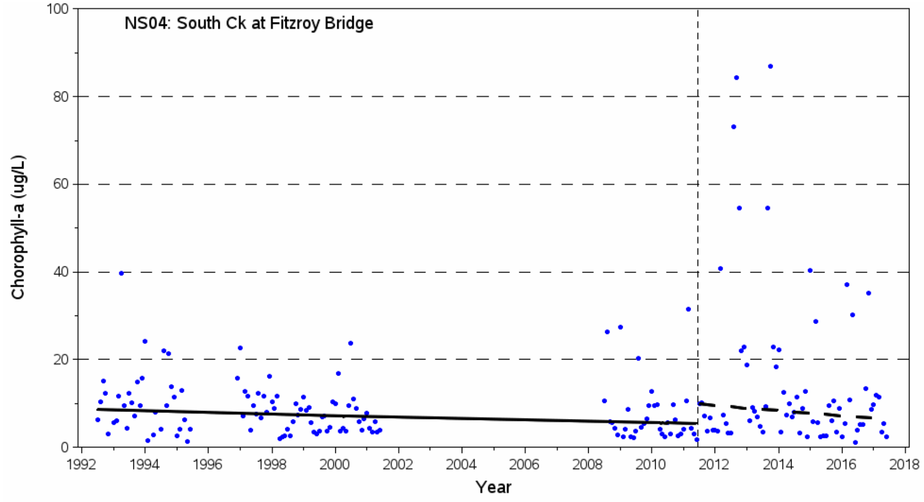
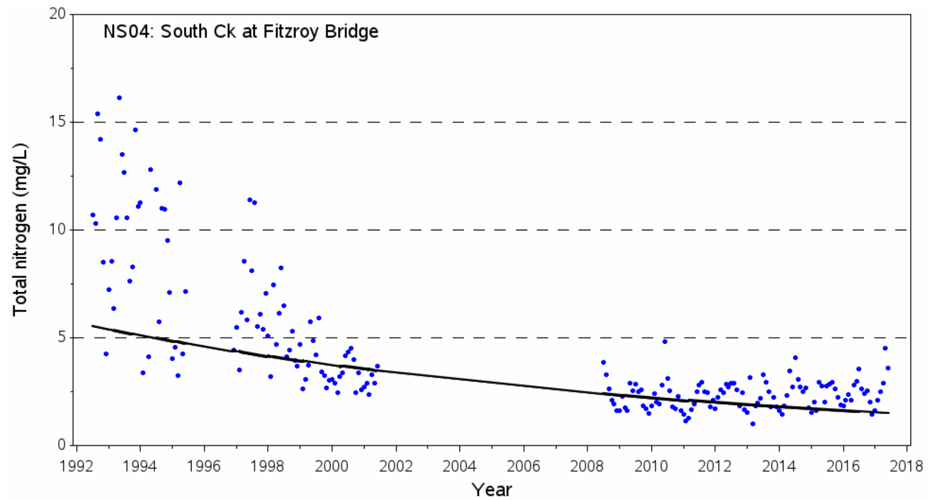
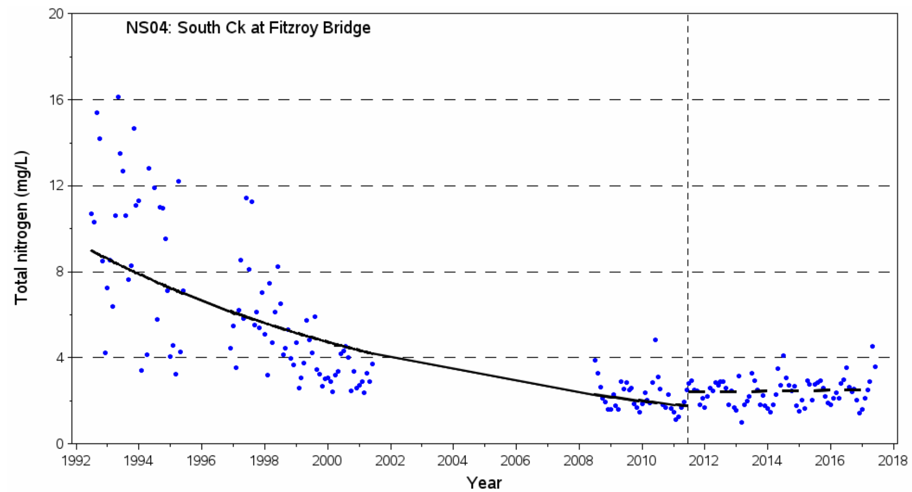
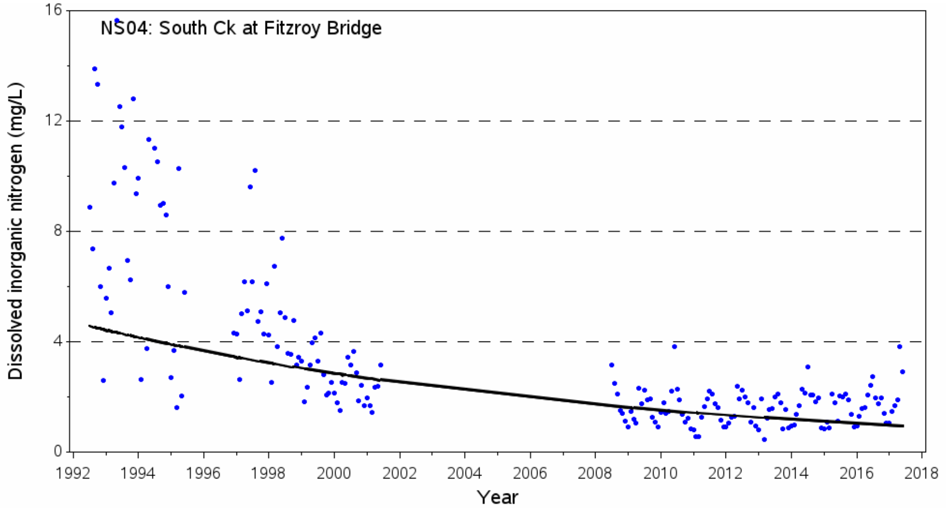
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

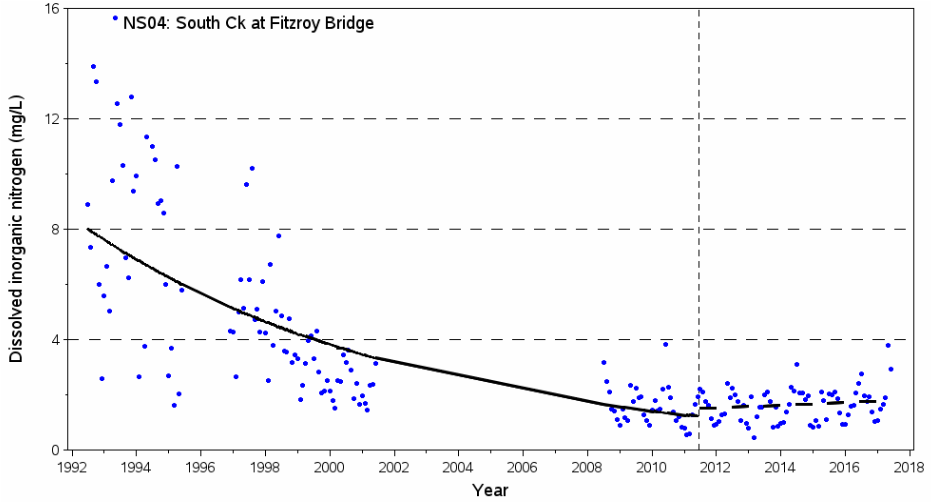
Figure E-8 Temporal trends in water quality: -South Creek at Fitzroy pedestrian bridge (NS04)

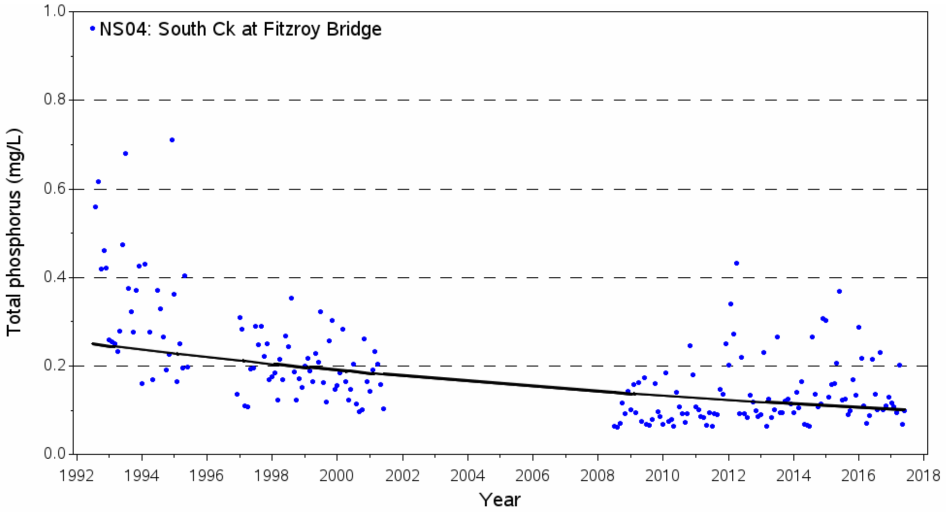
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

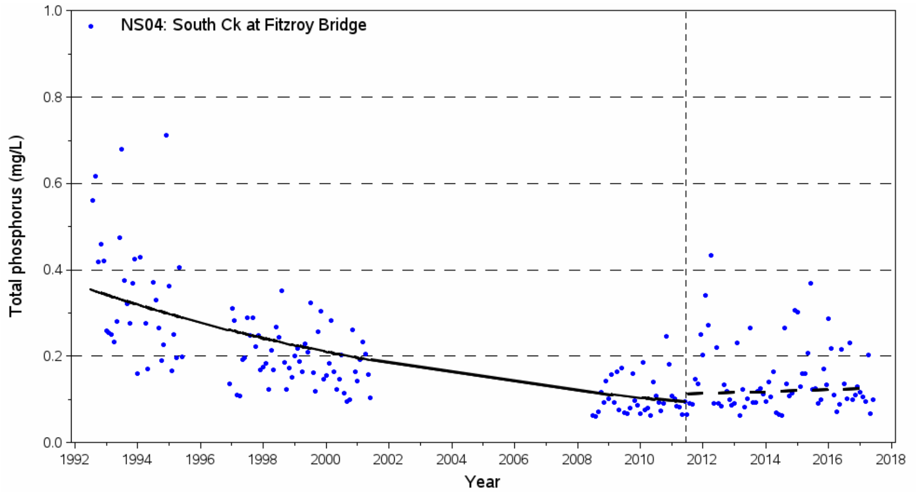
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
Limited algal data, no plots constructed	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

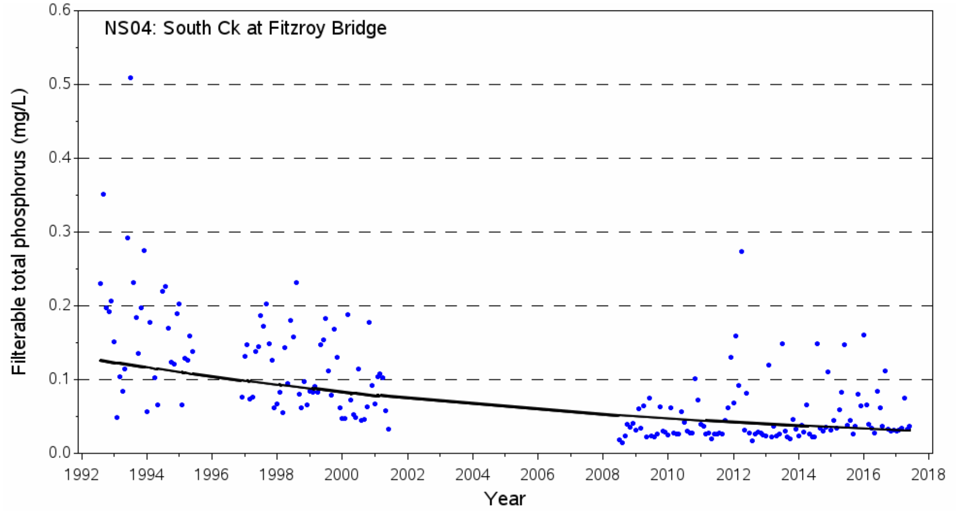


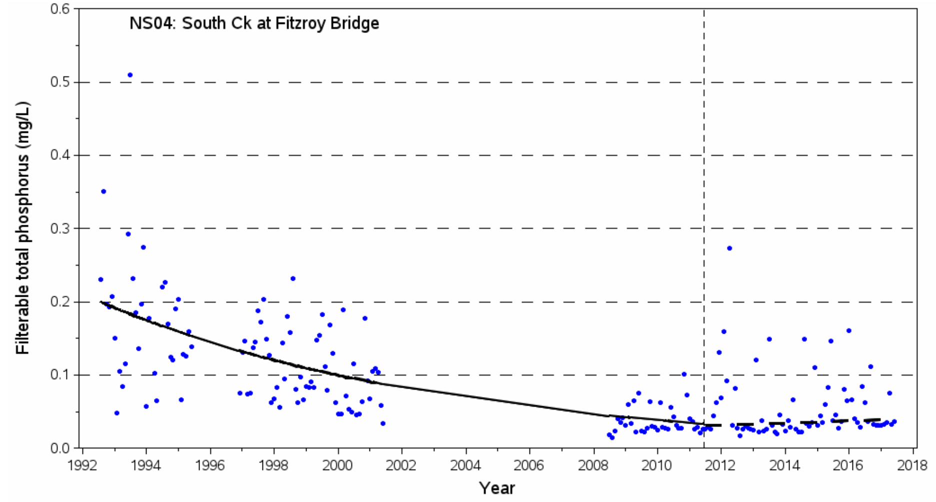


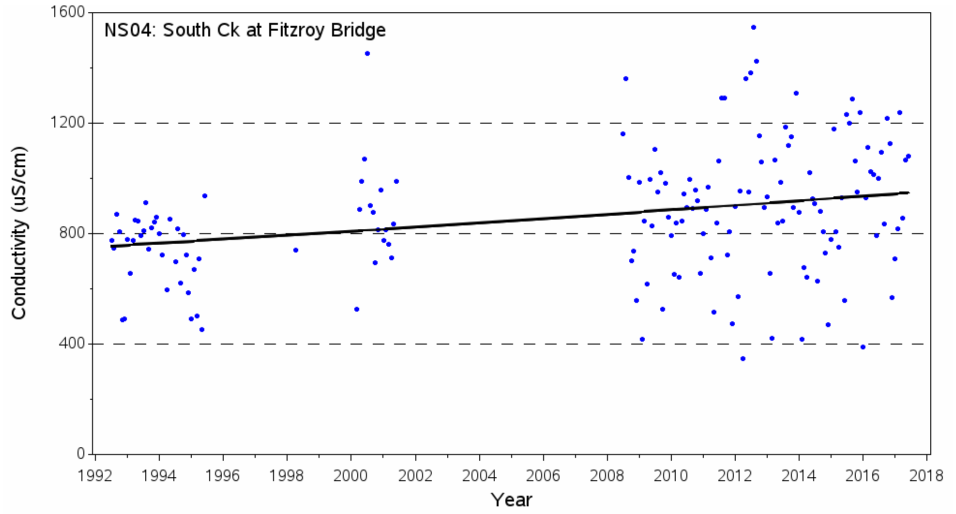


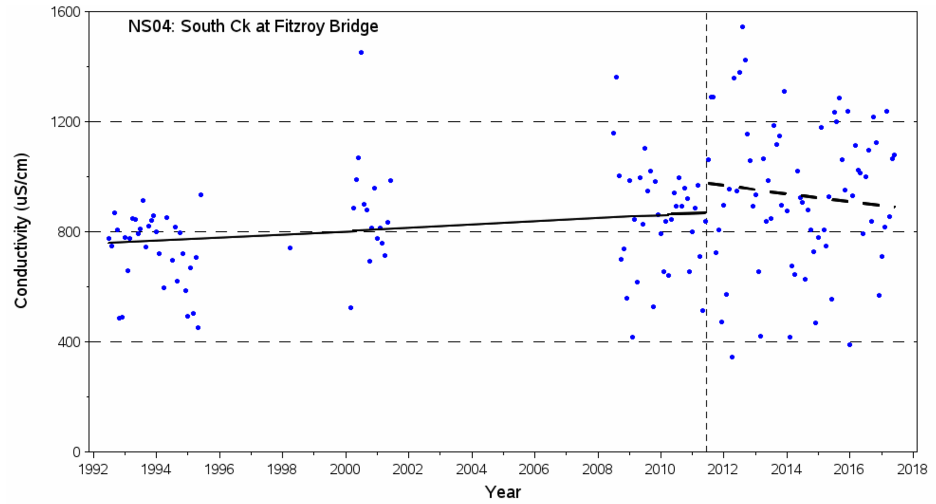


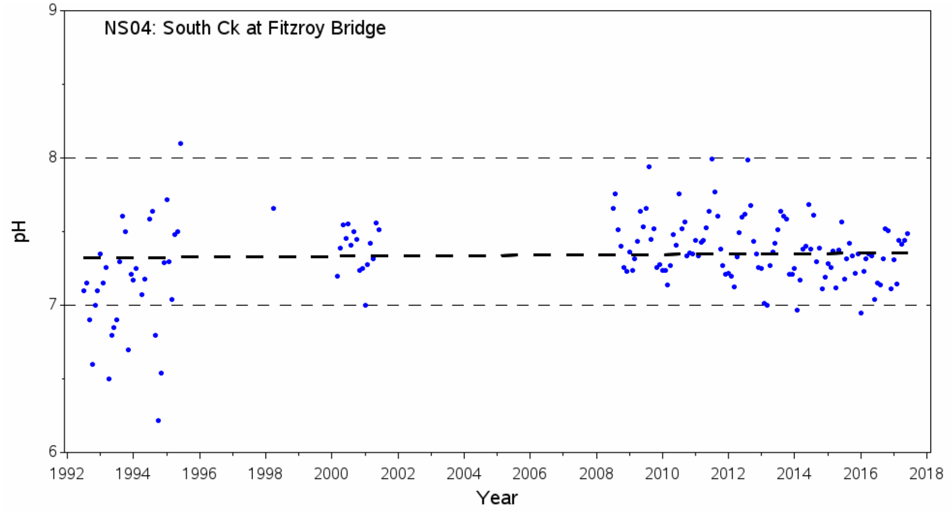
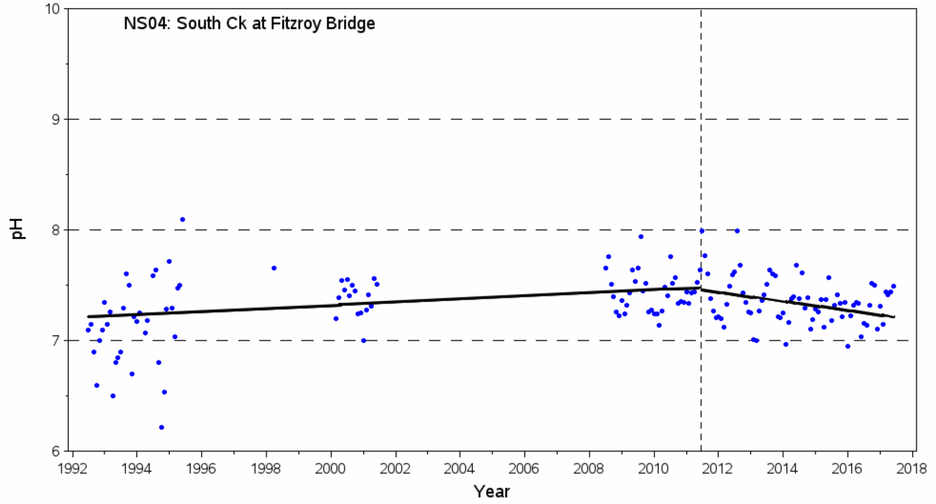
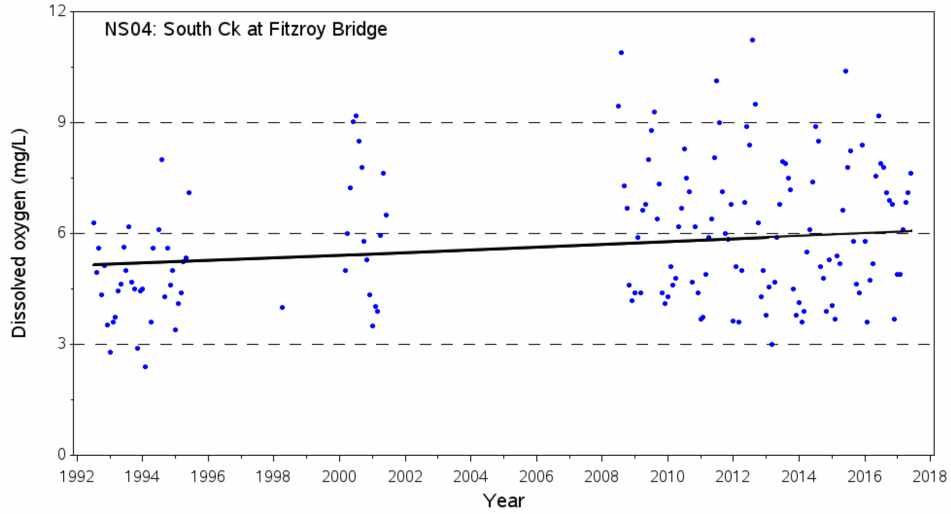
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

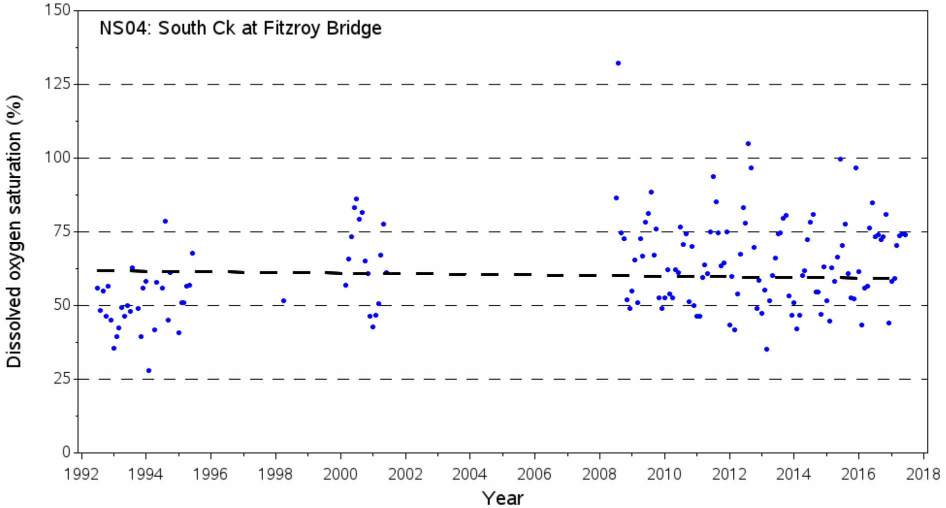
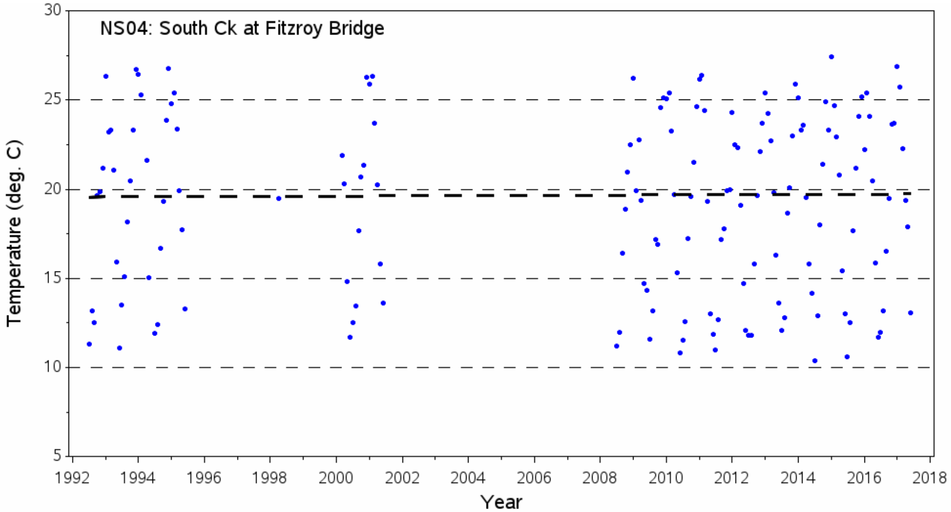








One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

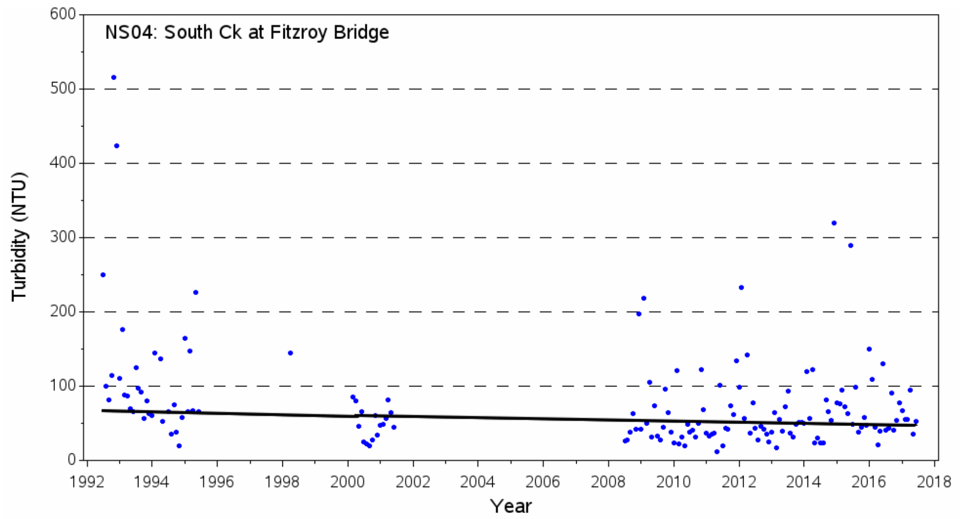
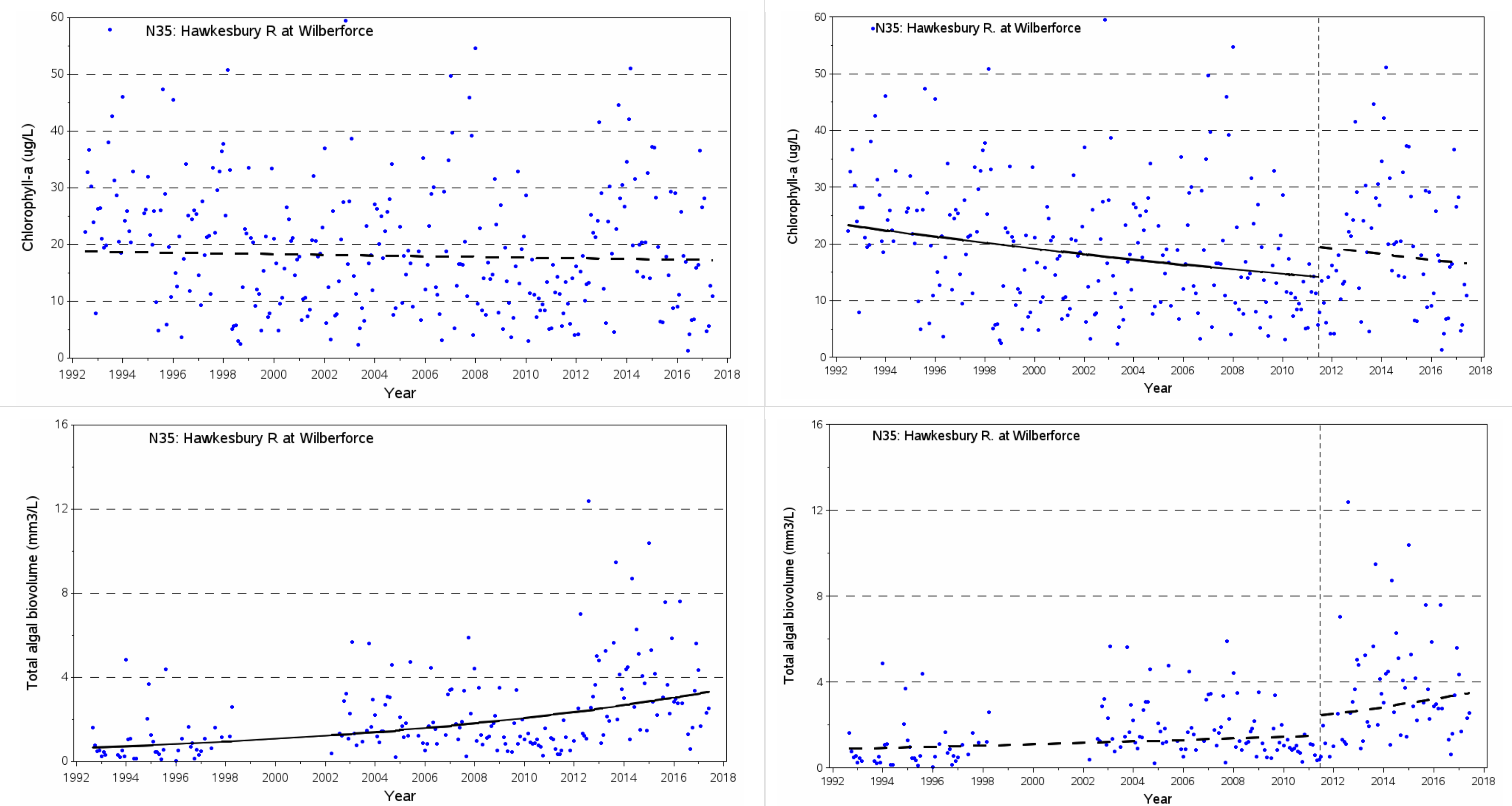
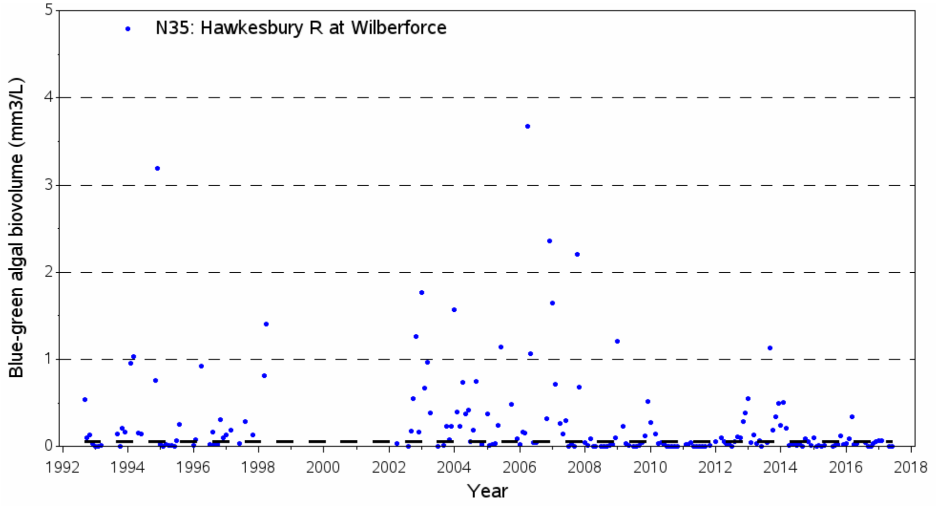
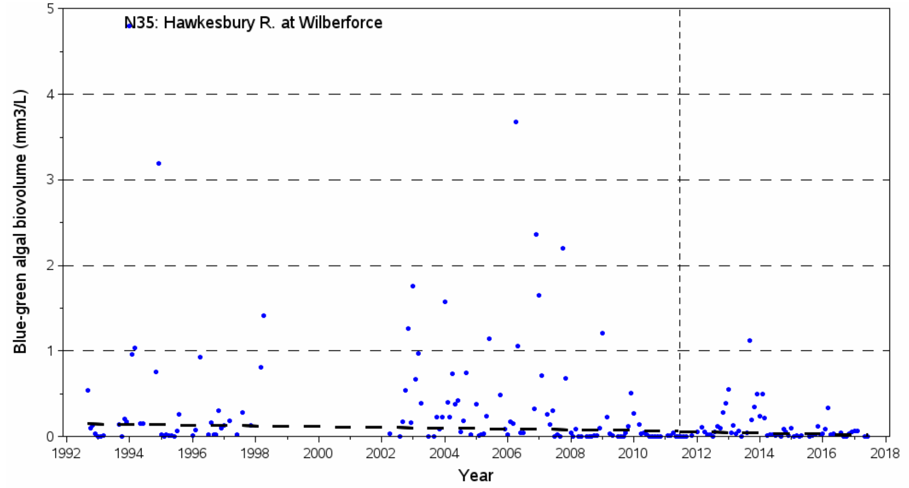
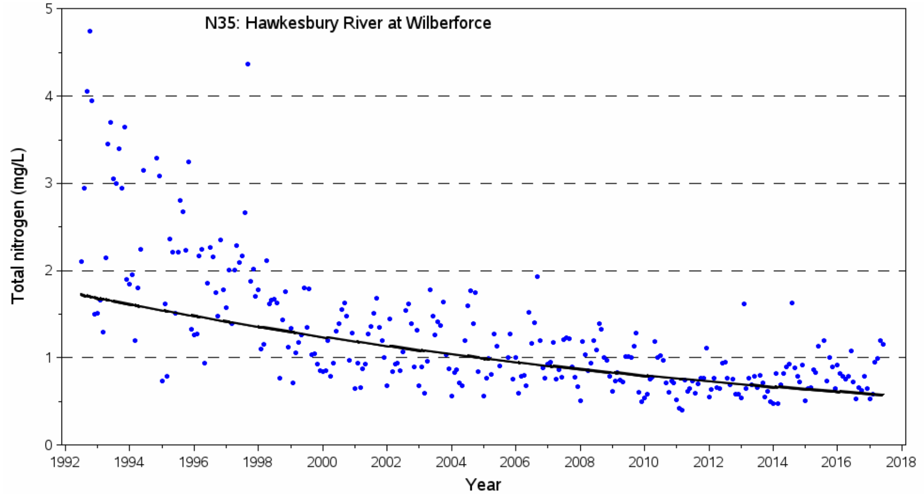
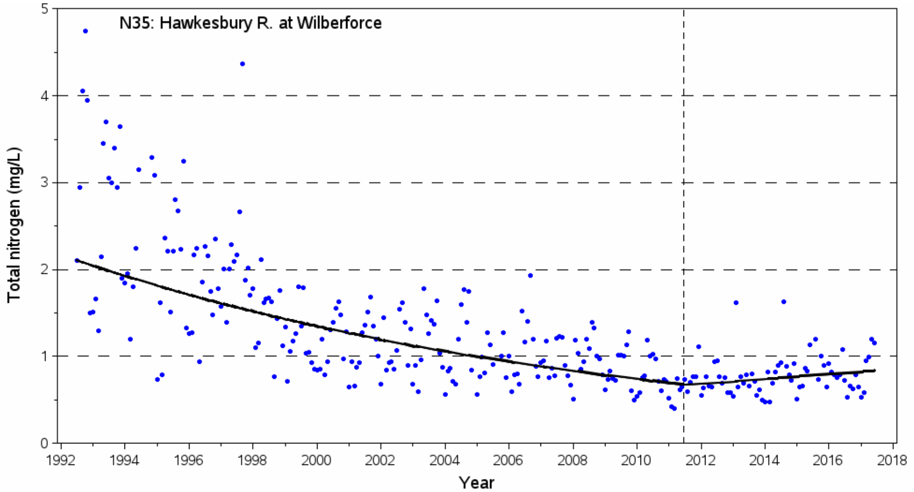
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

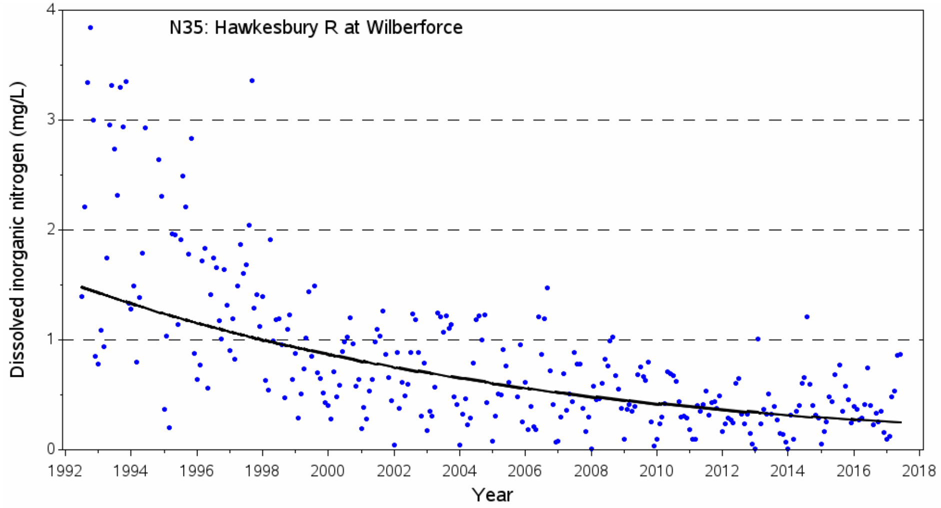
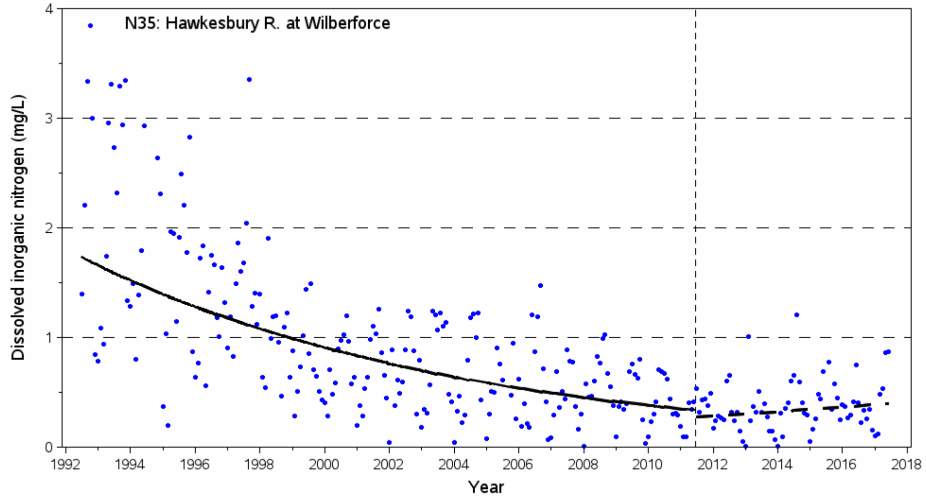
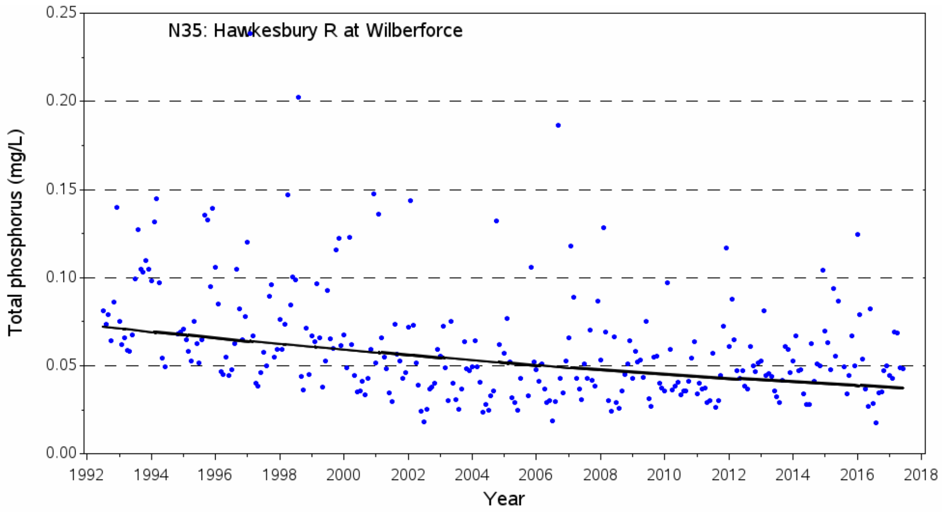
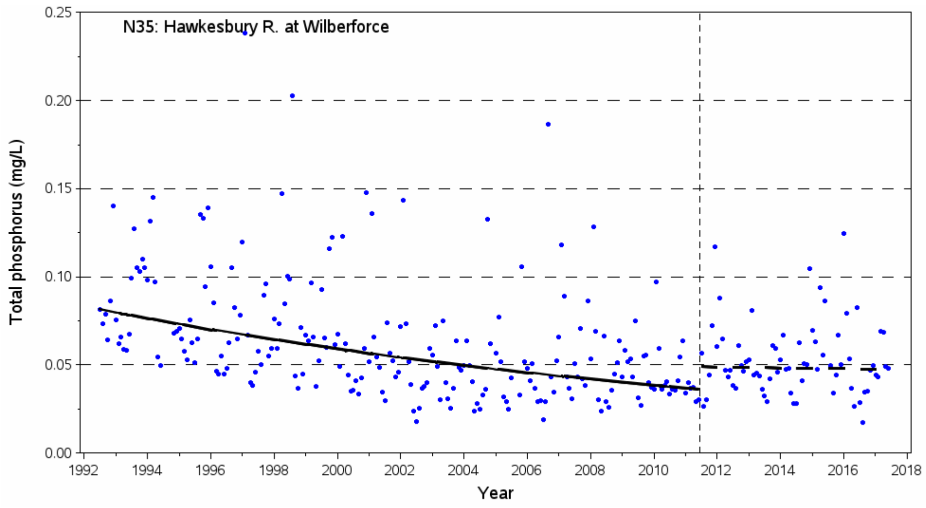
Figure E-9 Temporal trends in water quality: Hawkesbury River at Wilberforce (N35)

Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

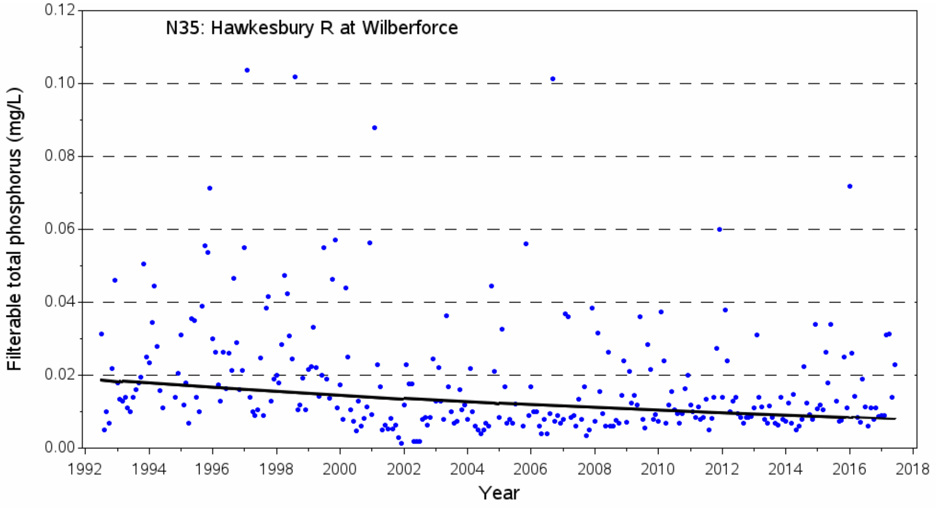
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

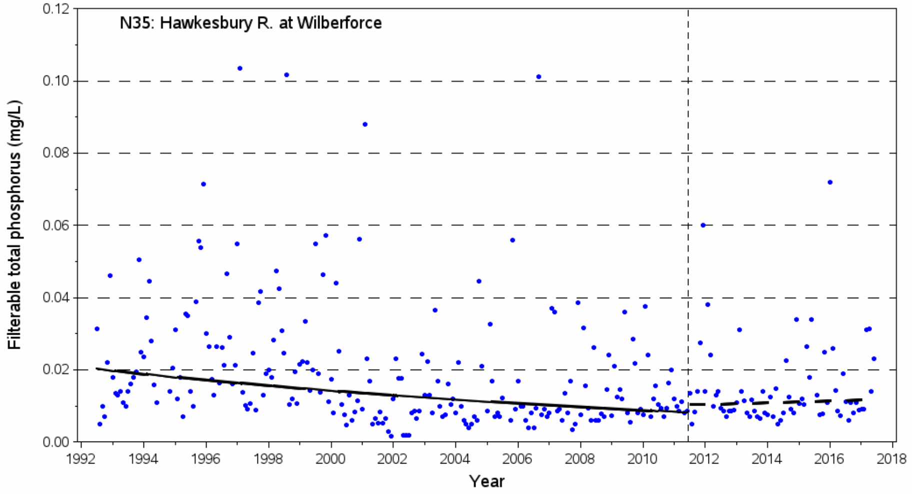


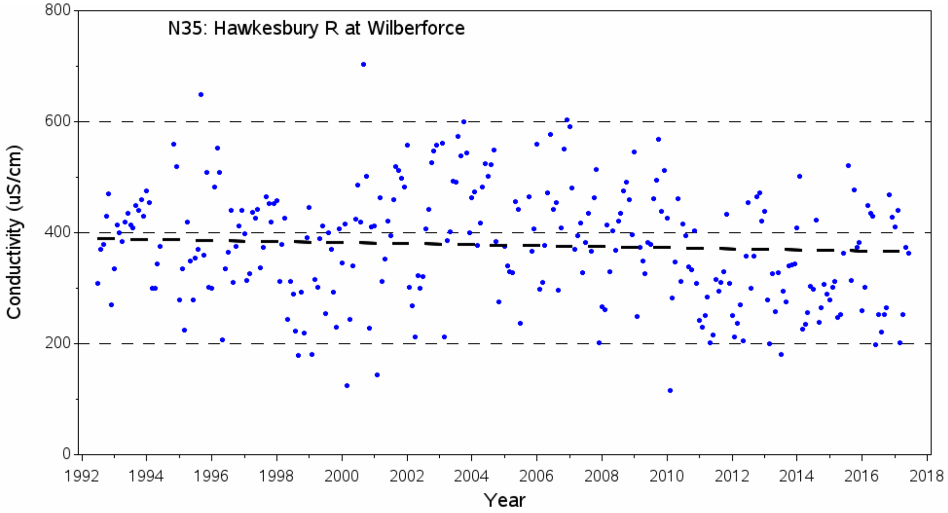
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

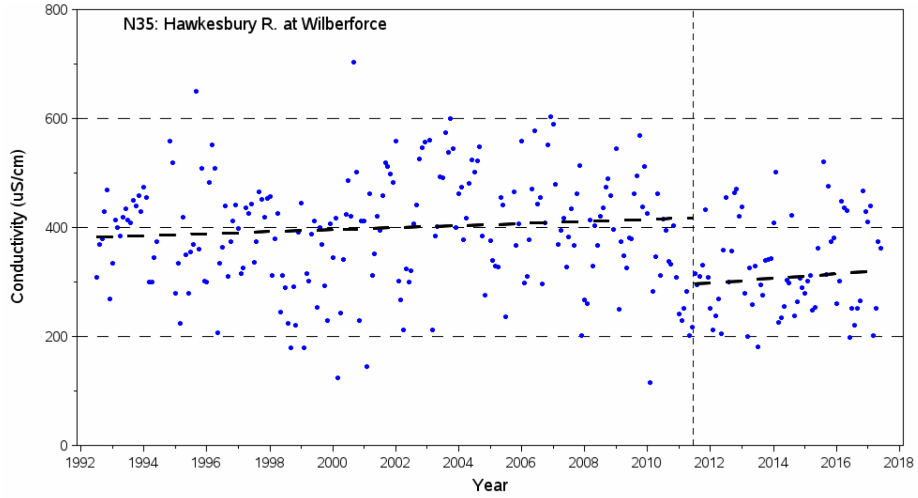
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

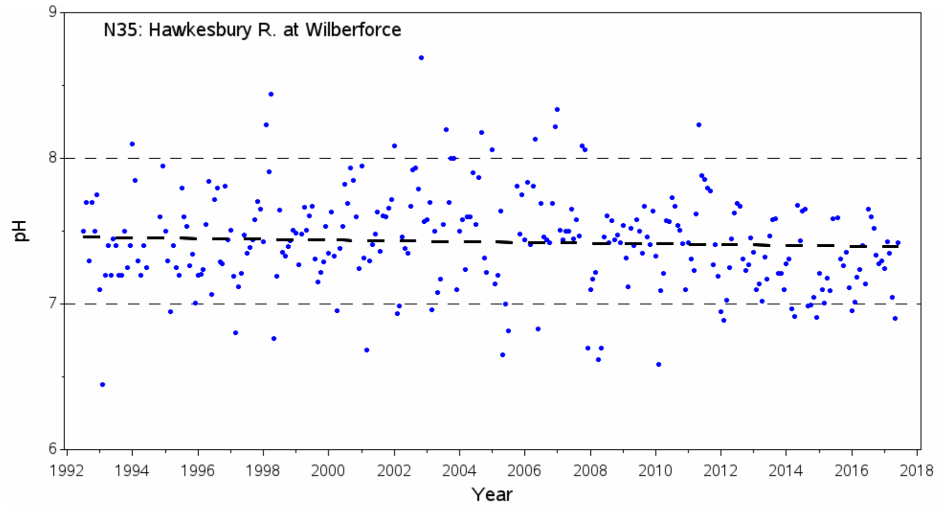
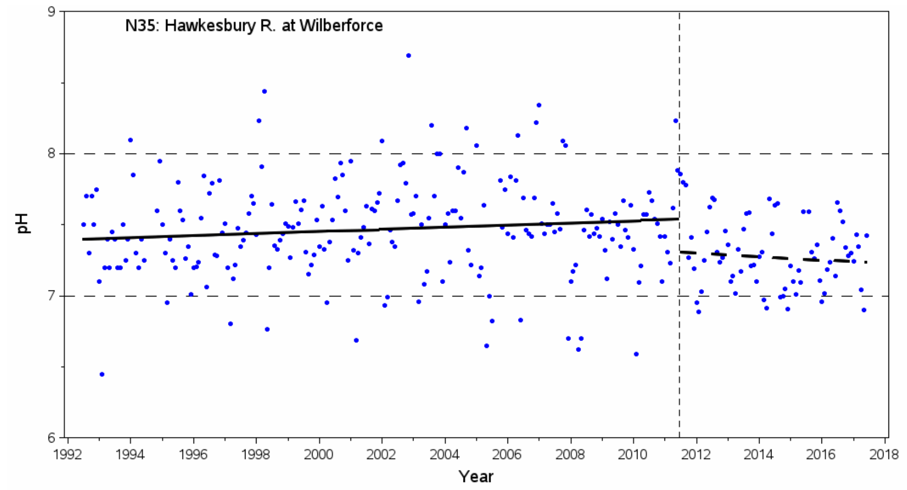
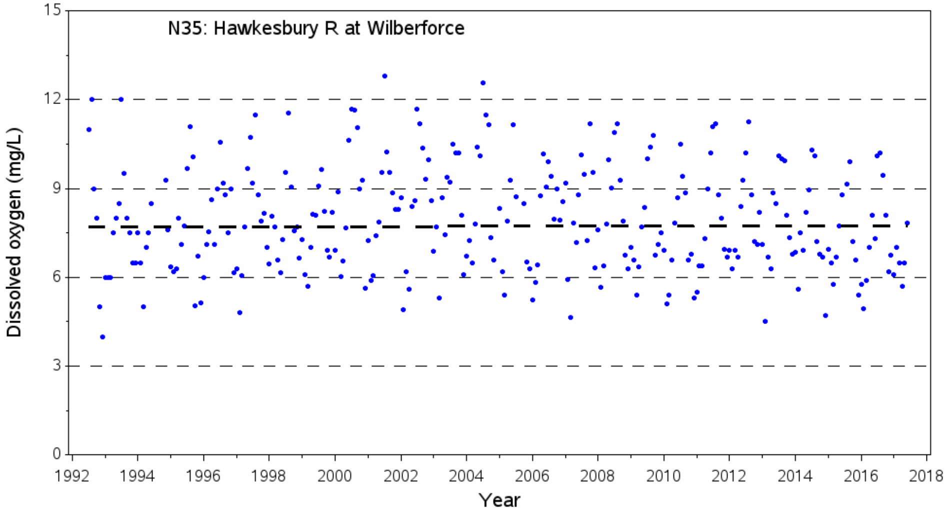
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

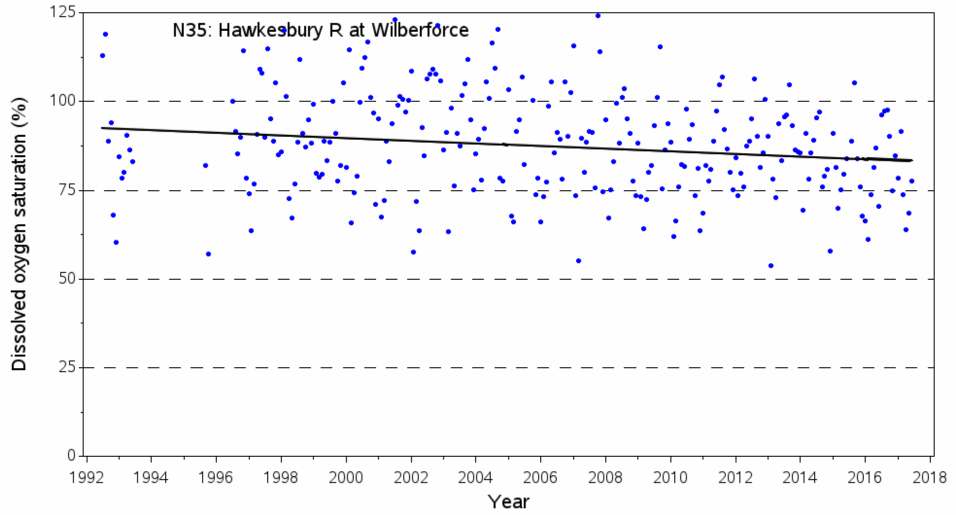
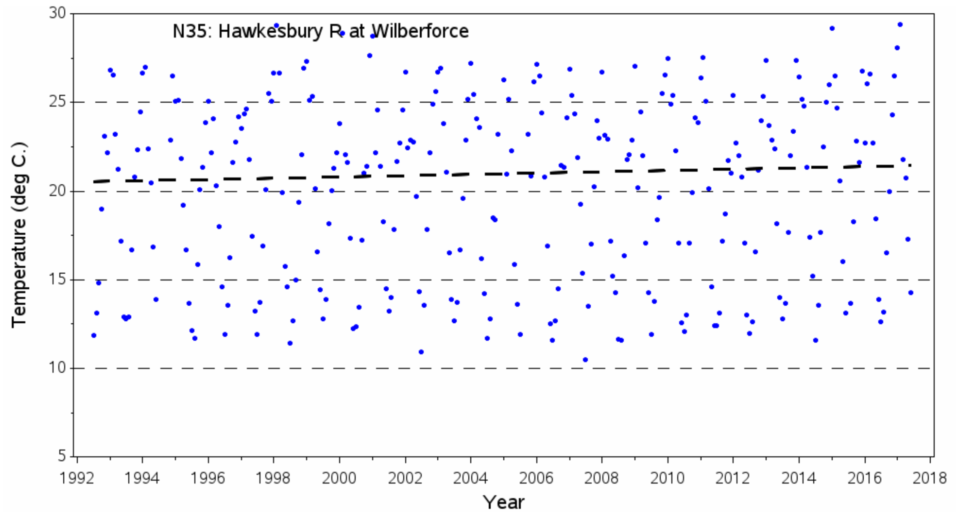








One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

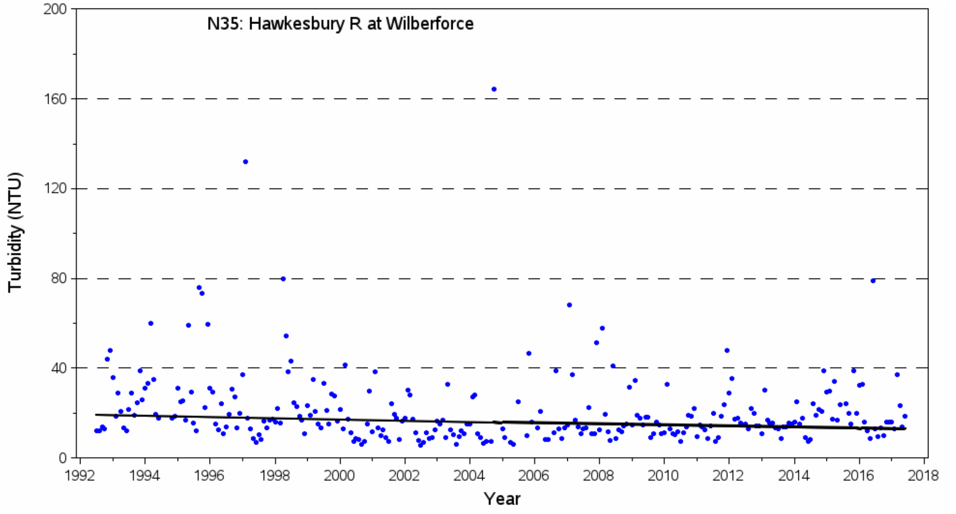
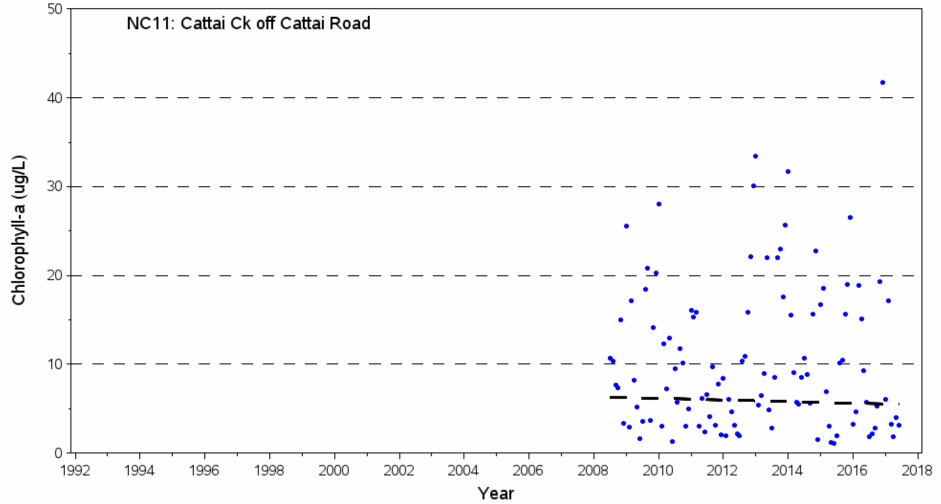
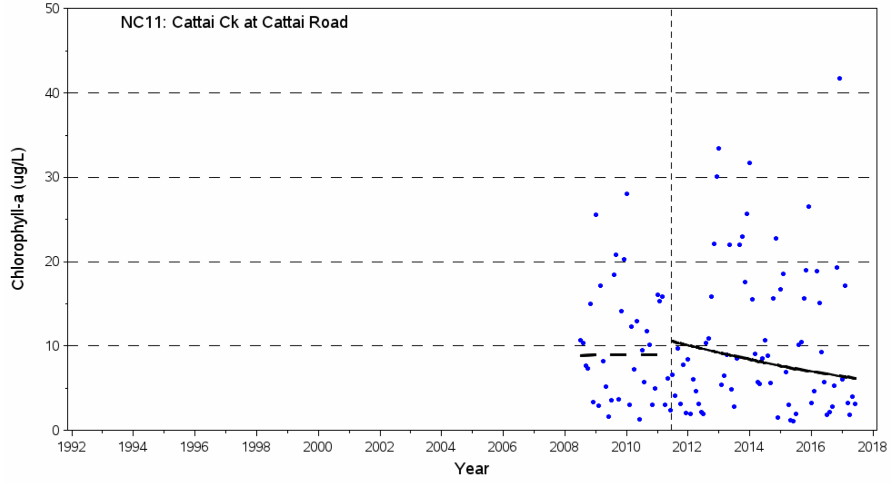
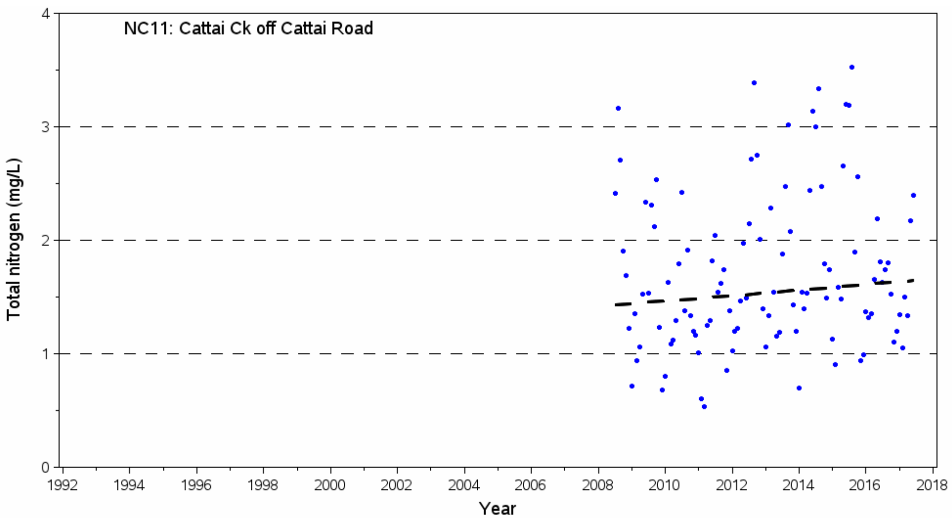
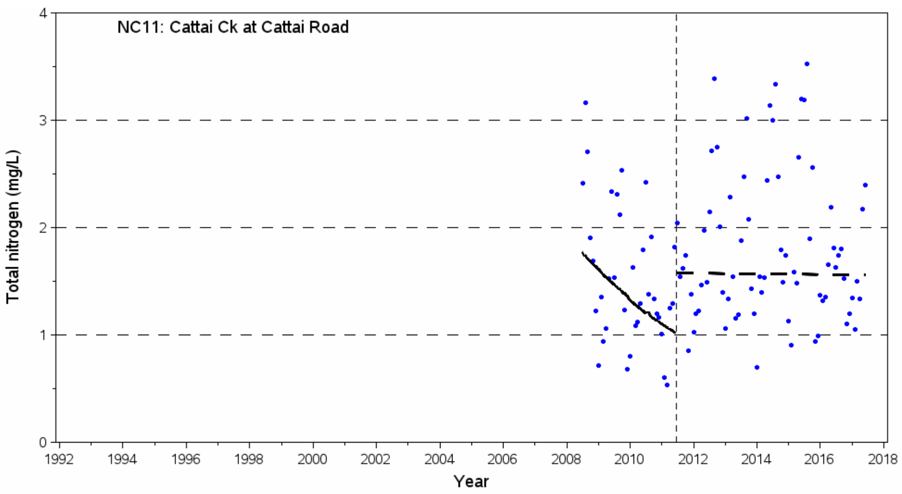
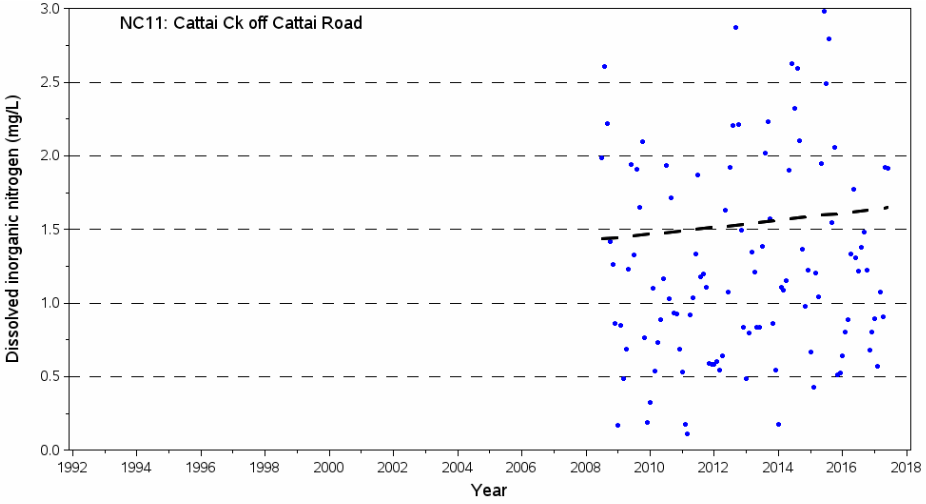
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

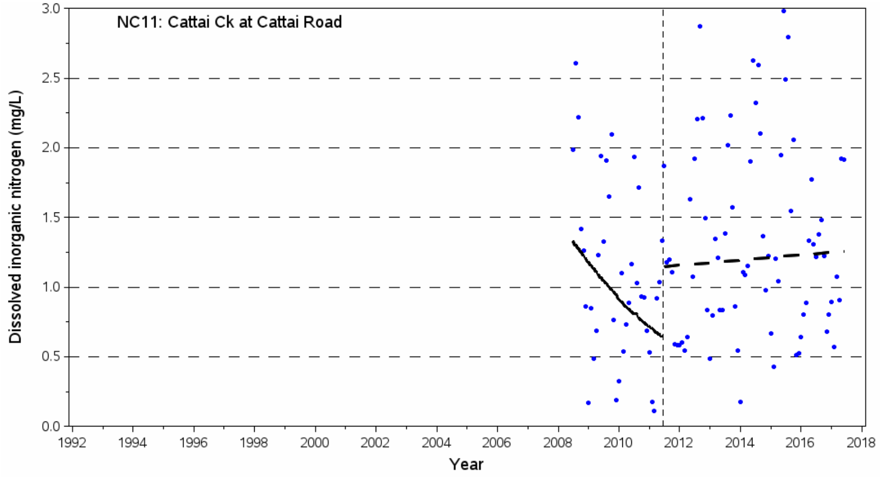
Figure E-10 Temporal trends in water quality: Cattai Creek at Cattai Road (NC11)

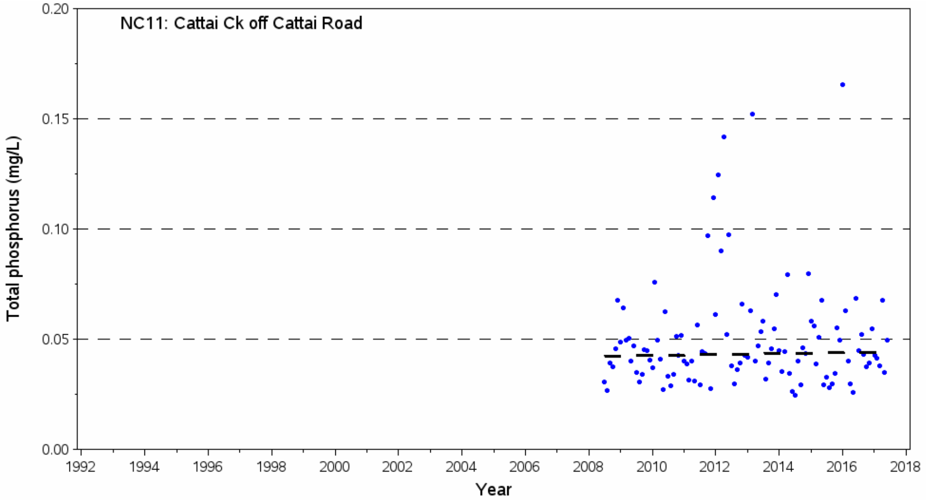
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

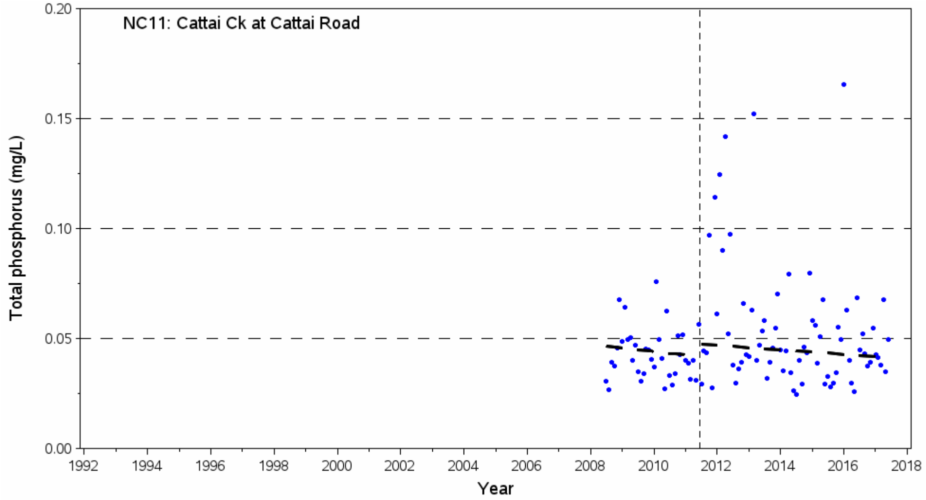
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
Limited algal data, no plots constructed	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

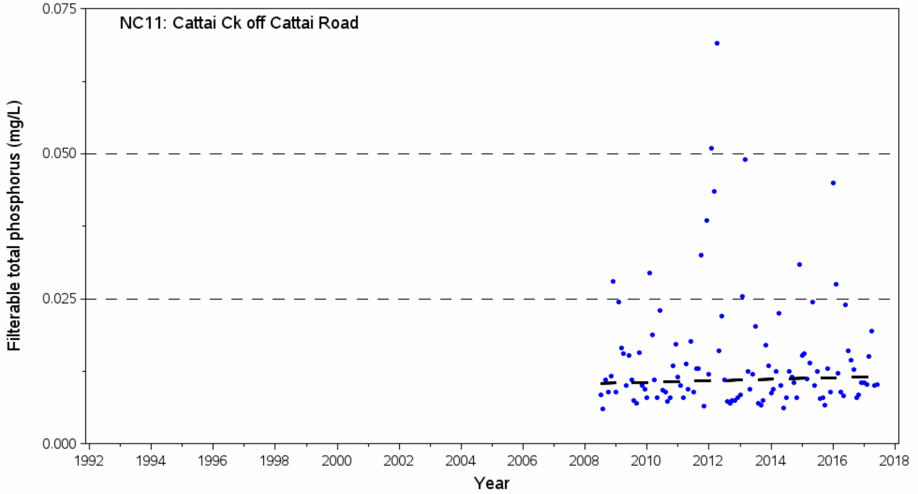


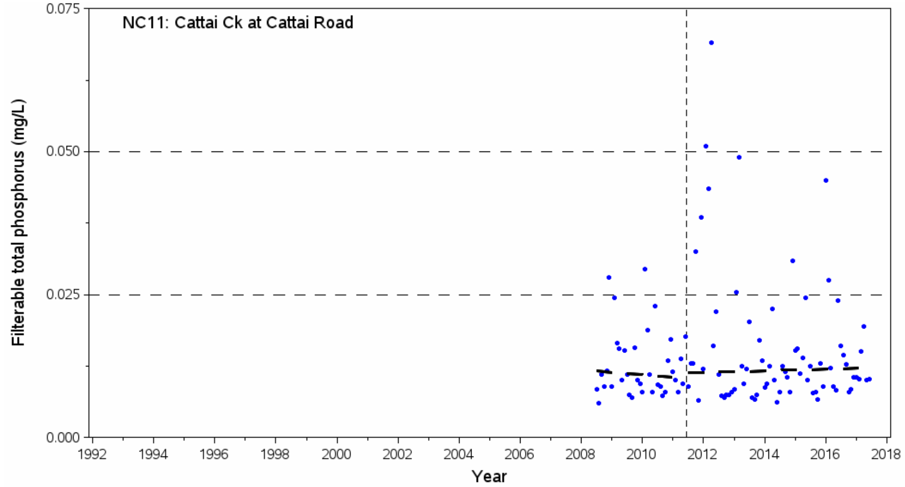


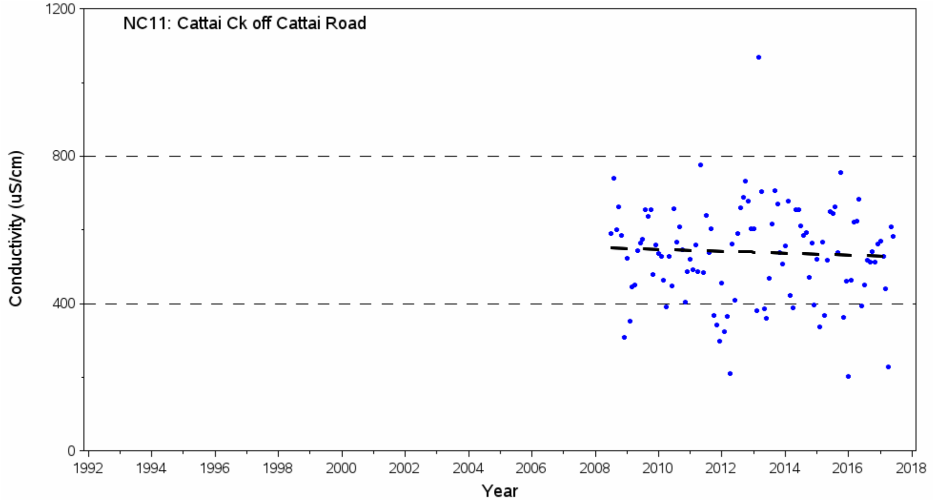


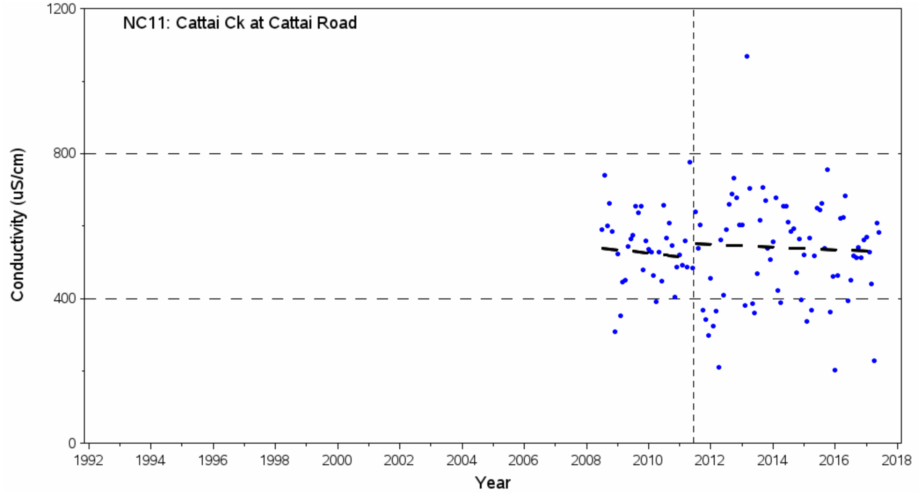


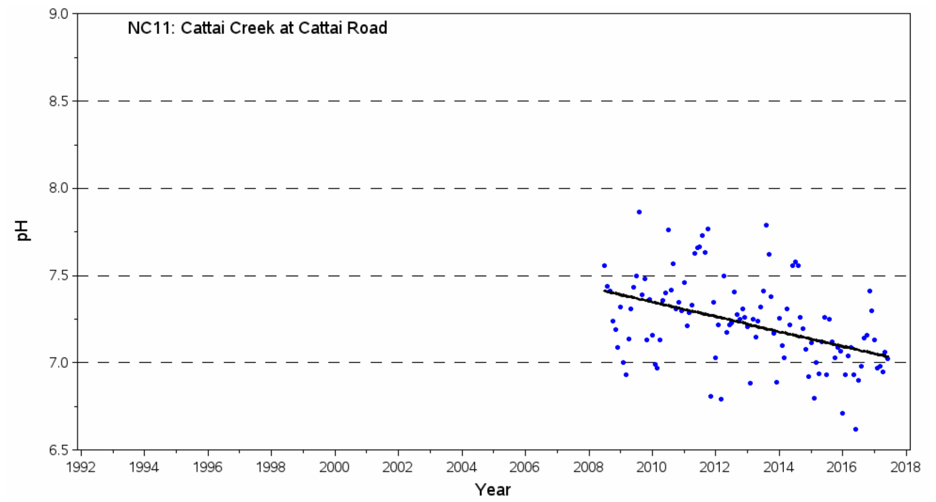
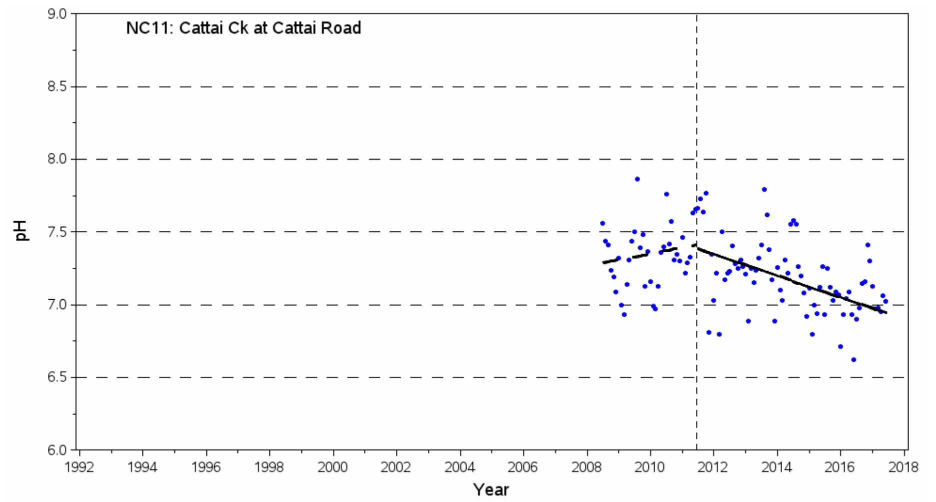
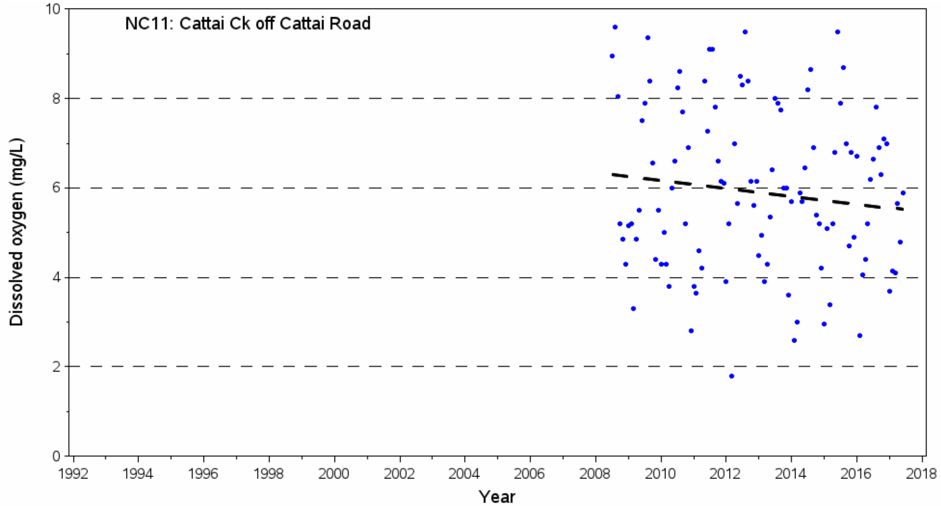
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

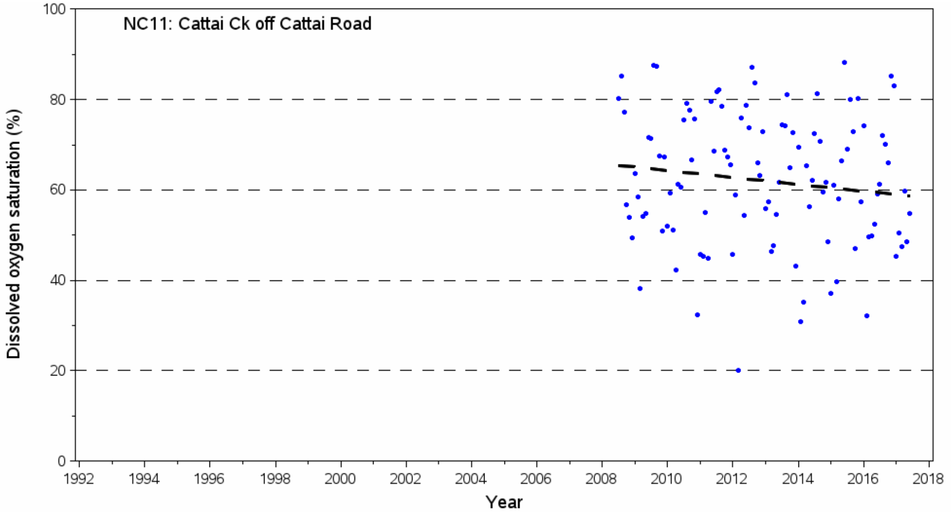
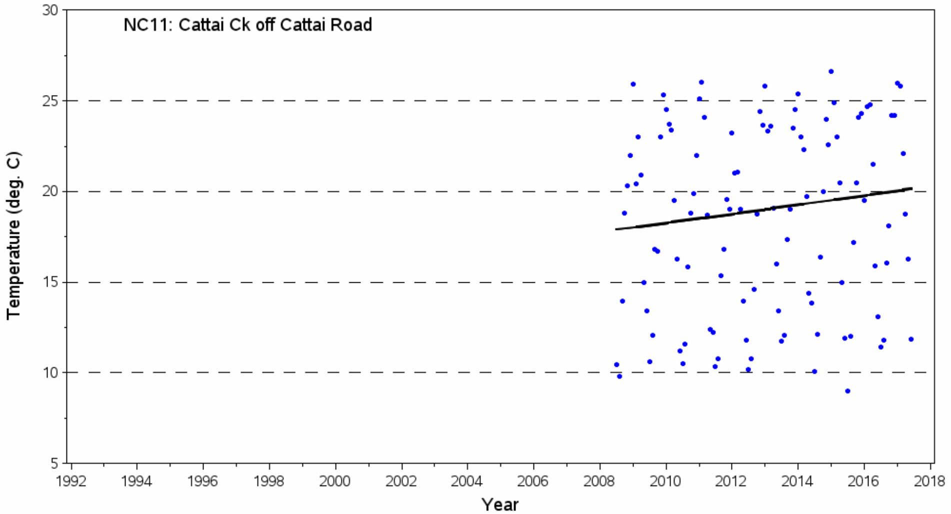








One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

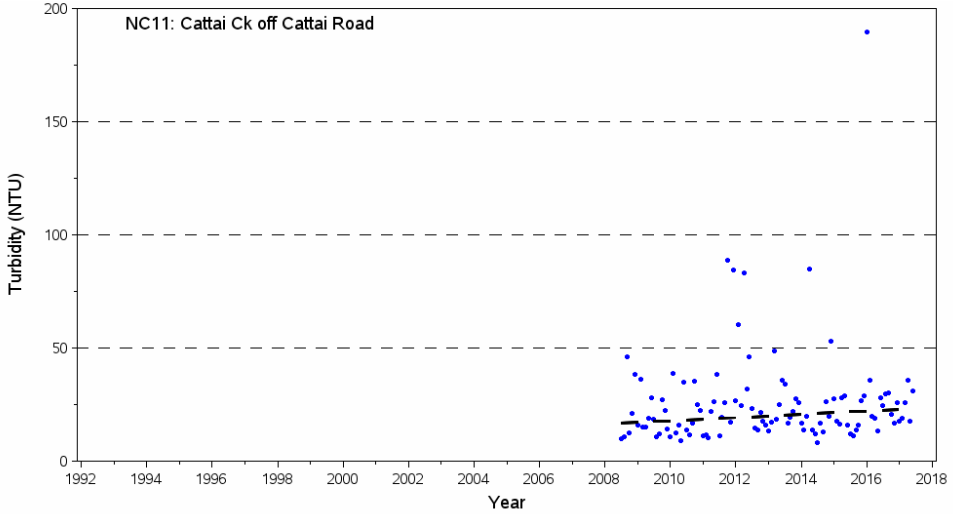
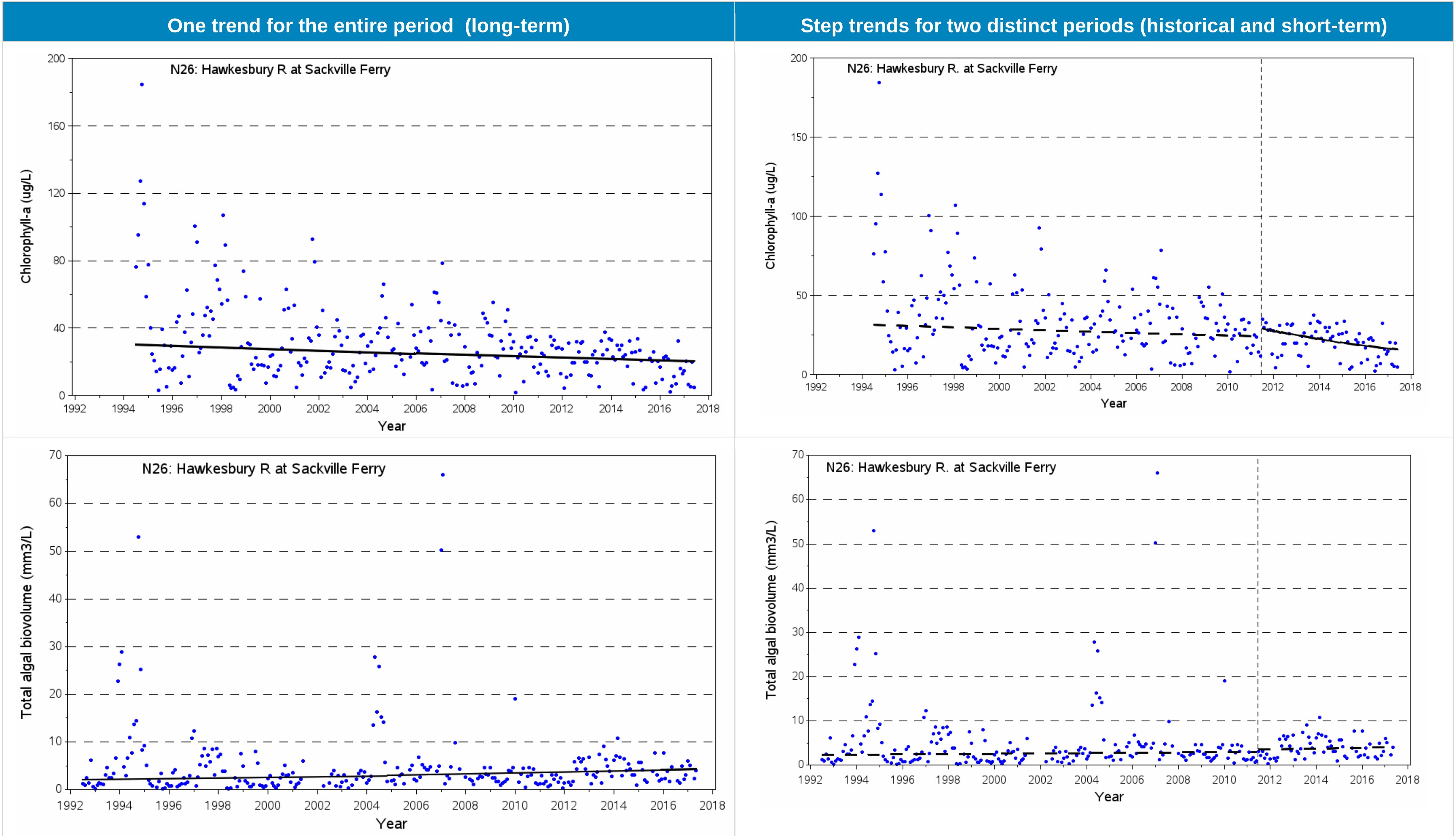
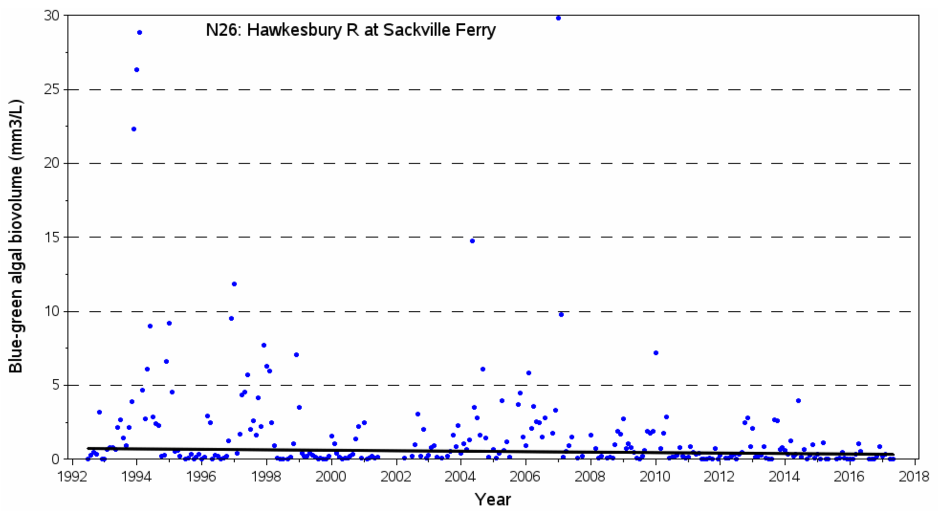
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

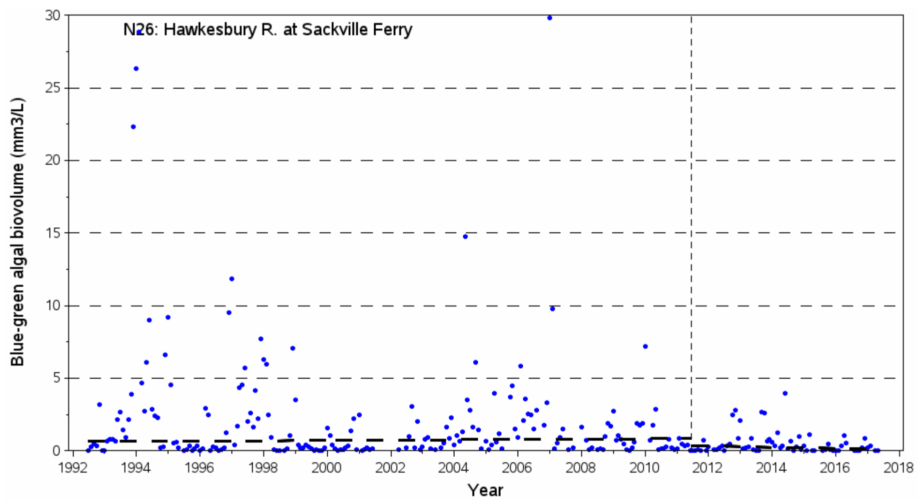
Figure E-11 Temporal trends in water quality: Hawkesbury River at Sackville Ferry (N26)

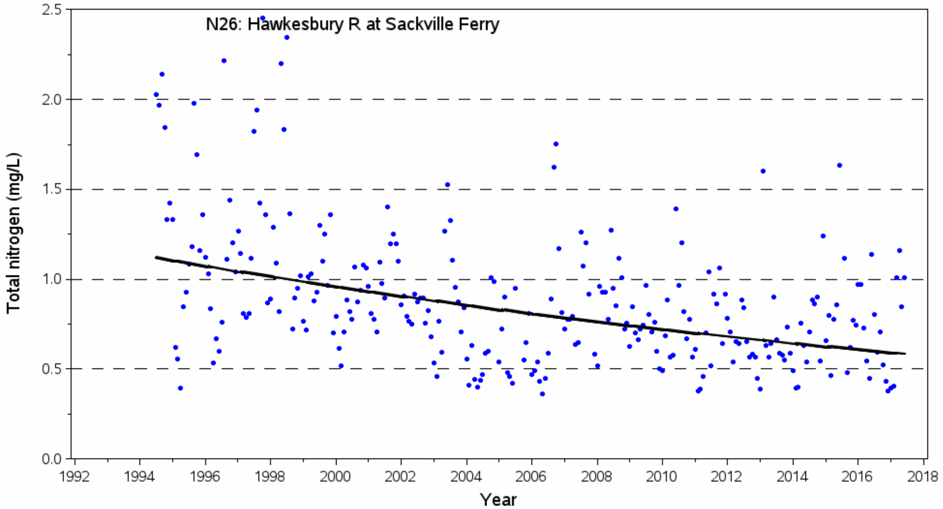
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major WWTP upgrade works in 2011 (separated by a vertical line)

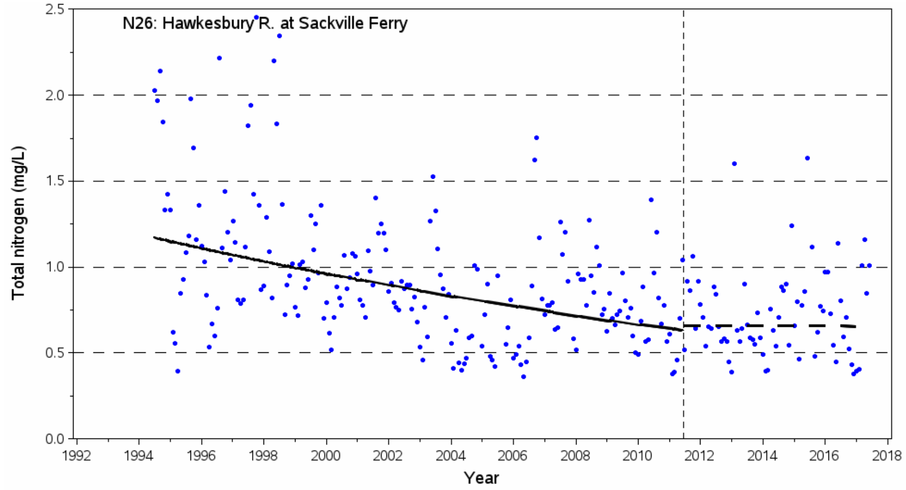


One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)



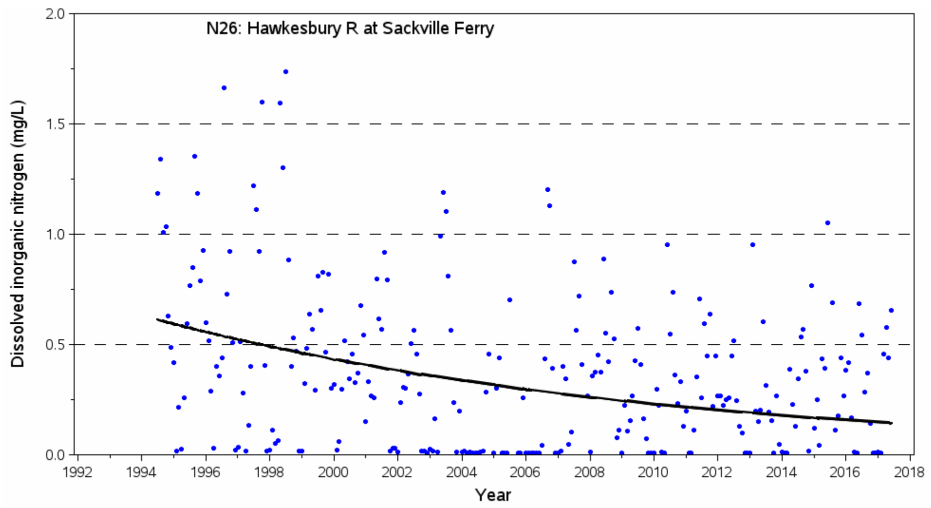


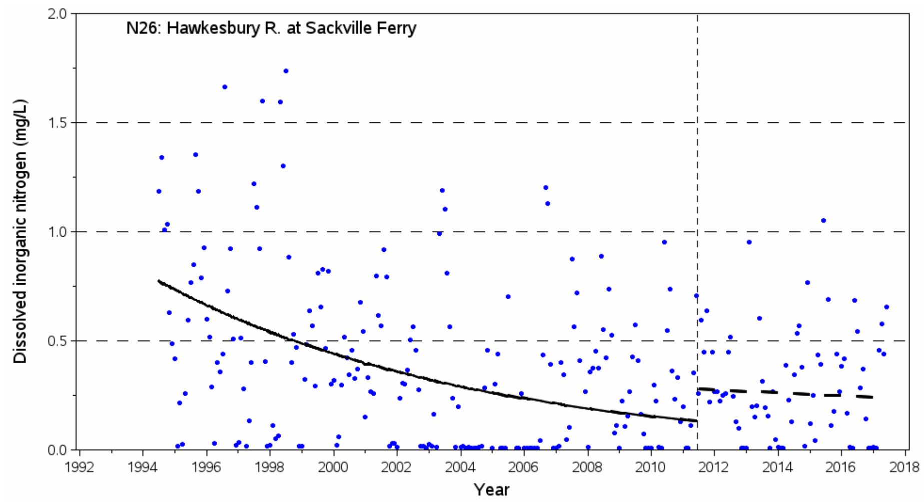


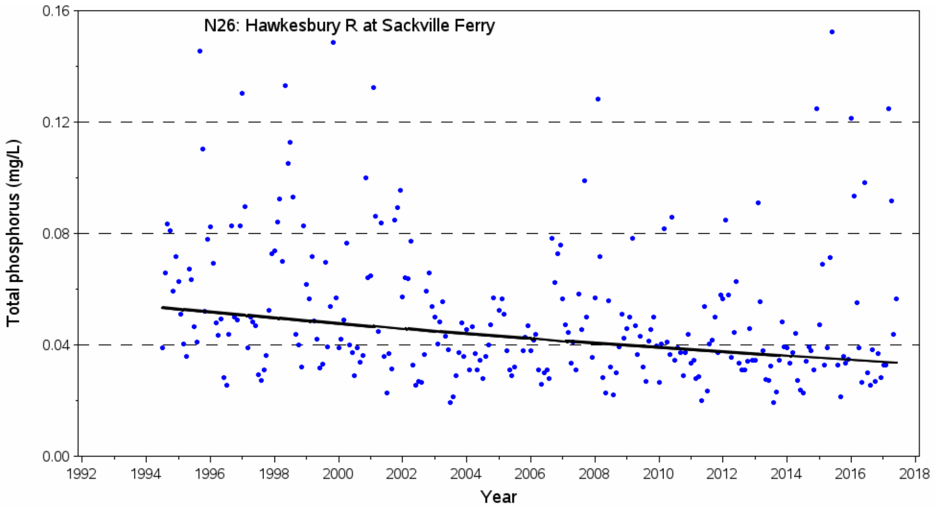


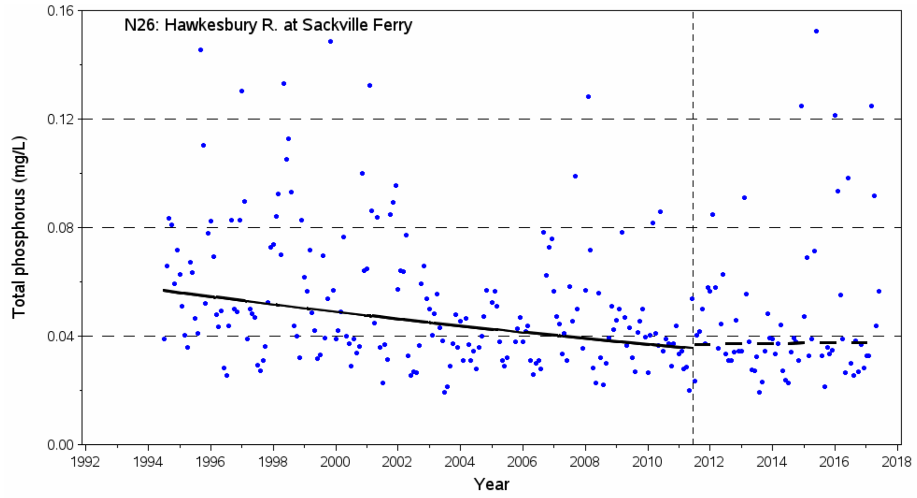
One trend for the entire period (long-term)

Step trends for two distinct periods (historical and short-term)

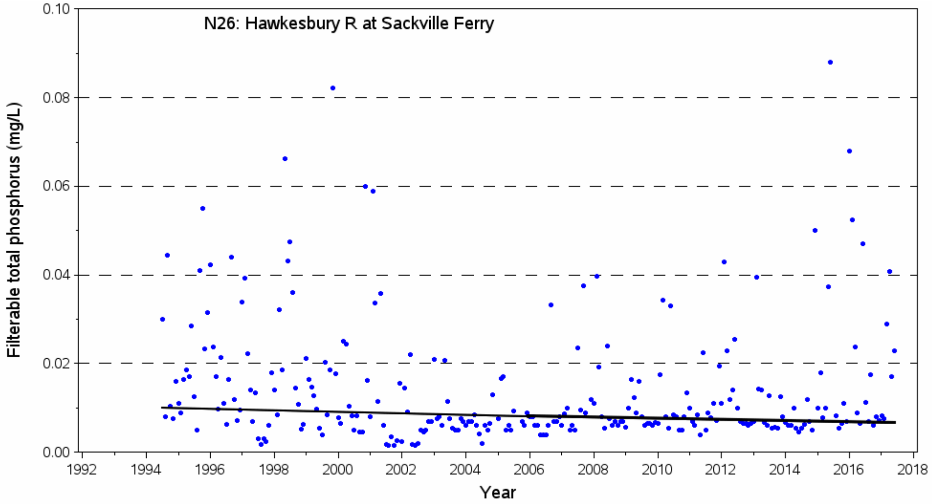


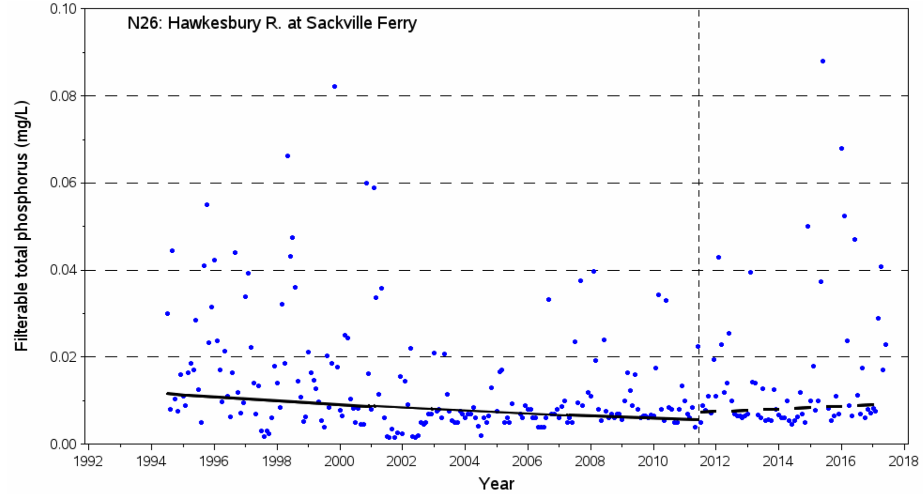


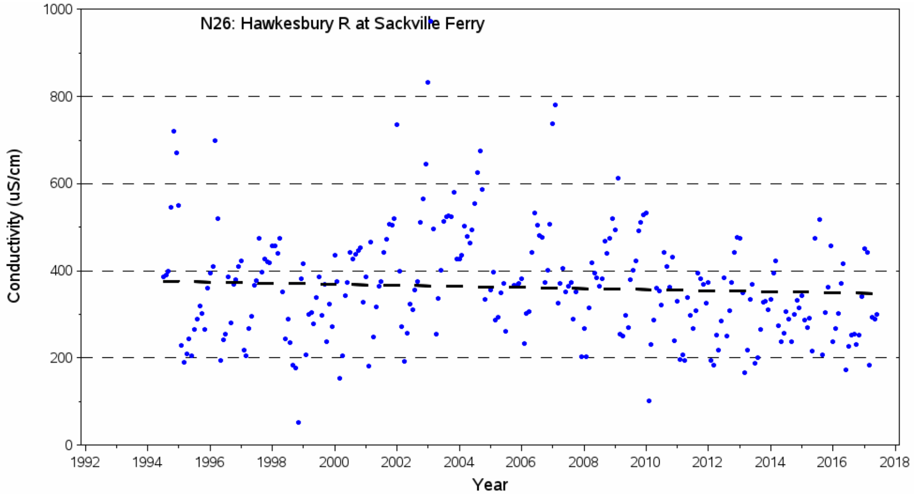


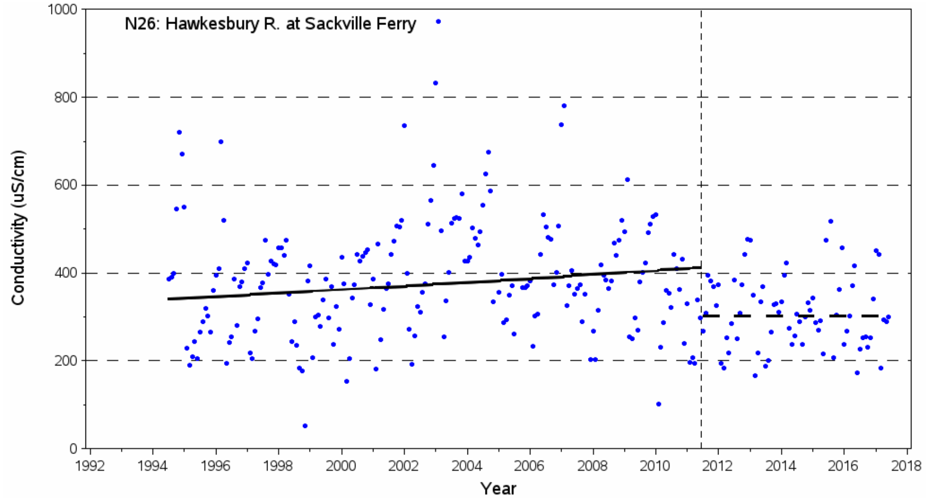


One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

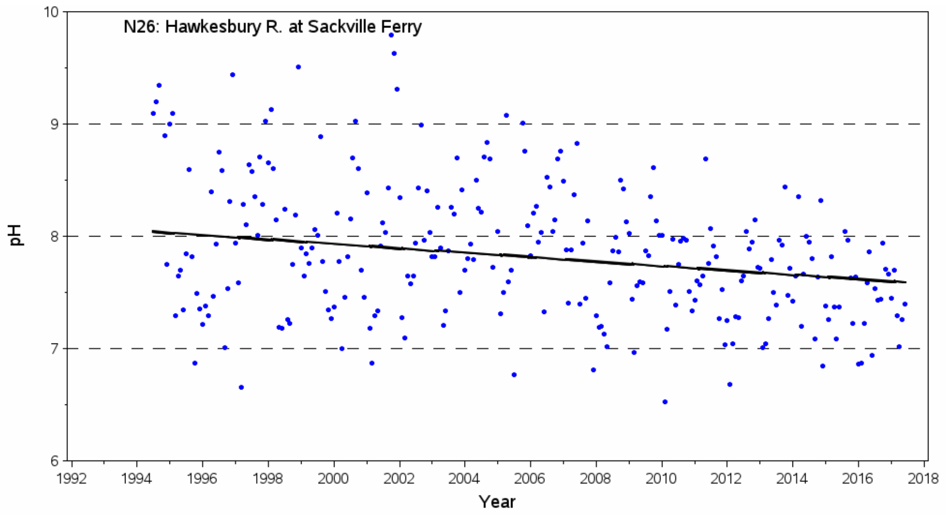


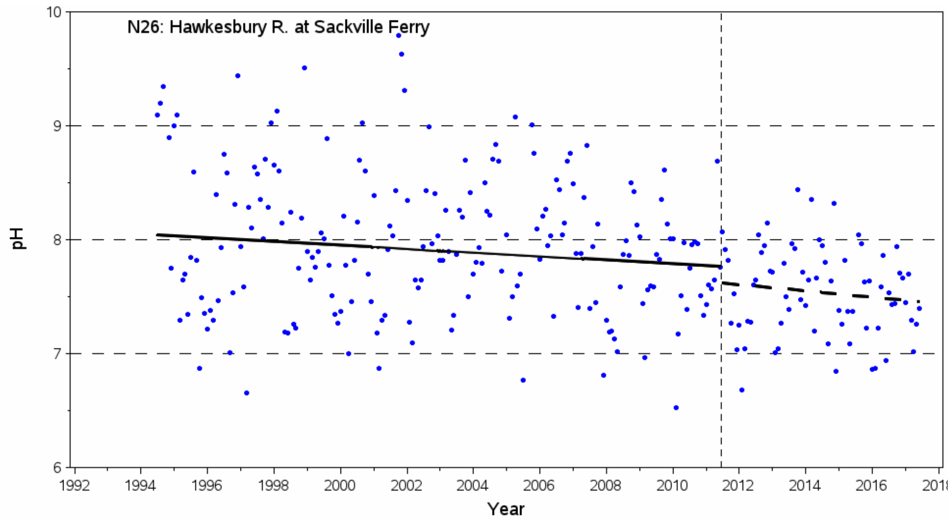


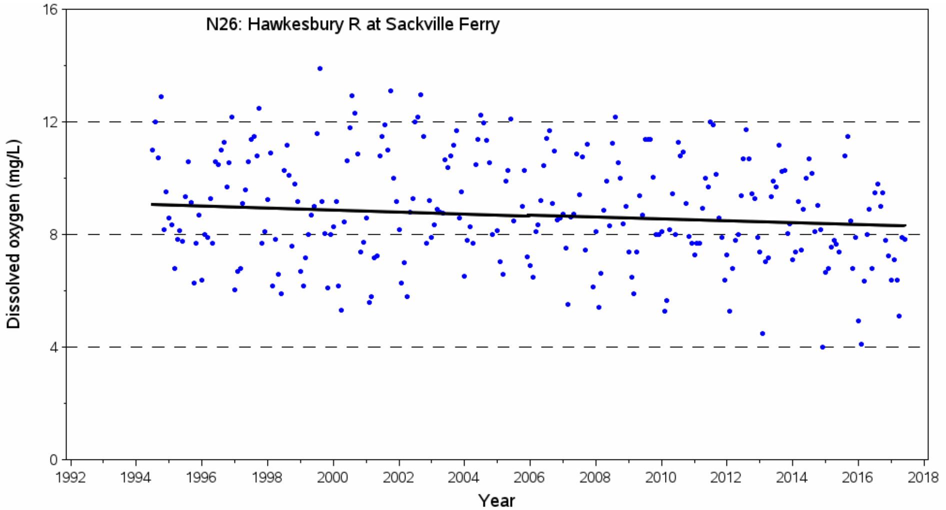


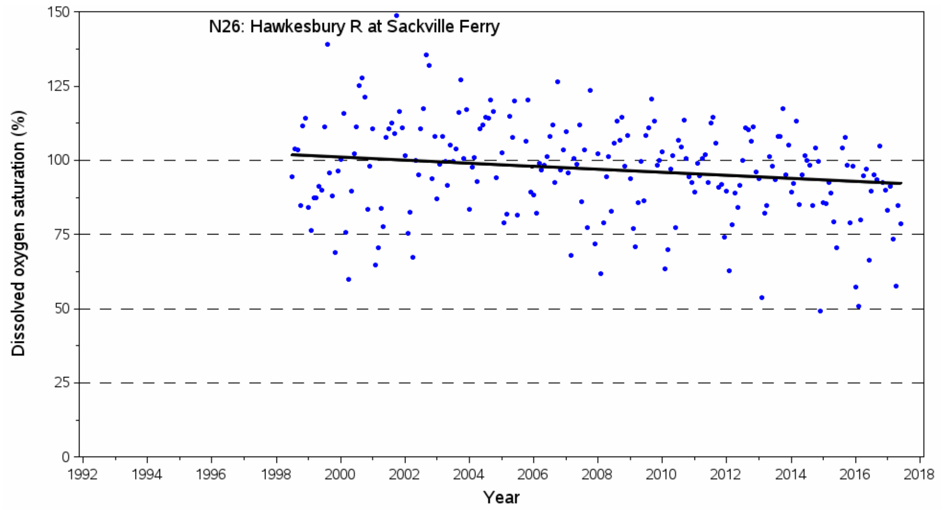
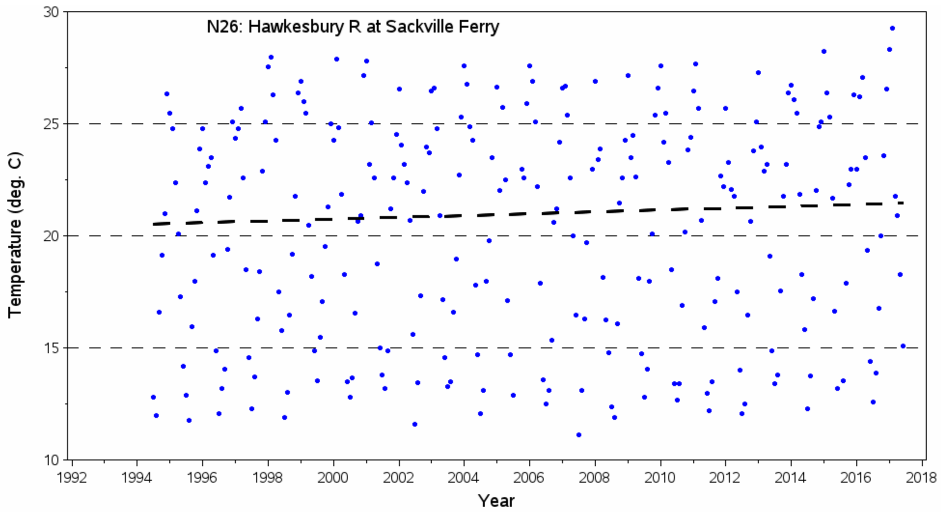


One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)







One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

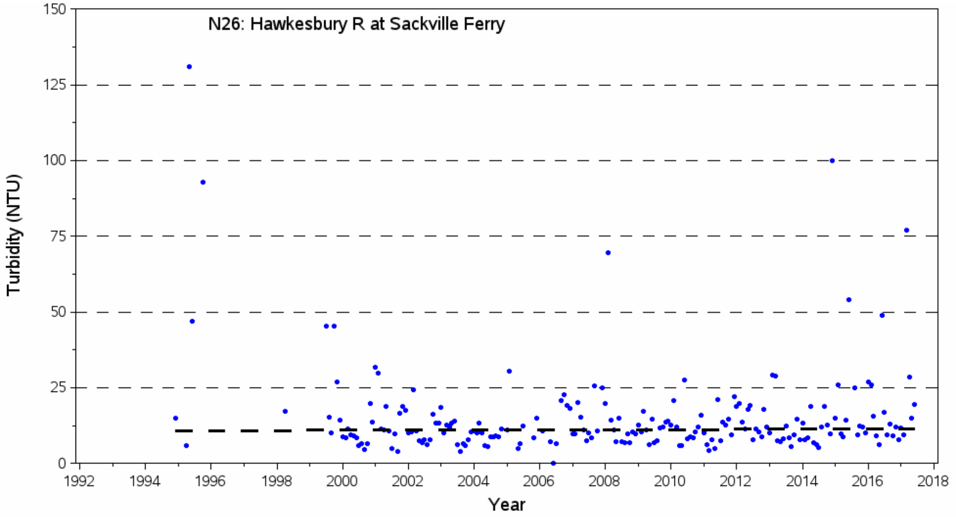
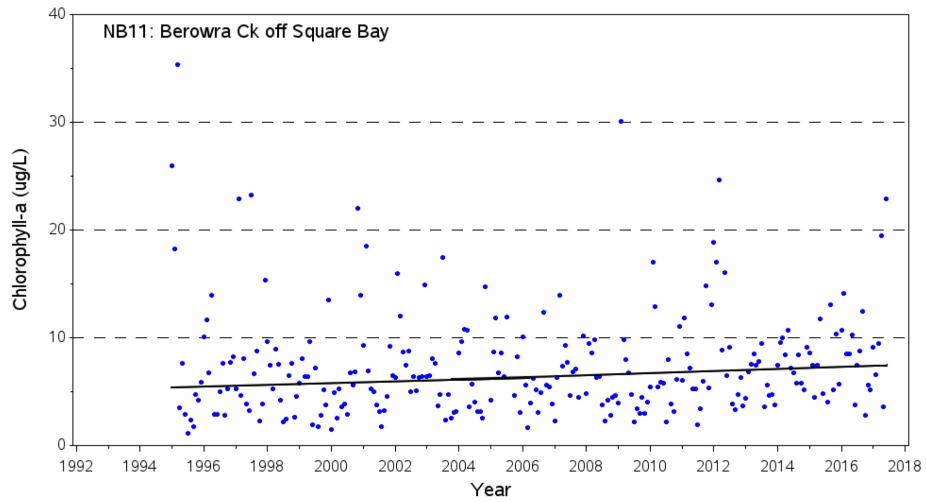
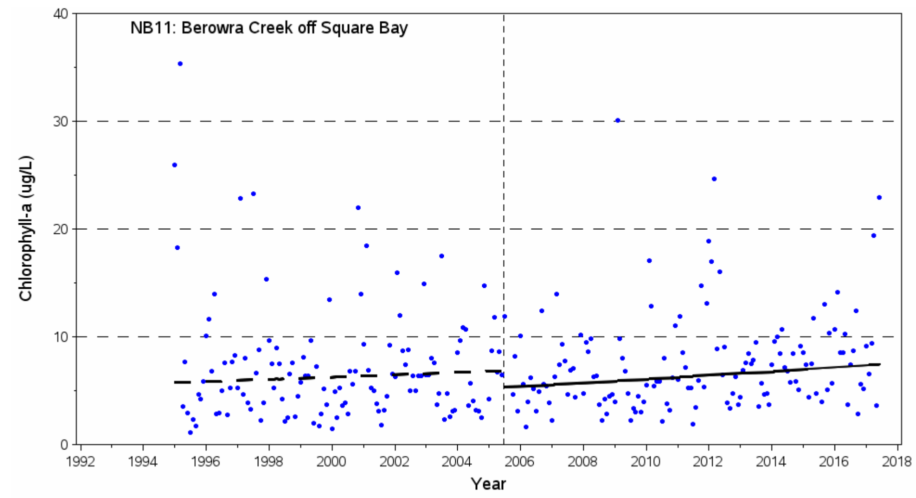
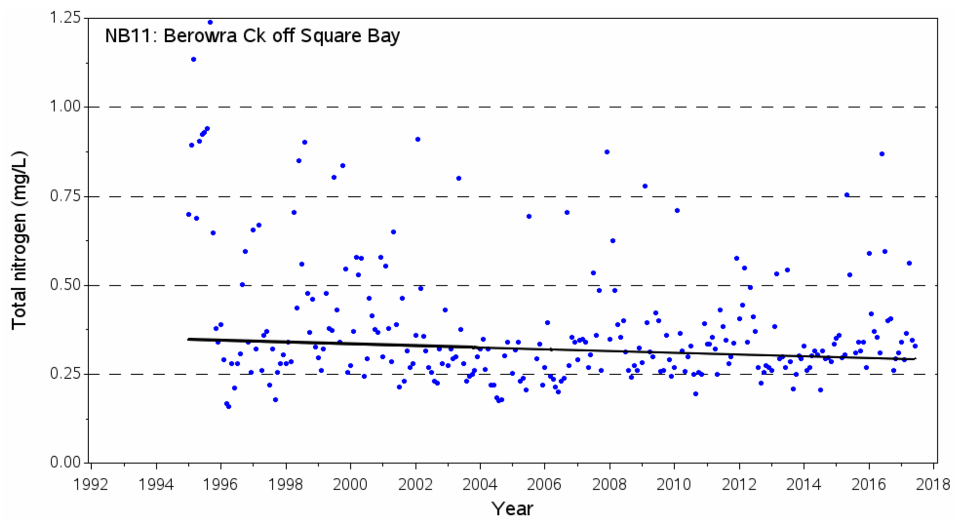
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

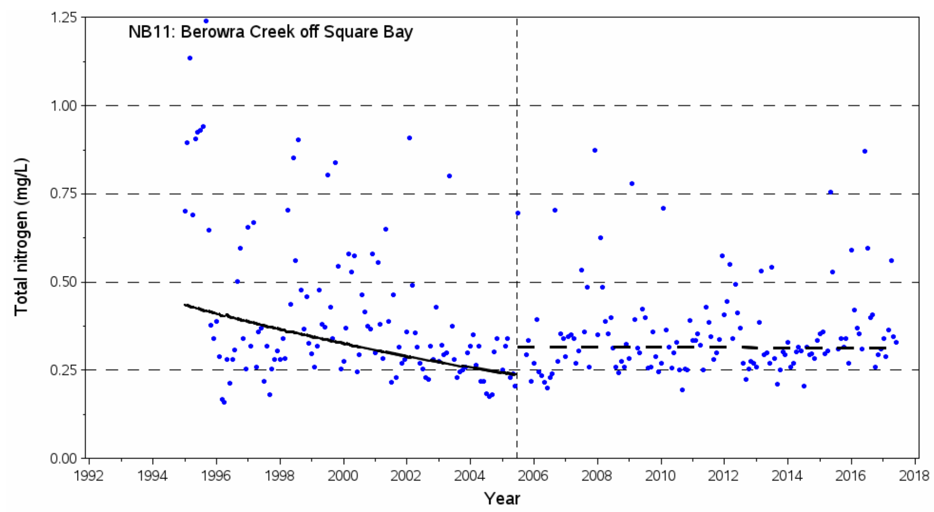
Figure E-12 Temporal trends in water quality: Berowra Creek off Square Bay (NB11)

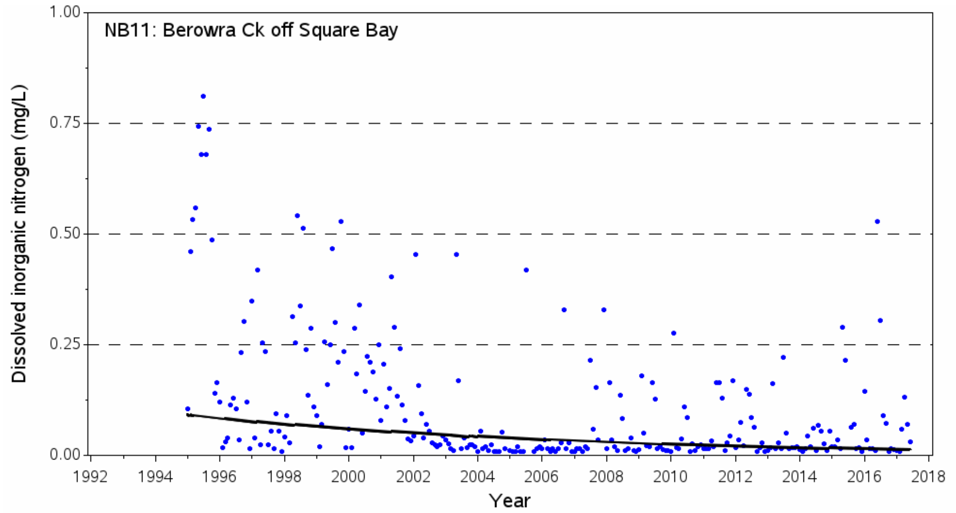
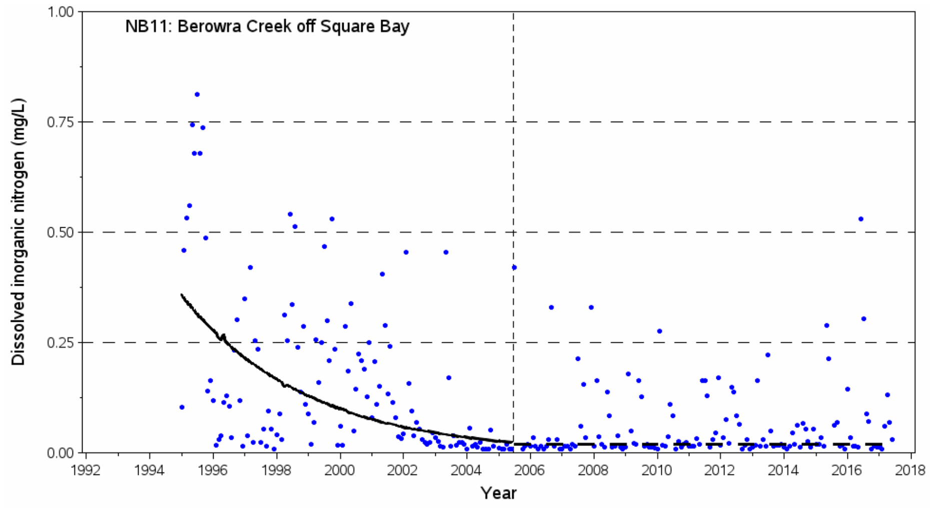
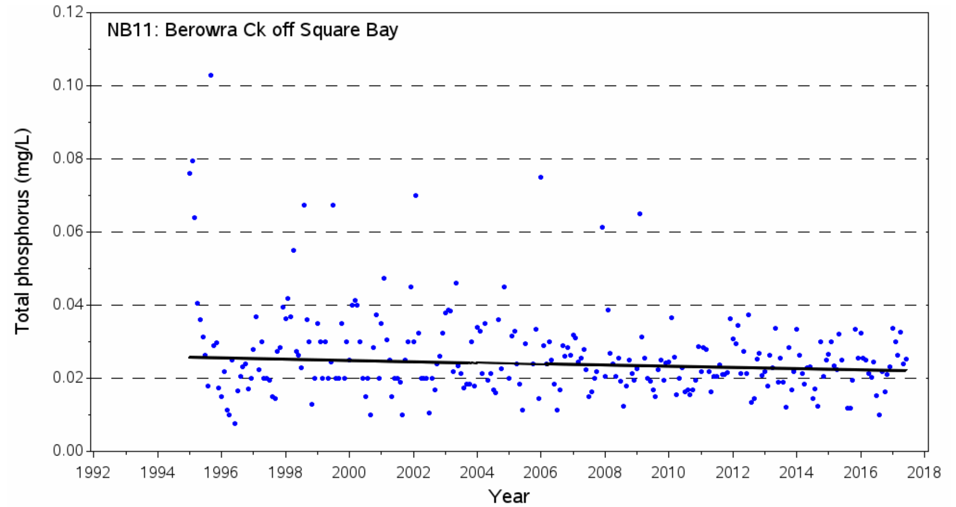
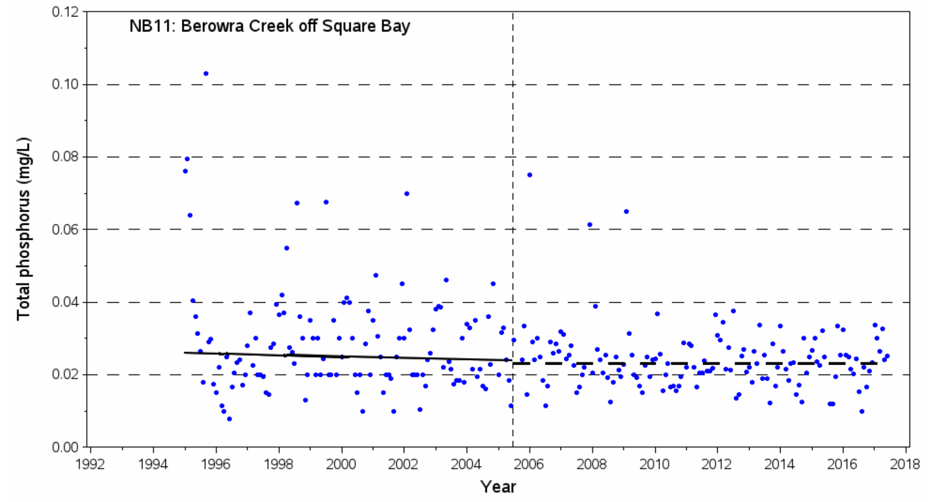
Solid line: statistically significant trend; Dotted line: statistically insignificant trend; Step trends fitted before and after the major plant upgrade works in 2011 (separated by a vertical line)

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

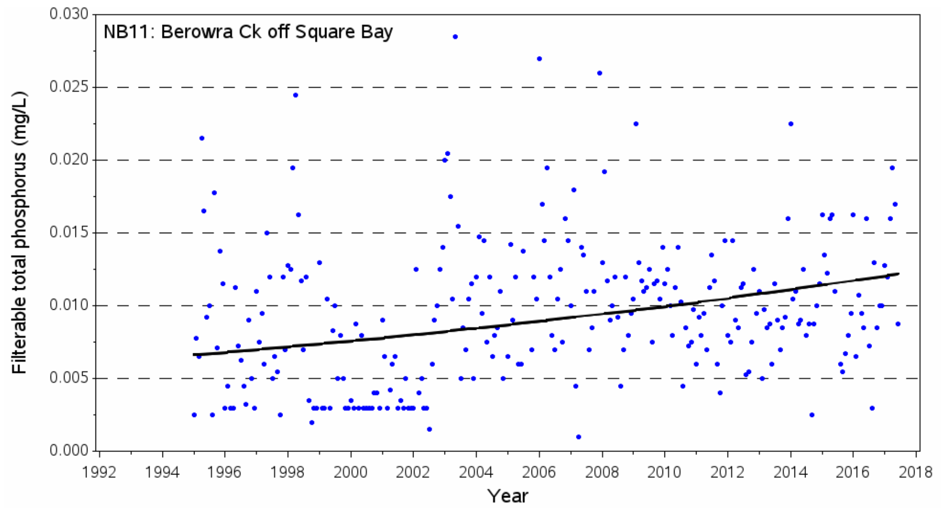
Limited algal data, no plots constructed

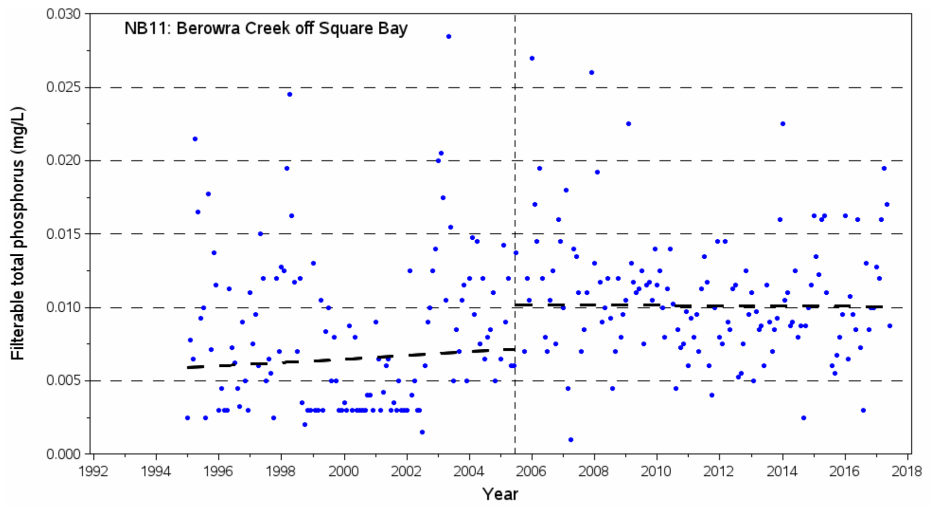


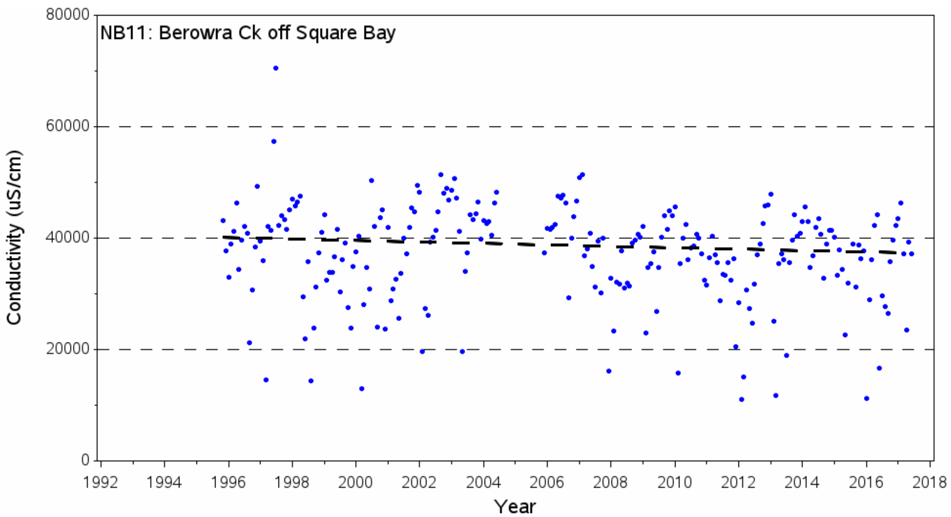


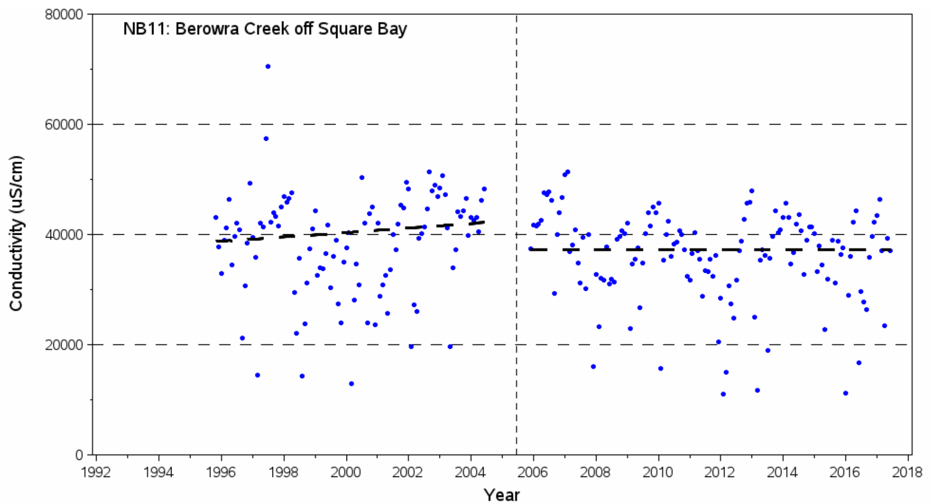
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

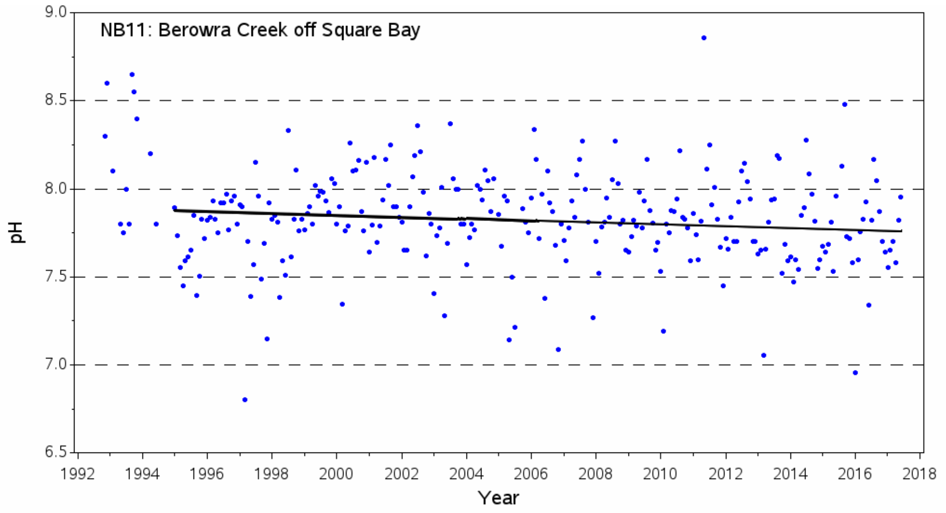
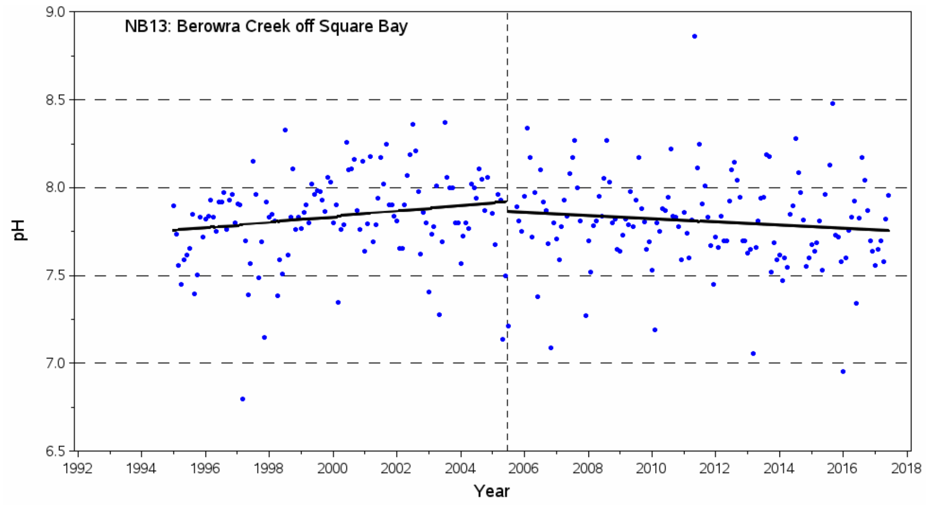
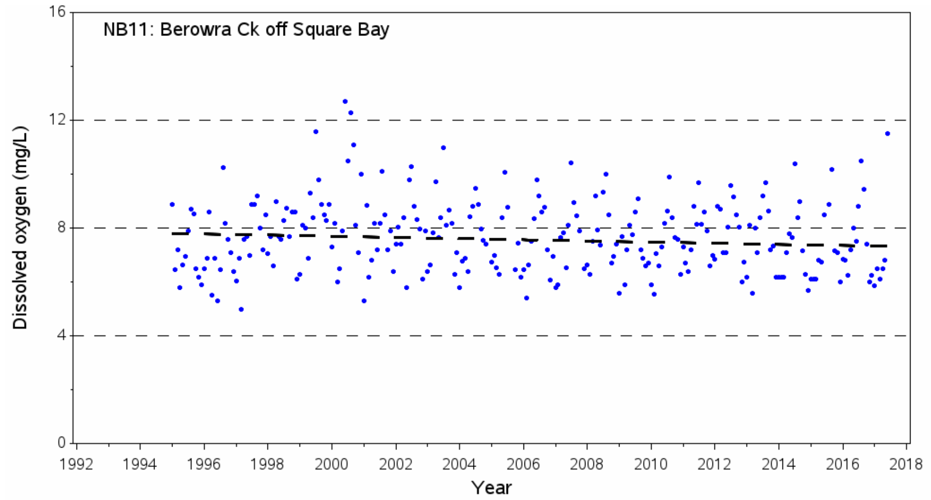
One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)

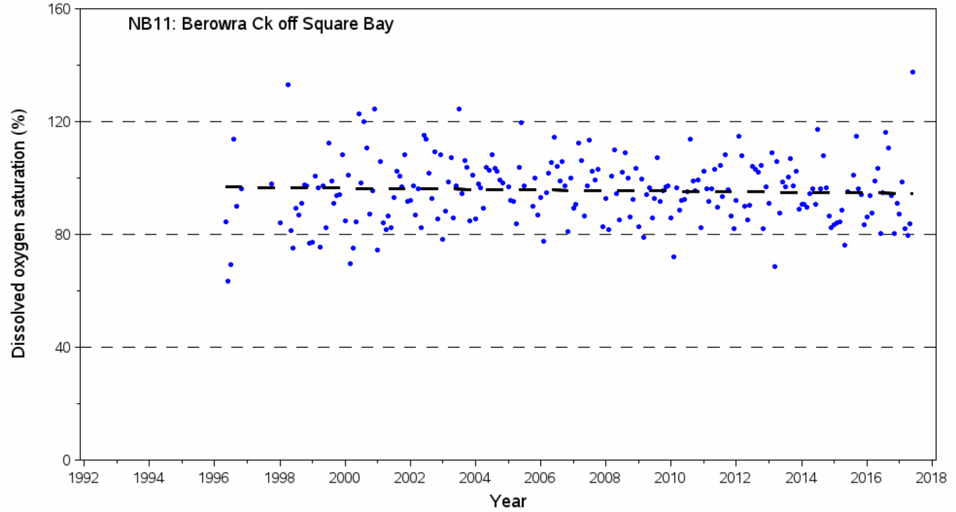
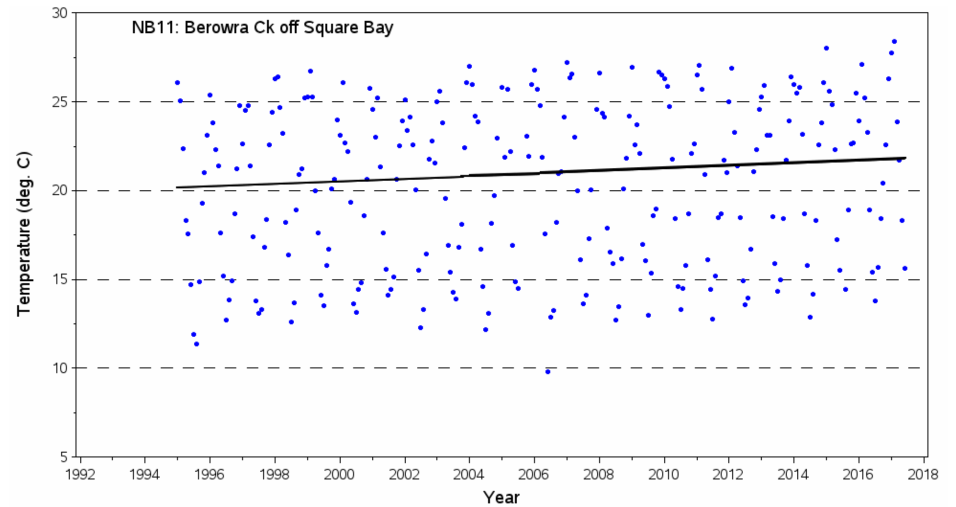


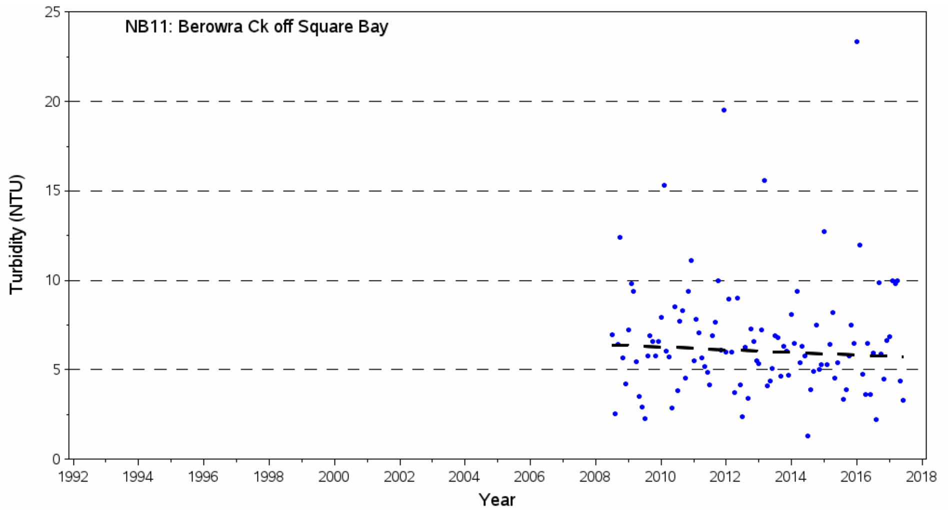






One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	
	

One trend for the entire period (long-term)	Step trends for two distinct periods (historical and short-term)
	

Appendix F: Detailed results, Spearman Correlation Analysis

Nepean River at Maldon Weir (N92)													
Spearman Correlation Coefficients													
Prob > |r| under H0: Rho=0													
Number of Observations													
	stats	**chla**	**totbv**	**bgbv**	**tn**	**din**	**tp**	**ftp**	**flow**	**turb**	**cond**	**pH**	**temp**
chla	Rho	1			-0.26	-0.35	0.15	-0.12	-0.30	-0.32	0.46	0.21	0.31
	p				0.007	0.0003	0.1263	0.2178	0.0017	0.0008	<.0001	0.0363	0.0016
	n	104	7	7	104	104	104	104	104	104	103	104	104
totbv	Rho												
	p												
	n		7	7	7	7	7	7	7	7	7	7	7
bgbv	Rho												
	p												
	n			7	7	7	7	7	7	7	7	7	7
tn	Rho				1	0.93	0.47	0.55	0.29	0.58	-0.16	-0.11	-0.46
	p					<.0001	<.0001	<.0001	0.0013	<.0001	0.0749	0.2496	<.0001
	n				122	122	122	104	122	122	121	122	122
din	Rho					1	0.32	0.48	0.19	0.49	-0.14	-0.05	-0.56
	p						0.0003	<.0001	0.0373	<.0001	0.135	0.5655	<.0001
	n					122	122	104	122	122	121	122	122
tp	Rho						1	0.83	0.47	0.55	-0.07	-0.16	-0.25
	p							<.0001	<.0001	<.0001	0.4451	0.074	0.0055
	n						122	104	122	122	121	122	122
ftp	Rho							1	0.41	0.42	-0.06	-0.10	-0.39
	p								<.0001	<.0001	0.5387	0.2984	<.0001
	n							104	104	104	103	104	104
flow	Rho								1	0.59	-0.53	-0.34	-0.21
	p									<.0001	<.0001	0.0001	0.0184
	n								122	122	121	122	122
turb	Rho									1	-0.44	-0.54	-0.37
	p										<.0001	<.0001	<.0001
	n									122	121	122	122
cond	Rho										1	0.49	0.08
	p											<.0001	0.3685
	n										121	121	121
pH	Rho											1	0.04
	p												0.6756
	n											122	122
temp	Rho												1
	p												
	n												122

	Strong correlation: Rho>0.50 and p<0.0001
	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Stonequarry Creek at Picton Farm, downstream of discharges (N911)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.48	0.04	0.25	0.23	0.05	0.31	0.49	0.37	0.24	0.25	-0.28	-0.15	0.34
	p		0.0104	0.8437	0.062	0.0083	0.5814	0.0177	<.0001	0.0001	0.0066	0.005	0.0015	0.0834	<.0001
	n	128	27	27	57	128	128	57	128	104	128	126	126	126	125
totbv	Rho		1	-0.02	0.45	-0.40	-0.42	0.50	0.42	-0.46	-0.02	-0.03	-0.04	-0.44	0.23
	p			0.9139	0.0391	0.0362	0.0285	0.0218	0.0275	0.1287	0.9182	0.8748	0.8566	0.0258	0.2541
	n		27	27	21	27	27	21	27	12	27	26	26	26	26
bgbv	Rho			1	-0.21	0.20	0.17	-0.08	0.36	0.60	0.23	0.36	-0.16	-0.10	-0.18
	p				0.3713	0.3169	0.397	0.719	0.0631	0.0393	0.2589	0.0682	0.4354	0.6143	0.3895
	n			27	21	27	27	21	27	12	27	26	26	26	26
tnload	Rho				1	-0.17	-0.27	0.90	0.58	0.59	0.63	0.43	-0.61	0.12	0.11
	p					0.1549	0.0202	<.0001	<.0001	0.0003	<.0001	0.0001	<.0001	0.3175	0.3465
	n				73	72	72	73	72	34	73	72	72	72	71
tn	Rho					1	0.93	-0.31	0.72	0.84	0.73	0.66	-0.68	0.26	0.03
	p						<.0001	0.0082	<.0001	<.0001	<.0001	<.0001	<.0001	0.0009	0.6912
	n					169	169	72	169	104	169	167	167	167	166
din	Rho						1	-0.45	0.56	0.66	0.71	0.64	-0.60	0.37	-0.19
	p							<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0167
	n						169	72	169	104	169	167	167	167	166
tpload	Rho							1	0.71	0.68	0.74	0.48	-0.72	0.06	0.37
	p								<.0001	<.0001	<.0001	<.0001	<.0001	0.6069	0.0015
	n							73	72	34	73	72	72	72	71
tp	Rho								1	0.93	0.73	0.75	-0.79	0.12	0.29
	p									<.0001	<.0001	<.0001	<.0001	0.1378	0.0002
	n								169	104	169	167	167	167	166
ftp	Rho									1	0.82	0.72	-0.84	0.22	0.29
	p										<.0001	<.0001	<.0001	0.0254	0.0035
	n									104	104	104	104	104	103
flow	Rho										1	0.77	-0.81	0.36	-0.11
	p											<.0001	<.0001	<.0001	0.1488
	n										170	168	168	168	167
turb	Rho											1	-0.70	0.26	0.03
	p												<.0001	0.0008	0.7319
	n											168	168	168	167
cond	Rho												1	-0.14	-0.11
	p													0.0715	0.1536
	n												168	168	167
pH	Rho													1	-0.47
	p														<.0001
	n													168	167
temp	Rho														1
	p														
	n														167

(dark blue)	Strong correlation: Rho>0.50 and p<0.0001
(light blue)	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
(grey)	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Nepean River at Sharpes Weir (N75)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
	Rho	1	0.62	0.24	-0.58	-0.31	-0.36	0.05	0.20	-0.04	-0.37	-0.13	0.25	0.15	0.46
chla	p		0.0002	0.1886	<.0001	0.0014	0.0002	0.6463	0.0375	0.7141	<.0001	0.1809	0.011	0.1407	<.0001
	n	104	31	31	103	104	104	103	104	104	104	104	104	104	104
	Rho		1	0.07	0.11	0.18	0.13	0.23	0.19	0.33	-0.07	0.06	-0.22	0.08	0.31
totbv	p			0.7084	0.5599	0.3423	0.4868	0.2186	0.2941	0.0696	0.727	0.7505	0.2393	0.6568	0.0847
	n		31	31	31	31	31	31	31	31	31	31	31	31	31
	Rho			1	-0.18	-0.20	-0.35	0.13	0.03	-0.01	-0.39	-0.12	-0.05	0.05	0.42
bgbv	p				0.3401	0.2911	0.0553	0.4695	0.89	0.9391	0.0312	0.5287	0.7949	0.8049	0.0185
	n			31	31	31	31	31	31	31	31	31	31	31	31
	Rho				1	0.55	0.53	0.30	0.08	0.31	0.49	0.35	-0.14	-0.45	-0.28
tnload	p					<.0001	<.0001	0.002	0.4069	0.0015	<.0001	0.0002	0.156	<.0001	0.0037
	n				107	103	103	107	103	103	107	107	107	107	107
	Rho					1	0.95	0.00	0.07	0.27	0.05	0.19	0.35	-0.23	-0.40
tn	p						<.0001	0.9711	0.452	0.0049	0.6209	0.0569	0.0003	0.0185	<.0001
	n					104	104	103	104	104	104	104	104	104	104
	Rho						1	-0.15	-0.14	0.11	0.03	0.07	0.31	-0.21	-0.49
din	p							0.1319	0.1607	0.2872	0.76	0.4551	0.0014	0.0299	<.0001
	n						104	103	104	104	104	104	104	104	104
	Rho							1	0.66	0.54	0.31	0.36	-0.10	-0.22	0.21
tpload	p								<.0001	<.0001	0.001	0.0001	0.3111	0.0255	0.0269
	n							107	103	103	107	107	107	107	107
	Rho								1	0.80	0.35	0.66	0.07	-0.04	0.13
tp	p									<.0001	0.0003	<.0001	0.4901	0.6534	0.1911
	n								104	104	104	104	104	104	104
	Rho									1	0.50	0.72	-0.04	-0.22	0.03
ftp	p										<.0001	<.0001	0.6789	0.0279	0.7496
	n									104	104	104	104	104	104
	Rho										1	0.69	-0.45	-0.26	-0.15
flow	p											<.0001	<.0001	0.0076	0.114
	n										108	108	108	108	108
	Rho											1	-0.15	-0.21	-0.09
turb	p												0.123	0.028	0.3783
	n											108	108	108	108
	Rho												1	0.20	-0.06
cond	p													0.035	0.5109
	n												108	108	108
	Rho													1	-0.19
pH	p														0.0448
	n													108	108
	Rho														1
temp	p														
	n														108

	Strong correlation: Rho>0.50 and p<0.0001
	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Nepean River at Penrith Weir (N57)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.65	0.38	-0.18	-0.28	-0.41	-0.06	0.21	-0.19	-0.44	-0.19	0.46	0.12	0.46
	p		<.0001	0.0044	0.0743	0.004	<.0001	0.5531	0.0289	0.0529	<.0001	0.0579	<.0001	0.2325	<.0001
	n	104	55	55	104	104	104	104	104	104	104	104	104	104	104
totbv	Rho		1	0.43	-0.23	-0.14	-0.34	0.01	0.13	-0.12	-0.08	0.07	0.26	0.22	0.30
	p			0.001	0.0921	0.301	0.0118	0.9579	0.3526	0.3704	0.585	0.6033	0.0535	0.0987	0.0266
	n		55	55	55	55	55	55	55	55	55	55	55	55	55
bgbv	Rho			1	0.05	-0.36	-0.49	-0.01	-0.04	-0.12	-0.10	-0.15	0.25	0.07	0.52
	p				0.7113	0.007	0.0001	0.9275	0.776	0.376	0.4818	0.2851	0.0676	0.6121	<.0001
	n			55	55	55	55	55	55	55	55	55	55	55	55
tnload	Rho				1	0.18	0.18	0.49	0.28	0.33	0.24	0.32	-0.16	-0.14	-0.14
	p					0.067	0.0607	<.0001	0.0045	0.0007	0.0148	0.0009	0.1145	0.1648	0.1625
	n				105	105	105	105	105	104	105	104	104	104	104
tn	Rho					1	0.90	0.11	0.30	0.44	0.43	0.57	-0.09	-0.38	-0.51
	p						<.0001	0.2656	0.0022	<.0001	<.0001	<.0001	0.3771	<.0001	<.0001
	n					105	105	105	105	104	105	104	104	104	104
din	Rho						1	0.10	0.10	0.31	0.40	0.42	-0.19	-0.38	-0.66
	p							0.3193	0.2867	0.0012	<.0001	<.0001	0.0596	<.0001	<.0001
	n						105	105	105	104	105	104	104	104	104
tpload	Rho							1	0.25	0.23	0.19	0.22	-0.13	0.08	-0.20
	p								0.0113	0.0193	0.0499	0.0278	0.1992	0.4352	0.0467
	n							105	105	104	105	104	104	104	104
tp	Rho								1	0.70	0.31	0.63	-0.04	-0.23	0.04
	p									<.0001	0.0011	<.0001	0.7237	0.0203	0.6821
	n								105	104	105	104	104	104	104
ftp	Rho									1	0.50	0.63	-0.32	-0.27	-0.20
	p										<.0001	<.0001	0.0008	0.0062	0.0423
	n									104	104	104	104	104	104
flow	Rho										1	0.56	-0.42	-0.24	-0.25
	p											<.0001	<.0001	0.014	0.0092
	n										105	104	104	104	104
turb	Rho											1	-0.26	-0.29	-0.37
	p												0.0082	0.0031	0.0001
	n											104	104	104	104
cond	Rho												1	0.09	0.29
	p													0.3533	0.0029
	n												104	104	104
pH	Rho													1	0.03
	p														0.7995
	n													104	104
temp	Rho														1
	p														
	n														104

	Strong correlation: Rho>0.50 and p<0.0001
	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Winmalee Lagoon outflow at Springwood Road (N464)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.58	0.52	-0.16	0.02	-0.09	-0.08	0.19	0.01	-0.31	0.08	0.40	0.14	0.57
	p		0.0007	0.003	0.2902	0.8831	0.5311	0.5951	0.2024	0.948	0.0331	0.6041	0.0044	0.3361	<.0001
	n	48	31	31	46	48	48	46	48	48	48	48	48	48	48
totbv	Rho		1	0.31	0.25	-0.19	-0.31	0.36	-0.08	-0.36	-0.01	-0.06	-0.41	0.18	0.08
	p			0.0903	0.1913	0.3054	0.0935	0.0583	0.6504	0.0487	0.9777	0.7584	0.0218	0.332	0.6512
	n		31	31	29	31	31	29	31	31	31	31	31	31	31
bgbv	Rho			1	-0.03	-0.39	-0.50	0.16	0.14	-0.09	0.36	0.15	-0.18	0.09	0.12
	p				0.8769	0.0322	0.0046	0.4159	0.4472	0.6155	0.0494	0.4071	0.3405	0.6337	0.523
	n			31	29	31	31	29	31	31	31	31	31	31	31
tnload	Rho				1	0.16	0.16	0.35	0.02	0.02	0.27	0.01	-0.11	-0.08	-0.23
	p					0.2804	0.294	0.0158	0.8795	0.8923	0.0677	0.9572	0.458	0.6142	0.1258
	n				48	47	47	48	47	46	48	46	46	46	46
tn	Rho					1	0.92	-0.07	0.38	0.38	-0.45	-0.13	0.57	-0.18	-0.14
	p						<.0001	0.6259	0.0071	0.0086	0.0012	0.3803	<.0001	0.2236	0.3388
	n					49	49	47	49	48	49	48	48	48	48
din	Rho						1	-0.17	0.19	0.24	-0.53	-0.35	0.56	-0.15	-0.23
	p							0.2645	0.1904	0.1072	0.0001	0.0158	<.0001	0.3159	0.1162
	n						49	47	49	48	49	48	48	48	48
tpload	Rho							1	0.48	0.42	0.43	0.15	-0.20	0.06	0.04
	p								0.0007	0.0037	0.0024	0.3105	0.1765	0.7009	0.7976
	n							48	47	46	48	46	46	46	46
tp	Rho								1	0.85	0.10	0.43	0.24	-0.37	0.30
	p									<.0001	0.4977	0.0024	0.0993	0.0086	0.0415
	n								49	48	49	48	48	48	48
ftp	Rho									1	0.11	0.30	0.21	-0.44	0.17
	p										0.462	0.0384	0.1586	0.0019	0.2505
	n									48	48	48	48	48	48
flow	Rho										1	0.46	-0.45	-0.17	-0.32
	p											0.001	0.0012	0.2354	0.0267
	n										50	48	48	48	48
turb	Rho											1	-0.23	-0.18	0.08
	p												0.1169	0.2219	0.5935
	n											48	48	48	48
cond	Rho												1	0.08	0.31
	p													0.5853	0.0343
	n												48	48	48
pH	Rho													1	0.23
	p														0.1115
	n													48	48
temp	Rho														1
	p														
	n														48

	Strong correlation: Rho>0.50 and p<0.0001
	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Hawkesbury River at North Richmond (N42)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.86	0.59	-0.33	0.04	-0.41	0.23	0.48	0.13	-0.45	0.02	0.31	0.27	0.37
	p		<.0001	<.0001	<.0001	0.4481	<.0001	<.0001	<.0001	0.1869	<.0001	0.6747	<.0001	<.0001	<.0001
	n	396	370	370	392	396	104	392	396	103	396	390	396	396	396
totbv	Rho		1	0.64	-0.34	-0.03	-0.52	0.14	0.42	0.02	-0.42	0.04	0.30	0.30	0.41
	p			<.0001	<.0001	0.5684	<.0001	0.0074	<.0001	0.8426	<.0001	0.3986	<.0001	<.0001	<.0001
	n		379	379	375	370	78	375	370	77	379	364	370	370	377
bgbv	Rho			1	-0.24	-0.13	-0.57	0.26	0.38	-0.09	-0.43	0.03	0.34	0.13	0.58
	p				<.0001	0.0108	<.0001	<.0001	<.0001	0.4178	<.0001	0.5413	<.0001	0.0104	<.0001
	n			379	375	370	78	375	370	77	379	364	370	370	377
tnload	Rho				1	0.04	0.26	0.08	-0.08	0.04	0.37	0.12	-0.15	-0.15	-0.21
	p					0.4697	0.0085	0.0962	0.1018	0.6935	<.0001	0.0169	0.0025	0.0026	<.0001
	n				401	392	103	401	392	102	401	387	392	392	399
tn	Rho					1	0.72	-0.05	0.27	0.30	0.00	0.29	-0.12	0.11	-0.45
	p						<.0001	0.2802	<.0001	0.0022	0.9814	<.0001	0.015	0.0287	<.0001
	n					396	104	392	396	103	396	390	396	396	396
din	Rho						1	-0.21	-0.14	0.03	0.21	0.0650	-0.08	-0.15	-0.71
	p							0.0347	0.1662	0.7851	0.0349	0.5121	0.4017	0.1373	<.0001
	n						104	103	104	103	104	104	104	104	104
tpload	Rho							1	0.60	0.56	0.13	0.27	-0.17	-0.01	0.15
	p								<.0001	<.0001	0.01	<.0001	0.001	0.8085	0.002
	n							401	392	102	401	387	392	392	399
tp	Rho								1	0.73	0.08	0.59	0.03	-0.03	0.19
	p									<.0001	0.1315	<.0001	0.5389	0.5579	0.0002
	n								396	103	396	390	396	396	396
ftp	Rho									1	0.33	0.44	-0.18	-0.20	0.00
	p										0.0007	<.0001	0.0697	0.0397	0.9709
	n									103	103	103	103	103	103
flow	Rho										1	0.47	-0.36	-0.15	-0.29
	p											<.0001	<.0001	0.0033	<.0001
	n										405	390	396	396	403
turb	Rho											1	-0.09	-0.10	-0.14
	p												0.0827	0.0481	0.0078
	n											304	390	390	390
cond	Rho												1	0.03	0.32
	p													0.5636	<.0001
	n												396	396	396
pH	Rho													1	-0.10
	p														0.0452
	n													396	396
temp	Rho														1
	p														
	n														403

(dark blue)	Strong correlation: Rho>0.50 and p<0.0001
(light blue)	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
(grey)	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

South Creek at Fitzroy Bridge (NS04)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.76	0.07	-0.44	-0.16	-0.16	-0.17	-0.36	-0.54	-0.46	-0.45	0.34	0.18	0.31
	p		<.0001	0.6018	<.0001	0.1075	0.0987	0.0765	0.0002	<.0001	<.0001	<.0001	0.0004	0.062	0.0012
	n	104	60	60	104	104	104	104	104	104	104	104	104	104	104
totbv	Rho		1	0.21	-0.05	-0.25	-0.37	0.09	0.24	-0.13	0.10	0.02	0.13	0.05	0.30
	p			0.1031	0.6828	0.0539	0.0038	0.4709	0.0694	0.3162	0.4355	0.8747	0.3249	0.7141	0.018
	n		60	60	60	60	60	60	60	60	60	60	60	60	60
bgbv	Rho			1	0.16	-0.37	-0.44	0.22	0.10	-0.09	0.01	0.13	-0.24	-0.21	0.31
	p				0.217	0.0036	0.0004	0.0964	0.4302	0.5006	0.9471	0.3314	0.0703	0.0997	0.016
	n			60	60	60	60	60	60	60	60	60	60	60	60
tnload	Rho				1	0.25	0.18	0.62	0.33	0.50	0.50	0.27	-0.15	-0.08	-0.18
	p					0.012	0.0698	<.0001	0.0007	<.0001	<.0001	0.0055	0.1219	0.4015	0.0702
	n				104	104	104	104	104	104	104	104	104	104	104
tn	Rho					1	0.93	-0.08	-0.19	0.05	0.04	-0.31	0.36	0.33	-0.67
	p						<.0001	0.4334	0.057	0.6317	0.7083	0.0016	0.0001	0.0007	<.0001
	n					104	104	104	104	104	104	104	104	104	104
din	Rho						1	-0.19	-0.38	-0.12	-0.11	-0.38	0.40	0.37	-0.69
	p							0.0498	<.0001	0.2155	0.2761	<.0001	<.0001	0.0001	<.0001
	n						104	104	104	104	104	104	104	104	104
tpload	Rho							1	0.45	0.51	0.44	0.32	-0.34	-0.31	0.17
	p								<.0001	<.0001	<.0001	0.001	0.0004	0.0016	0.0928
	n							104	104	104	104	104	104	104	104
tp	Rho								1	0.79	0.59	0.79	-0.50	-0.39	0.21
	p									<.0001	<.0001	<.0001	<.0001	<.0001	0.0288
	n								104	104	104	104	104	104	104
ftp	Rho									1	0.64	0.61	-0.43	-0.43	0.07
	p										<.0001	<.0001	<.0001	<.0001	0.4798
	n									104	104	104	104	104	104
flow	Rho										1	0.53	-0.35	-0.19	-0.12
	p											<.0001	0.0003	0.0537	0.2181
	n										104	104	104	104	104
turb	Rho											1	0.57	-0.39	0.27
	p												<.0001	<.0001	0.0057
	n											104	104	104	104
cond	Rho												1	0.51	-0.29
	p													<.0001	0.0031
	n												104	104	104
pH	Rho													1	-0.51
	p														<.0001
	n													104	104
temp	Rho														1
	p														
	n														104

(dark blue)	Strong correlation: Rho>0.50 and p<0.0001
(light blue)	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
(grey)	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Hawkesbury River at Wilberforce (N35)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.70	0.54	-0.43	-0.36	-0.49	-0.13	-0.04	-0.53	-0.65	-0.22	0.40	-0.02	0.49
	p		<.0001	<.0001	<.0001	0.0002	<.0001	0.1966	0.7204	<.0001	<.0001	0.0277	<.0001	0.8062	<.0001
	n	102	85	85	102	102	102	102	102	102	102	102	102	102	102
totbv	Rho		1	0.41	-0.21	-0.11	-0.26	-0.06	-0.05	-0.35	-0.41	-0.10	0.14	-0.01	0.25
	p			0.0001	0.0543	0.3123	0.0161	0.5789	0.6788	0.0009	<.0001	0.3848	0.1913	0.8952	0.0229
	n		85	85	85	85	85	85	85	85	85	85	85	85	85
bgbv	Rho			1	-0.36	-0.43	-0.57	0.01	0.19	-0.22	-0.32	0.02	0.11	-0.11	0.44
	p				0.0008	<.0001	<.0001	0.9334	0.0804	0.044	0.0029	0.8833	0.3228	0.3149	<.0001
	n			85	85	85	85	85	85	85	85	85	85	85	85
tnload	Rho				1	0.54	0.47	0.56	0.23	0.48	0.50	0.23	-0.01	0.00	-0.27
	p					<.0001	<.0001	<.0001	0.0198	<.0001	<.0001	0.0177	0.8861	0.9717	0.006
	n				102	102	102	102	102	102	102	102	102	102	102
tn	Rho					1	0.91	0.25	0.16	0.37	0.29	0.20	0.16	0.10	-0.47
	p						<.0001	0.0129	0.1107	0.0002	0.0033	0.0405	0.1031	0.3031	<.0001
	n					102	102	102	102	102	102	102	102	102	102
din	Rho						1	0.11	-0.05	0.26	0.31	0.06	0.03	0.21	-0.67
	p							0.2732	0.5985	0.0078	0.0014	0.5426	0.734	0.0327	<.0001
	n						102	102	102	102	102	102	102	102	102
tpload	Rho							1	0.39	0.39	0.26	0.37	0.13	-0.18	0.12
	p								<.0001	<.0001	0.008	0.0002	0.177	0.075	0.2257
	n							102	102	102	102	102	102	102	102
tp	Rho								1	0.69	0.31	0.86	0.02	-0.51	0.44
	p									<.0001	0.0018	<.0001	0.8275	<.0001	<.0001
	n								102	102	102	102	102	102	102
ftp	Rho									1	0.65	0.70	-0.19	-0.39	0.10
	p										<.0001	<.0001	0.0596	<.0001	0.3295
	n									102	102	102	102	102	102
flow	Rho										1	0.45	-0.49	-0.11	-0.26
	p											<.0001	<.0001	0.2633	0.0072
	n										102	102	102	102	102
turb	Rho											1	-0.11	-0.50	0.31
	p												0.2561	<.0001	0.0014
	n											102	102	102	102
cond	Rho												1	0.25	0.19
	p													0.0101	0.0558
	n												102	102	102
pH	Rho													1	-0.57
	p														<.0001
	n													102	102
temp	Rho														1
	p														
	n														102

	Strong correlation: Rho>0.50 and p<0.0001
	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Cattai Creek at Cattai Road (NC11)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.74	0.62	-0.42	-0.20	-0.18	-0.35	-0.23	-0.56	-0.51	-0.38	0.36	0.25	0.52
	p		<.0001	<.0001	<.0001	0.0418	0.076	0.0004	0.0215	<.0001	<.0001	<.0001	0.0002	0.0113	<.0001
	n	103	59	59	103	103	103	103	103	103	103	103	103	103	103
totbv	Rho		1	0.60	-0.03	-0.27	-0.32	-0.01	0.16	-0.14	-0.11	0.06	-0.01	0.03	0.55
	p			<.0001	0.8503	0.0366	0.0149	0.9424	0.2336	0.2856	0.3903	0.6389	0.9597	0.8024	<.0001
	n		59	59	59	59	59	59	59	59	59	59	59	59	59
bgbv	Rho			1	-0.17	-0.47	-0.52	-0.15	0.45	0.12	-0.01	0.17	-0.32	-0.07	0.54
	p				0.1981	0.0002	<.0001	0.2492	0.0004	0.3641	0.9211	0.1885	0.0131	0.5969	<.0001
	n			59	59	59	59	59	59	59	59	59	59	59	59
tnload	Rho				1	0.10	0.10	0.38	-0.06	0.17	0.09	0.03	-0.21	-0.35	-0.24
	p					0.2979	0.2939	<.0001	0.5366	0.0929	0.3931	0.7808	0.0353	0.0002	0.0158
	n				103	103	103	103	103	103	103	103	103	103	103
tn	Rho					1	0.97	0.17	-0.52	-0.40	0.01	-0.35	0.67	0.34	-0.65
	p						<.0001	0.0921	<.0001	<.0001	0.9503	0.0003	<.0001	0.0005	<.0001
	n					103	103	103	103	103	103	103	103	103	103
din	Rho						1	0.14	-0.60	-0.46	-0.06	-0.37	0.69	0.35	-0.67
	p							0.1609	<.0001	<.0001	0.5507	<.0001	<.0001	0.0003	<.0001
	n						103	103	103	103	103	103	103	103	103
tpload	Rho							1	0.13	0.16	0.25	0.17	-0.11	-0.10	-0.20
	p								0.1967	0.0964	0.0103	0.0881	0.253	0.331	0.0441
	n							103	103	103	103	103	103	103	103
tp	Rho								1	0.79	0.41	0.78	-0.64	-0.10	0.32
	p									<.0001	<.0001	<.0001	<.0001	0.331	0.0009
	n								103	103	103	103	103	103	103
ftp	Rho									1	0.46	0.68	-0.67	-0.26	0.13
	p										<.0001	<.0001	<.0001	0.0078	0.2065
	n									103	103	103	103	103	103
flow	Rho										1	0.36	-0.26	-0.13	-0.17
	p											0.0002	0.0079	0.1843	0.0805
	n										103	103	103	103	103
turb	Rho											1	-0.53	-0.17	0.08
	p												<.0001	0.083	0.4202
	n											103	103	103	103
cond	Rho												1	0.38	-0.16
	p													<.0001	0.102
	n												103	103	103
ph	Rho													1	-0.30
	p														0.0024
	n													103	103
temp	Rho														1
	p														
	n														103

(dark blue)	Strong correlation: Rho>0.50 and p<0.0001
(light blue)	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
(grey)	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Hawkesbury River at Sackville Ferry (N26)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1	0.31	0.30	-0.40	-0.24	-0.36	-0.17	-0.24	-0.58	-0.47	-0.35	0.26	0.53	0.13
	p		0.003	0.0041	<.0001	0.0157	0.0002	0.0847	0.0138	<.0001	<.0001	0.0004	0.0094	<.0001	0.1811
	n	102	87	87	102	102	102	102	102	102	102	102	102	102	102
totbv	Rho		1	0.38	-0.14	-0.31	-0.33	-0.08	-0.31	-0.46	-0.35	-0.22	0.07	0.45	-0.02
	p			0.0003	0.195	0.0035	0.0018	0.4748	0.0035	<.0001	0.0010	0.0405	0.5039	<.0001	0.8313
	n		87	87	87	87	87	87	87	87	87	87	87	87	87
bgbv	Rho			1	-0.31	-0.57	-0.70	-0.14	-0.25	-0.53	-0.53	-0.34	0.24	0.47	0.29
	p				0.003	<.0001	<.0001	0.2096	0.0173	<.0001	<.0001	0.0013	0.0237	<.0001	0.0068
	n			87	87	87	87	87	87	87	87	87	87	87	87
tnload	Rho				1	0.29	0.34	0.54	0.20	0.36	0.45	0.23	-0.20	-0.31	-0.22
	p					0.0032	0.0004	<.0001	0.039	0.0002	<.0001	0.0179	0.0451	0.0017	0.0262
	n				102	102	102	102	102	102	102	102	102	102	102
tn	Rho					1	0.94	0.18	0.56	0.63	0.46	0.55	-0.13	-0.48	-0.38
	p						<.0001	0.0734	<.0001	<.0001	<.0001	<.0001	0.1953	<.0001	<.0001
	n					102	102	102	102	102	102	102	102	102	102
din	Rho						1	0.17	0.41	0.59	0.45	0.45	-0.20	-0.46	-0.53
	p							0.0801	<.0001	<.0001	<.0001	<.0001	0.0429	<.0001	<.0001
	n						102	102	102	102	102	102	102	102	102
tpload	Rho							1	0.25	0.21	0.34	0.35	-0.03	-0.18	0.04
	p								0.01	0.0375	0.0005	0.0003	0.7296	0.0637	0.6805
	n							102	102	102	102	102	102	102	102
tp	Rho								1	0.79	0.38	0.77	-0.07	-0.67	0.25
	p									<.0001	<.0001	<.0001	0.4695	<.0001	0.0108
	n								102	102	102	102	102	102	102
ftp	Rho									1	0.56	0.66	-0.25	-0.84	0.06
	p										<.0001	<.0001	0.0126	<.0001	0.5322
	n									102	102	102	102	102	102
flow	Rho										1	0.45	-0.44	-0.54	-0.26
	p											<.0001	<.0001	<.0001	0.0087
	n										102	102	102	102	102
turb	Rho											1	-0.14	-0.56	0.09
	p												0.1562	<.0001	0.3796
	n											102	102	102	102
cond	Rho												1	0.31	0.34
	p													0.0017	0.0005
	n												102	102	102
ph	Rho													1	-0.23
	p														0.0178
	n													102	102
temp	Rho														1
	p														
	n														102

(dark blue)	Strong correlation: Rho>0.50 and p<0.0001
(light blue)	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
(grey)	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05

Berowra Creek off Square Bay (NB11)

Spearman Correlation Coefficients

Prob > |r| under H0: Rho=0

Number of Observations

	stats	chla	totbv	bgbv	tnload	tn	din	tpload	tp	ftp	flow	turb	cond	pH	temp
chla	Rho	1.00	0.41	0.13	0.05	0.37	0.05	-0.05	0.36	-0.05	0.24	0.18	-0.29	-0.05	0.16
	p		0.0035	0.3594	0.5866	0.0001	0.588	0.6156	0.0002	0.6006	0.0151	0.0661	0.0029	0.6052	0.1188
	n	102	50	50	102	102	102	102	102	102	102	102	102	102	102
totbv	Rho		1.00	0.32	-0.12	0.18	-0.15	-0.18	-0.03	-0.13	0.10	0.06	-0.18	0.04	0.10
	p			0.0243	0.4126	0.2028	0.2909	0.2041	0.812	0.3691	0.5081	0.6596	0.2237	0.7904	0.4751
	n		50	50	50	50	50	50	50	50	50	50	50	50	50
bgbv	Rho			1.00	-0.16	-0.06	-0.17	-0.16	-0.07	-0.08	0.20	0.12	0.03	-0.32	0.24
	p				0.2658	0.6642	0.2389	0.2721	0.6498	0.5655	0.1759	0.4005	0.8215	0.0247	0.089
	n			50	50	50	50	50	50	50	50	50	50	50	50
tnload	Rho				1.00	0.29	0.28	0.47	0.12	0.15	0.32	-0.04	-0.17	-0.16	-0.08
	p					0.0031	0.0037	<.0001	0.227	0.1411	0.0009	0.6792	0.097	0.1103	0.4114
	n				102	102	102	102	102	102	102	102	102	102	102
tn	Rho					1.00	0.72	0.12	0.37	0.34	0.55	0.15	-0.74	-0.20	-0.05
	p						<.0001	0.2366	0.0001	0.0004	<.0001	0.1356	<.0001	0.0413	0.5906
	n					102	102	102	102	102	102	102	102	102	102
din	Rho						1.00	0.12	0.11	0.23	0.44	-0.01	-0.65	0.09	-0.51
	p							0.2243	0.2805	0.0202	<.0001	0.9116	<.0001	0.346	<.0001
	n						102	102	102	102	102	102	102	102	102
tpload	Rho							1.00	0.15	0.07	0.18	0.07	-0.08	-0.24	0.15
	p								0.1219	0.5136	0.0716	0.4606	0.4021	0.0156	0.144
	n							102	102	102	102	102	102	102	102
tp	Rho								1.00	0.54	0.22	0.38	-0.11	-0.45	0.36
	p									<.0001	0.0255	<.0001	0.2736	<.0001	0.0002
	n								102	102	102	102	102	102	102
ftp	Rho									1.00	0.15	0.23	0.03	-0.38	0.19
	p										0.1260	0.0189	0.7966	<.0001	0.0557
	n									102	102	102	102	102	102
flow	Rho										1.00	0.14	-0.49	-0.23	0.08
	p											0.1666	<.0001	0.0202	0.4166
	n										102	102	102	102	102
turb	Rho											1	-0.06	-0.41	0.38
	p												0.5184	<.0001	<.0001
	n											102	102	102	102
cond	Rho												1.00	0.00	0.24
	p													0.9733	0.0159
	n												102	102	102
pH	Rho													1	-0.71
	p														<.0001
	n													102	102
temp	Rho														1.00
	p														
	n														102

(dark blue)	Strong correlation: Rho>0.50 and p<0.0001
(light blue)	Moderate correlation: Rho>0.50 and p=0.0001 to 0.05 or Rho=0.30 to 0.50 and p<0.0001
(grey)	Weak correlation: Rho=0.30 to 0.50 and p=0.0001 to 0.05