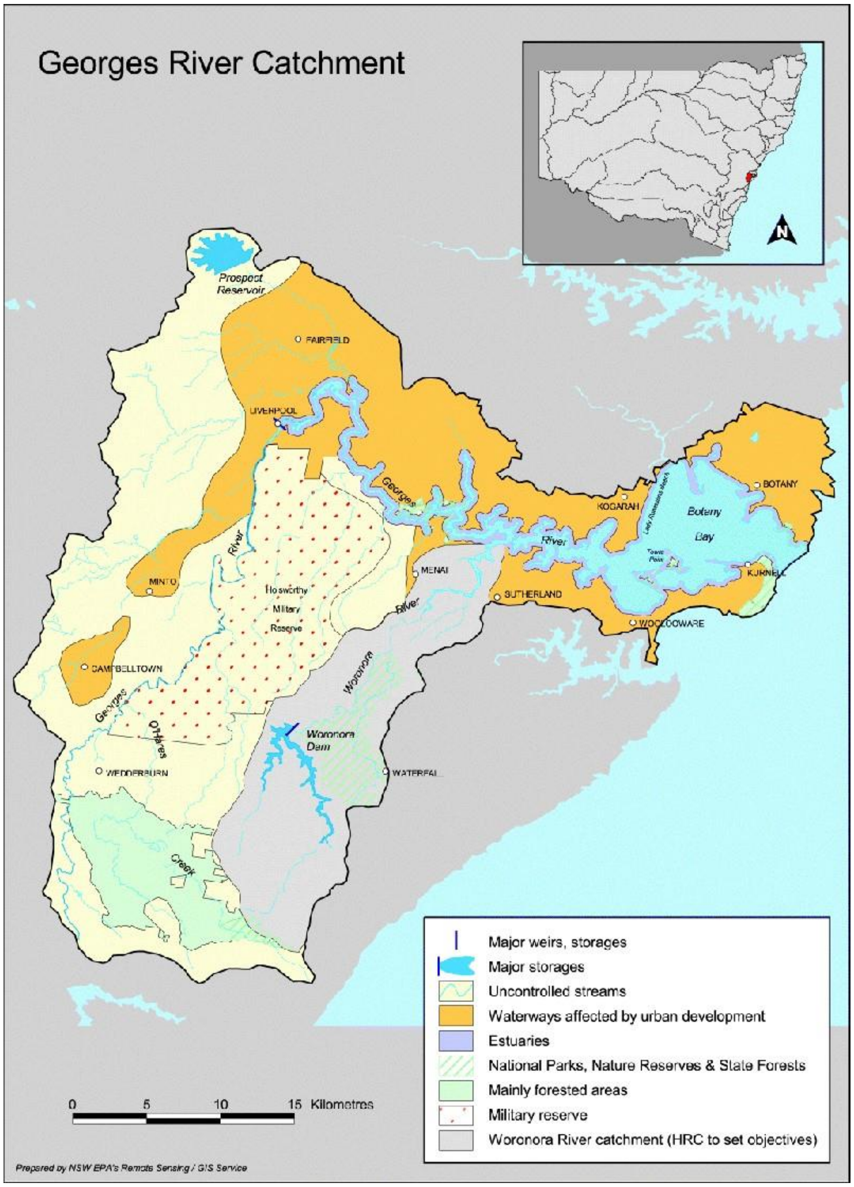
TEMPORAL TRENDS IN WATER QUALITY- GEORGES RIVER



This report was completed on behalf of Georges Riverkeeper.

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1. Executive Summary

Georges Riverkeeper has collected water quality data at 40 freshwater locations throughout the catchment dating back to 2009 in order to monitor the health of the river. The most recent and only collated report on the temporal trends in water quality was published in November 2016 by the Georges River Combined Councils Committee which presented the trends of key water quality parameters, namely; electrical conductivity, turbidity, total nitrogen and total phosphorus. The purpose of this report is to continue to monitor and interrogate the additional data collected and observe any developing trends in order to assist Georges Riverkeeper. Our aim is to assist Georges Riverkeeper by providing this report as a potential reference for future reporting on water quality in the catchment as well as offering up-to-date insights.

A literature review was conducted with an aim to understand the methods utilised by other published works on temporal trends reporting of water quality, this empowered our team to make an informed judgement on the suitability of the methods employed in the 2016 report which we found to ultimately be sound and appropriate. However in our review, some alternative statistical tests looked to be suitable for offering further additional insight that had not been explored in the 2016 report.

In a similar fashion to the 2016 report, temporal trends were analysed by plotting the selected parameters along with both a linear model to describe the overall trend since 2009, and a polynomial model to explain more of the temporal variability in the datasets. This was programmed in R as it is a more capable tool and is widely used across studies. What we found across the sites analysed was general expected fluctuation in the values across most parameters, but not necessarily any notable increase or decrease over the period since 2009.

Additionally, Mann-Kendall tests were performed among other statistical tests to allow us to make judgements on the monotonic trends, and this particular statistical test has shown to be worth recommending in future reporting on water quality, as the literature also supports this.

In order to adequately support the integrity of future temporal trends reports that will no doubt be vital for the continued care of the river’s health, the recommendation for more frequent sampling and data collection cannot be understated, as there is a noticeable decrease in data collected in more recent years, which impairs the ability to confidently pull out trends from the datasets.

2. Introduction

Georges River is a tide dominant, urban river within Sydney's South, that is approximately 100km long with a catchment area around 960km2. This catchment area falls into eight separate council areas with a total population of 1.5 million people, 454 fauna species, 30 vegetation communities, and 29 Endangered Ecological Communities (1). Therefore, due to the large populations of people, flora, and fauna that occupy the Georges River and its tributaries, monitoring and analyses of the water quality plays an integral role in maintaining river health. This water quality data is routinely collected by the catchment management authority, Georges Riverkeeper, who act in conjunction with the surrounding local councils, in order to ensure the condition of the River is maintained and work to improve the river health.

The Georges River catchment area is greatly impacted upon by human occupation. The river and its riparian areas undergo a diverse range of activities, this includes but is not limited to; recreational use, stormwater run-off, illegal dumping, ecological degradation, and littering. All these activities impact upon the river health, with the regular and diverse uses of Georges River, regular assessment of water quality is important to ensure safe water for human use, along with allowing for maintaining, and ideally improving the ecological habitats.

In 2016, Georges Riverkeeper released the Georges River Health Temporal Trends Report (GRHTTR), which analysed the water quality, riparian vegetation, and aquatic macroinvertebrates from 2009 to 2016. The GRHTTR, as done by David Reid, determined trends within the total nitrogen (mgL-1), electrical conductivity (uS cm-1), turbidity (NTU), and total phosphorus (mg L-1) to evaluate the water quality from 40 freshwater sites within the catchment. Taxon richness, and Shannon biodiversity index was used to determine the aquatic macroinvertebrate populations from the 40 sites. The rationale for macroinvertebrate sampling can be found within the 2003 study by Chessman in which the Stream Invertebrate Grade Number - Average Level (SIGNAL) score for Australian macroinvertebrates is outlined.

Since this 2016 report, further data has been collected from these 40 sites as a continued effort to monitor the water quality and health of Georges River. The 2016 GRHTTR set the precedent for further analyses to be performed and completed on the water quality of the Georges River catchment area. This project aims to utilise the data and analysis methods as used by Reid, to determine longer term water quality trends from data collected at O'Hares Creek Woolwash, Iluka Creek, Cobbong Creek, Stokes Creek, Woronora River, and Bottle Creek. The investigation into long-term water quality trends, such as that by Kuruppu and Rahman (2015), highlights the importance of and the rationale behind this project. Successful long-term analysis leads to better planning and land use management by identifying how changes in the catchment have altered water quality, informing future development and remediation.

2.1 Project Aim

Throughout this project, we have been challenged to review the latest data collected by Georges Riverkeeper, from 2009 to 2021. An analysis of the temporal trends of the SIGNAL, electrical conductivity, turbidity, total nitrogen, and total phosphorus will be completed in order to assess the overall water quality and river health. The analysis will be performed by the same method as outlined within the 2016 GRHTTR, along with alternative methods as proposed within other literature. Due to time constraints, a statistical analysis of the following sites will be performed:

- O'Hares Creek Woolwash
- Iluka Creek
- Cobbong Creek
- Stokes Creek
- Woronora River
- Bottle Creek

Concurrently, a review of literature from January 1st, 2017 until 17th September, 2021, will be performed in order to determine alternative and other commonly utilised statistical analysis methods. This literature review will be conducted in order to create recommendations going forth on monitoring and analysing water quality data, along with enabling for possible explanations as to trends noticed within the given data.

2.2 Project Outcomes

This project has overall five outcomes that we aim to meet in order to complete the aims outlines, of which are:

1. Conduct appropriate statistical analysis of the data for the aforementioned six sites within the Georges River catchment area.
2. Review the suitability of the statistical methods utilised within the 2016 GRHTTR.
3. Perform a literature review to compare and contrast analytical methods utilised throughout literature to that within the 2016 GRHTTR.
4. Complete an investigation into the potential causative factors for the trends found.
5. Develop an ongoing social media campaign for Georges Riverkeeper, utilising their current platforms, in order to educate the public in an accessible and engaging manner.

3. Methods

3.1 Literature review

A search of literature was conducted using the online database, Web of Knowledge, restricting the search results to analyses of water quality in rivers, streams and catchments across New South Wales. These search restrictions produced 98 articles which were then further refined based on their titles and abstracts. These remaining articles were reviewed and important information was extracted into a spreadsheet. This spreadsheet contained accessible records and information directly related to both freshwater and estuarine water quality analysis. This information was then written into a literature review containing an analysis of the methodologies used for assessing the temporal trends in quality in estuarine and freshwater environments in NSW.

3.2 Statistical Analysis

Using the appropriate statistical methods, the water quality at the sites was plotted using R. The water quality consists of four separate graphs representing turbidity, electrical conductivity, total nitrogen content and total phosphorus content of the water. Each of these graphs was fitted with a polynomial trend line and an average best fit, these allow the temporal trends in the water quality to be analysed.

The process for obtaining these graphs and the graphs themselves can be found here:
Plots (1) (1).pdf

4. Results

ANZECC Trigger values

These values depict the current Australian and New Zealand water quality objects, which have been developed specifically for NSW rivers and estuaries. The relevant information for the parameters and sites used have been indicated within Table 1.

Table 1: The ANZECC trigger values for Georges River and other NSW rivers and estuaries, which help to indicate the health of the river. If the values indicated below are exceeded, it indicates potential for harmful environmental impacts to happen.

	Upland River	Lowland River
Total Phosphorus (µg/L)	20	25
Total Nitrogen (µg/L)	250	350
Turbidity (NTU)	2-25 (flow and vegetation dependent)	6-50 (flow and vegetation dependent)
Electrical Conductivity (µS/cm)	30-350	125-2200

Ecological Conditions Assessment Table

Table 2: These values assess the relative health of the freshwater rivers within the Georges River and cateorgises certain parameter values as ‘Excellent’, ‘Good’, ‘Fair’, or ‘Poor’.

	Parameter	Regional guideline	Worst case scenario	Excellent	Good	Fair	Poor
Riparian	RARC score	> 36.5	18.6	≥ 35.6	32.9 - 35.5	28.3 - 32.8	≤ 28.2
Water quality	Dissolved oxygen (% saturation)	> 75	24	≥ 72.5	64.9 - 72.4	52.1 - 64.8	≤ 52.0
	pH	5.19 to 7.01	5.18 or 8.31	5.19 - 7.07	7.08 – 7.27	7.28 – 7.59	≤ 5.18 or ≥ 7.60
	Electrical conductivity (μS cm^{-1})	169	1833	≤ 252	251- 501	502 - 917	≥ 918
	Turbidity (NTU)	3.5	41	≤ 5.3	5.2 – 11.0	11.1 – 20.3	≥ 20.4
	Total nitrogen (mg L^{-1})	0.30	1.60	≤ 0.36	0.37 – 0.55	0.56 – 0.88	≥ 0.89
	Total Kjeldahl nitrogen (mg L^{-1})	0.29	1.09	≤ 0.33	0.34 – 0.45	0.46 – 0.64	≥ 0.65
	Ammonia (mg L^{-1})	0.02	0.15	≤ 0.02	0.03 – 0.04	0.05 – 0.07	≥ 0.08
	Nitrates-nitrites (mg L^{-1})	0.03	0.75	≤ 0.06	0.07 – 0.17	0.18 – 0.35	≥ 0.36
	Total phosphorus (mg L^{-1})	0.02	0.28	≤ 0.03	0.04 – 0.07	0.08 – 0.13	≥ 0.14
	Soluble reactive phosphorus (mg L^{-1})	0.002	0.082	≤ 0.006	0.007 – 0.018	0.019 – 0.038	≥ 0.039

O’Hare’s Creek at Woolwash – Lowland River

There is a slight trend of increasing electrical conductivity (EC) at O’Hares Creek at Woolwash with the majority of measurements meeting the ‘Excellent’ criteria, with three occasions of “Fair” and with outliers coming under “Fair” and “Poor”. No measurements exceeded the maximum trigger values for EC. The turbidity of the site did not exceed the maximum trigger value and was within the range of trigger values, however, this is flow and vegetation dependent. There is a slight downward trend, with values fluctuating between “Good” and “Excellent”. There are variations within the values collected for the total nitrogen at O’Hares Creek, as seen in Figure 3, however, none of these values exceeded the ANZECC trigger value, Table 1. A slight downward trend of the total nitrogen values can be noticed within Figure 3, whilst still remaining within the “Good” category for water quality assessment, Table 2. There has been a current downwards trend of the total phosphorus, Figure 4, however these values have all remained below the trigger value of 25μg/L, Table 1, and can be classified as “Excellent’ water quality, Table 2.

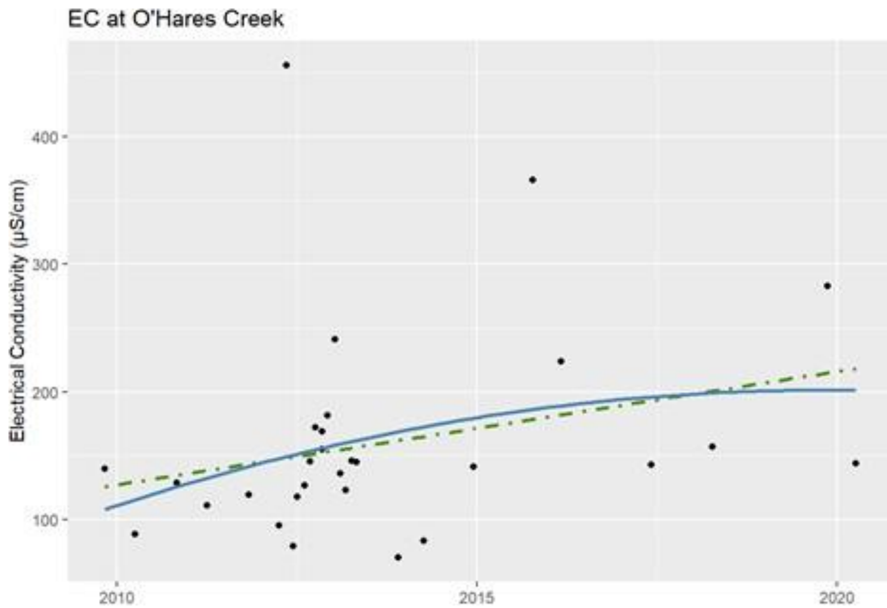


Figure 1: The electrical conductivity values collected at O'Hares Creek at Woolwash from 2009 to 2021. The line of best fit and 2nd degree polynomials had R-squared values of 0.076 and 0.084, respectively. 2 outliers were dropped from this graph, 2016-11-07, 703.6667 (µS/cm) and 2017-12-27, 1730.0 (µS/cm)

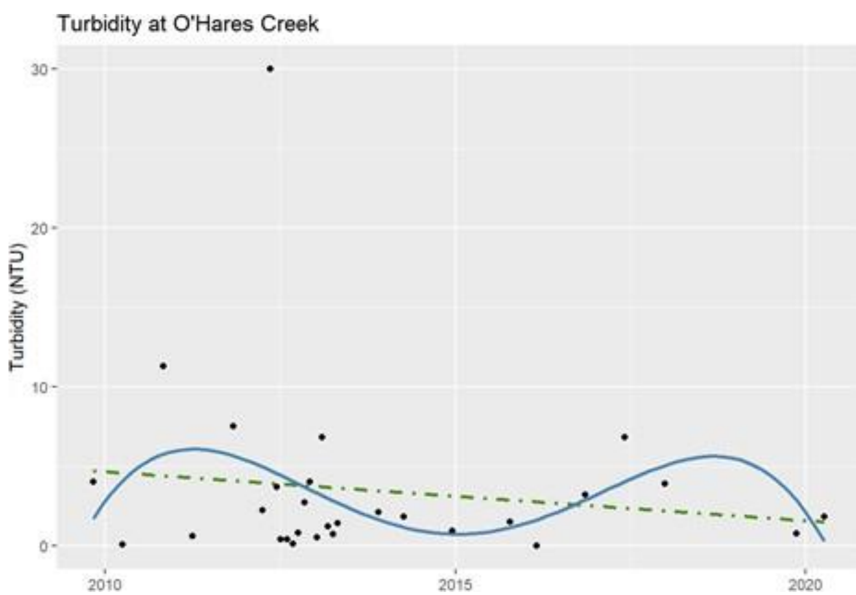


Figure 2: . The turbidity values collected at O'Hares Creek at Woolwash from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.020 and 0.083, respectively.

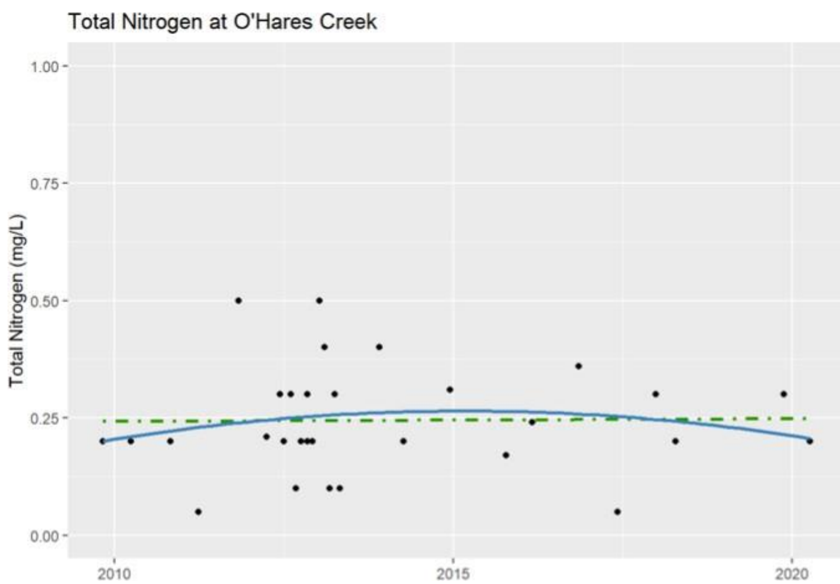


Figure 3: The total nitrogen values collected at O'Hares Creek at Woolwash from 2009 to 2021. The line of best fit and 2nd degree polynomials had R-squared values of 0.00015 and 0.019, respectively. The outlier of 3.0 (mg/L) from 10/05/2012 was dropped.

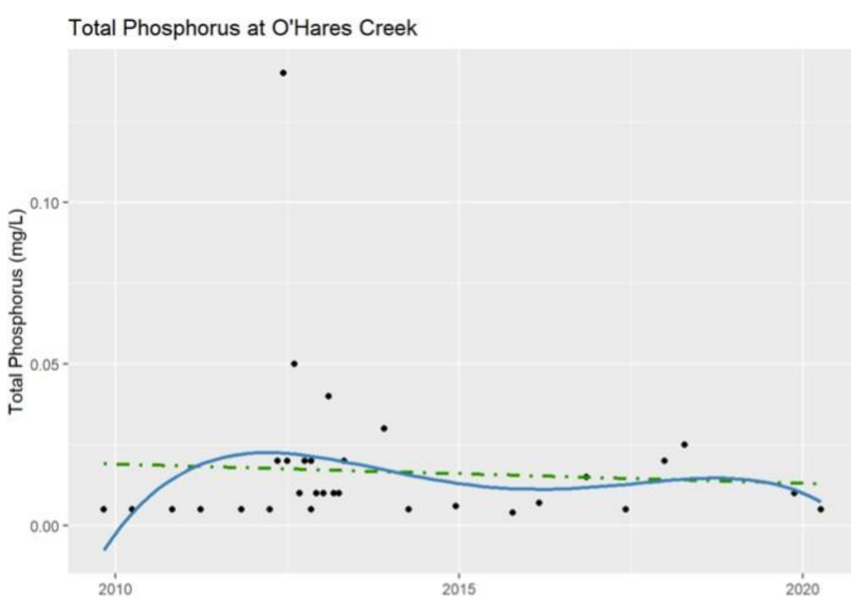


Figure 4: The total phosphorus values collected at O'Hares Creek at Woolwash from 2009 to 2021. The line of best fit and 4th degree polynomial had R-squared values of 0.0041 and 0.073, respectively.

Iluka Creek - Upland River

Electrical conductivity is trending slightly upwards at Iluka Creek but has remained "Excellent" since 2009. The maximum ANZECC trigger values have not been exceeded for EC. Turbidity has remained stable at this site early 2012 and late 2013 where turbidity was "Good". Maximum trigger values for turbidity may have been exceeded with two instances of reaching lower values of concern.. The total nitrogen at Iluka Creek has been trending downwards, with a peak occurring during 2012, Figure 7. The total nitrogen data however, does not exceed the trigger value as in Table 1, and is classified as 'Excellent' water quality overall, with this peak in 2012 causing a brief shift to 'Fair' water quality, Table 2. Total phosphorus has been consistently classified as 'Good', however, there appears to be a recent upwards trend within the last 5 years, Figure 8. Whilst these values have remained below the ANZECC trigger values, this needs to be monitored more closely to ensure this upwards trend does not continue.

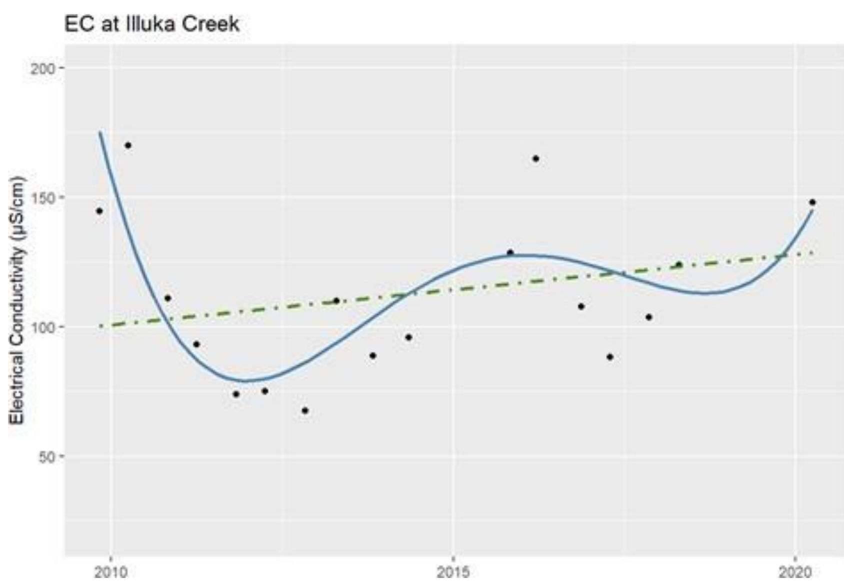


Figure 5: The electrical conductivity values collected at Iluka Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.064 and 0.614 respectively.

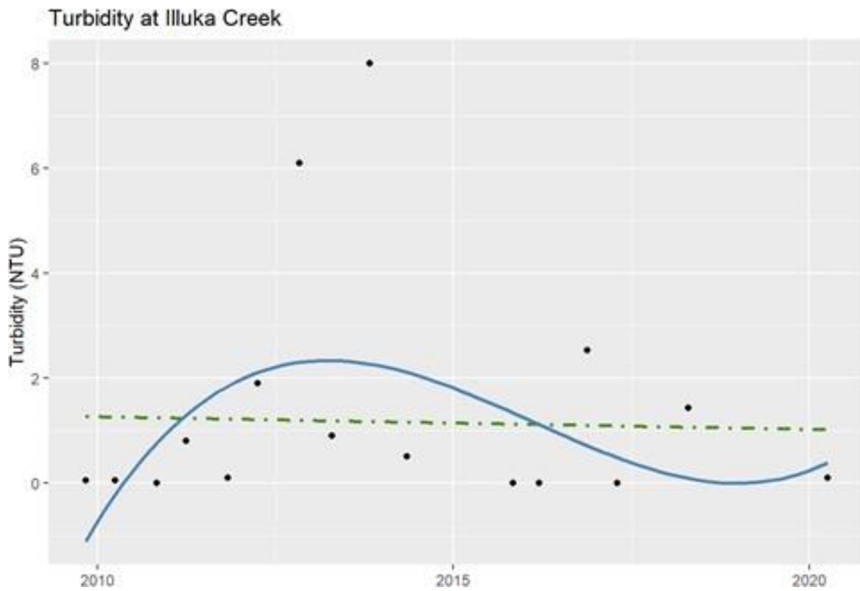


Figure 6: The turbidity values collected at Iluka Creek from 2009 to 2021. The line of best fit and 3rd degree polynomials had R-squared values of 0.001 and 0.185 respectively.

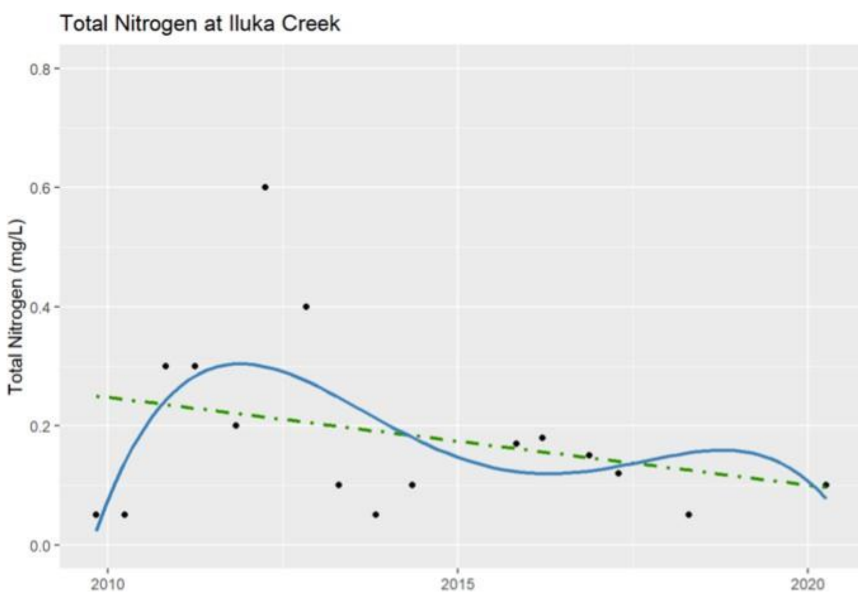


Figure 7: The total nitrogen values collected at Iluka Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.019 and 0.22, respectively. The outlier of 3.0 (mg/L) from 10/05/2012 was dropped.

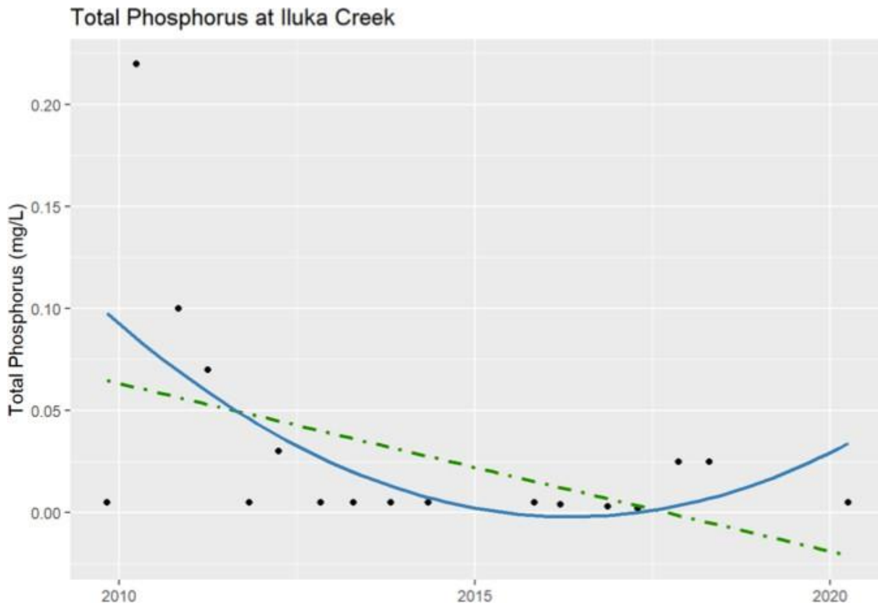


Figure 8: The total phosphorus values collected at Iluka Creek from 2009 to 2021. The line of best fit and 2nd degree polynomials had R-squared values of 0.23 and 0.37, respectively.

Cobbong Creek – Upland River

Electrical conductivity at Cobbong Creek has predominantly remained below 252µS/cm which is “Excellent” with only two measurements of 252.6 µS/cm and 287 µS/cm being “Good”. There is a slight upward trend with noticeable fluctuations since 2009 however the measurements indicate appropriate dissolved solids and remain below maximum trigger values. Turbidity has remained relatively constant with one larger, but still low measurement in early 2018. These may still exceed trigger values due to values being consistently very low. However, by regional guidelines, turbidity has remained “Excellent” since 2009. The total nitrogen values determined from Cobbong Creek have varied greatly from 2009 to 2021, Figure 11, having maximum values above 0.3 mg/L and minimum values of 0.05mg/L. Whilst the maximum values are still above the trigger value, Table 1, the overall values can still be categorised as ‘Excellent’ water quality. However, the current upwards trend of the data suggests that closer monitoring needs to be done to ensure these values are maintained or start to level out in their trending. The total phosphorus concentrations found at Cobbong Creek have remained relatively consistent, with a peak occurring during 2011 at 0.07mg/L, Figure 12. These values for total phosphorus are below the ANZECC trigger values, and can be classified as having ‘Excellent’ water quality, as in Tables 1 and 2.

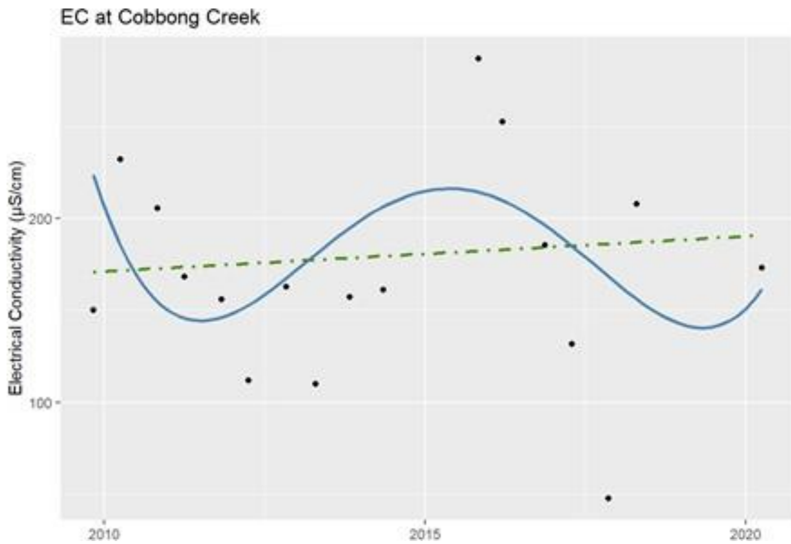


Figure 9: The electrical conductivity values collected at Cobbong Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.009 and 0.206, respectively.

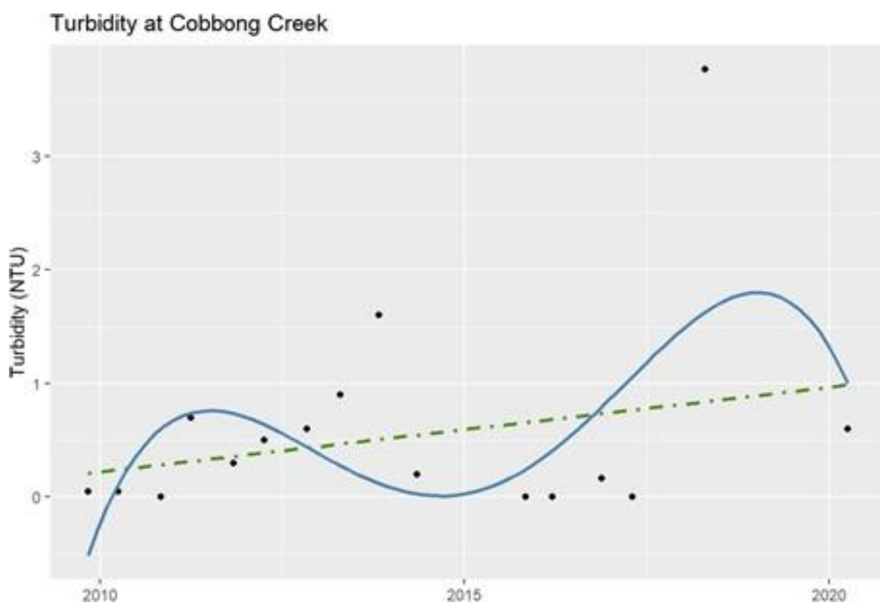


Figure 10: The turbidity values collected at Cobbong Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.064 and 0.273, respectively.

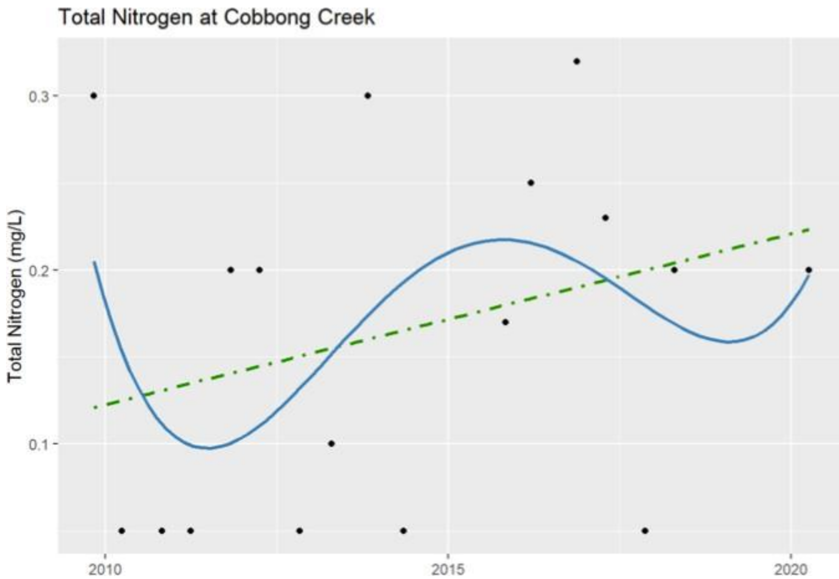


Figure 11: The total nitrogen values collected at Cobbong Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.095 and 0.23, respectively.

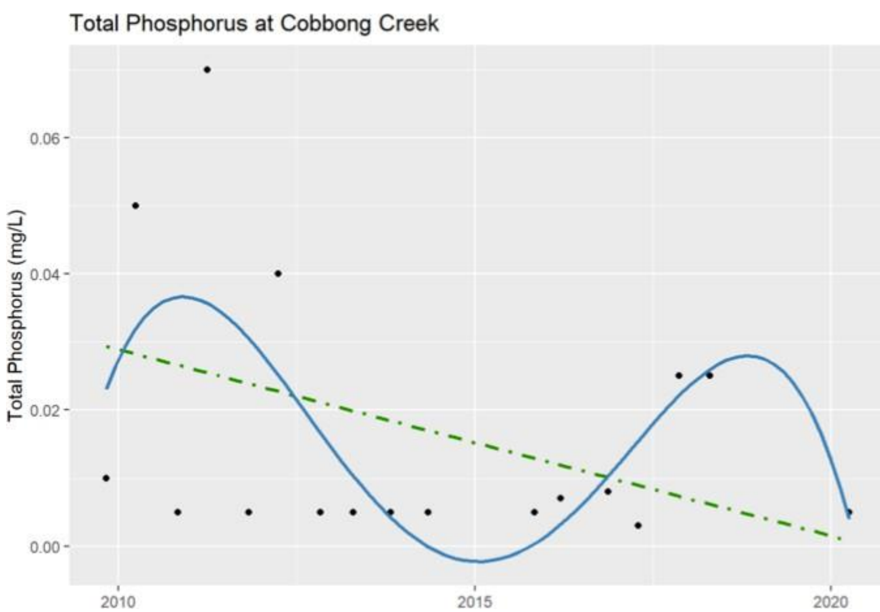


Figure 12: The total phosphorus values collected at Cobbong Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.14 and 0.38, respectively.

Stokes Creek – Upland River

At Stokes Creek there is a trend of increasing EC shown by the linear trendline in figure 13. EC has remained “Excellent” to “Good” since 2009 to early 2021, with all except early 2016 being “Excellent”. Turbidity has been increasing slightly between 2009 and 2021 with most measurements “Excellent”. Does not exceed any ANZECC trigger values for EC or maximum trigger values for turbidity. Whilst there has been a mild increase in the total nitrogen as from the line of best fit, Figure 15, the variability of these values makes it difficult to conclude if there is a definitive increase or decrease in the total nitrogen concentration. Comparatively, there has been a steady decrease in the total phosphorus, with values remaining relatively constant over the 12 year period, Figure 16. Both the total nitrogen and phosphorus do not exceed the ANZECC trigger values, however, the total nitrogen varies the water quality from ‘Fair’ to ‘Excellent’ and the total phosphorus varies between ‘Good’ to ‘Excellent’ in the same 12 year period, as taken from Tables 1 and 2.

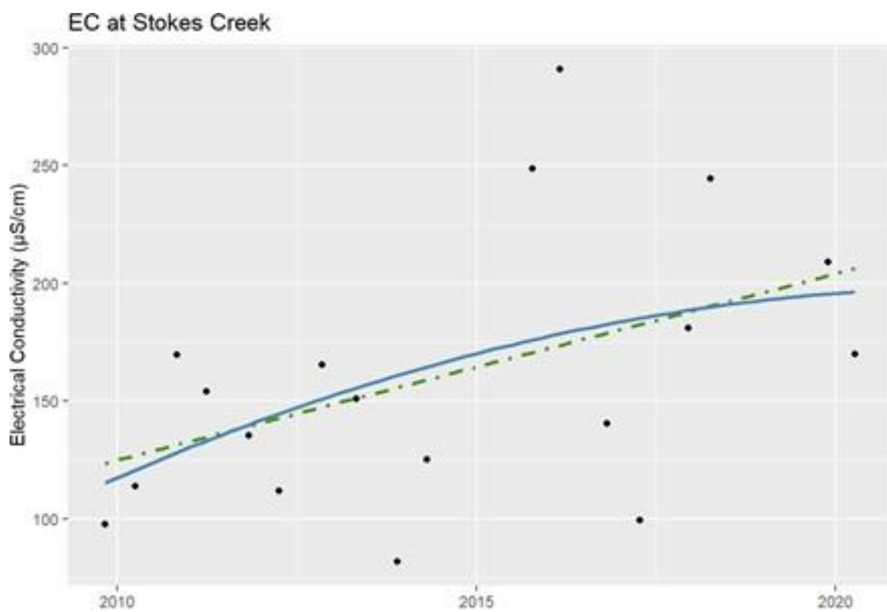


Figure 13: The electrical conductivity values collected at Stokes Creek from 2009 to 2021. The line of best fit and 2nd degree polynomials had R-squared values of 0.227 and 0.234, respectively.

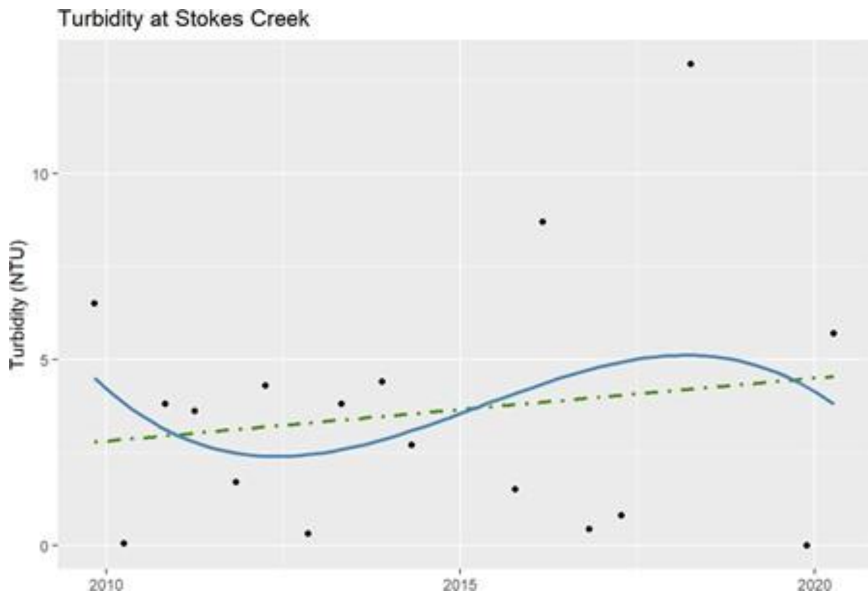


Figure 14: The turbidity values collected at Stokes Creek from 2009 to 2021. The line of best fit and 3rd degree polynomials had R-squared values of 0.028 and 0.083, respectively.

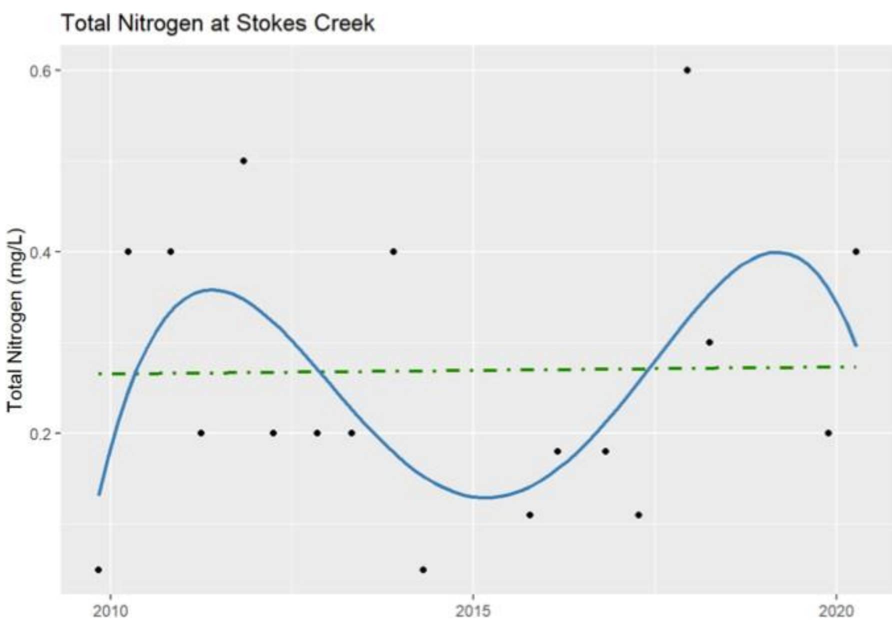


Figure 15: The total nitrogen values collected at Stokes Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.00025 and 0.27, respectively.

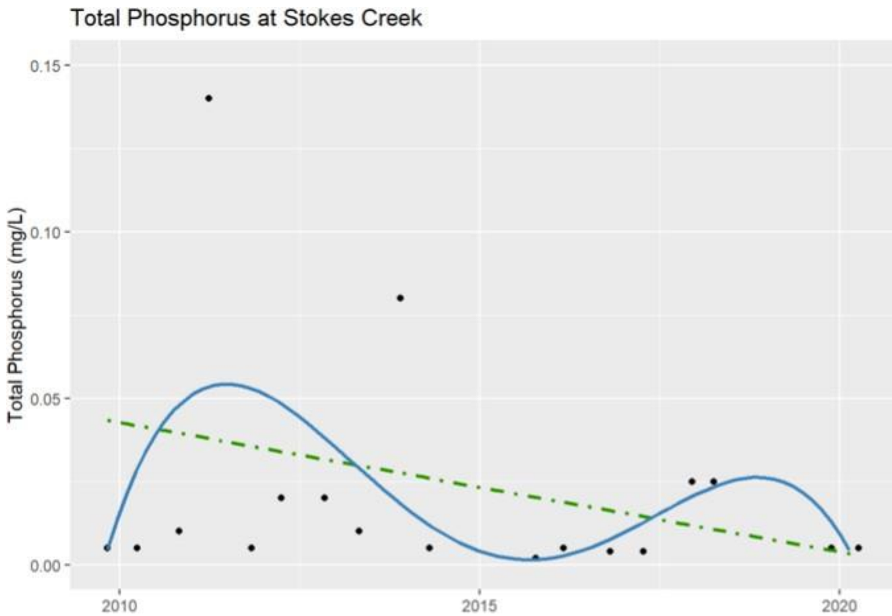


Figure 16: The total phosphorus values collected at Stokes Creek from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.089 and 0.22, respectively.

Woronora River – Lowland River

There is little to no trend in EC at Woronora river with values remaining constant over the study period. "Excellent" with one instance of "Good" in August 2012. Turbidity has shown a decline indicated by the linear trendline in figure 18 with four instances above 2 NTU, however all measurements are still "Excellent". Woronora River does not exceed any ANZECC trigger values for EC or maximum trigger values for turbidity. Based on the line of best fit in Figure 19, the total nitrogen has slightly increased. However, due to the variability of the data, with a peak occurring at 0.6mg/L, and a minimum of 0.05mg/L, gaining an accurate trend is difficult. Whilst most of the data is below the ANZECC trigger values, based on the classifications within Table 2 the river health of total nitrogen is considered 'Excellent'. The total phosphorus of the Woronora River remains relatively constant, with a slight decrease occurring from 2009 to 2011 and a slight increase occurring from 2018 onwards, Figure 20. The trigger values for the total phosphorus are typically not exceeded, however the current upwards trend will force this value to become exceeded shortly. However, from Table 2, the river health is still classed as 'Excellent'.

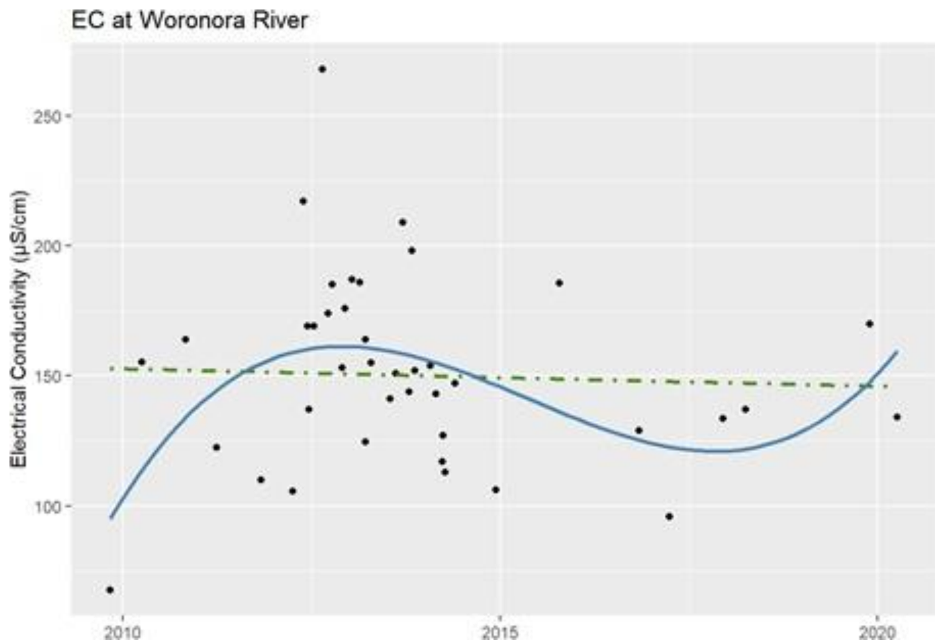


Figure 17: The electrical conductivity values collected at Woronora River from 2009 to 2021. The line of best fit and 3rd degree polynomials had R-squared values of 0.002 and 0.185, respectively.

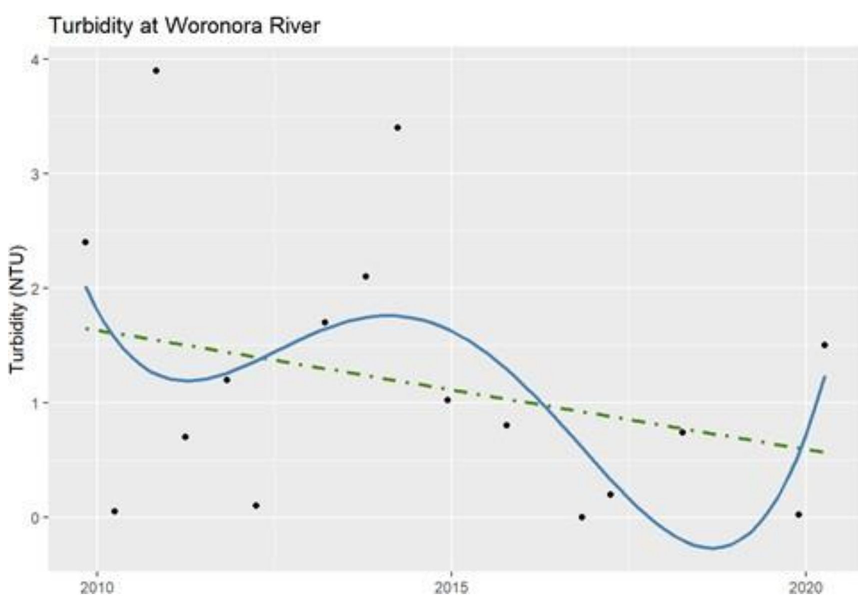


Figure 18: The turbidity values collected at Woronora River from 2009 to 2021. The line of best fit and 4th degree polynomials had R-squared values of 0.091 and 0.242, respectively.

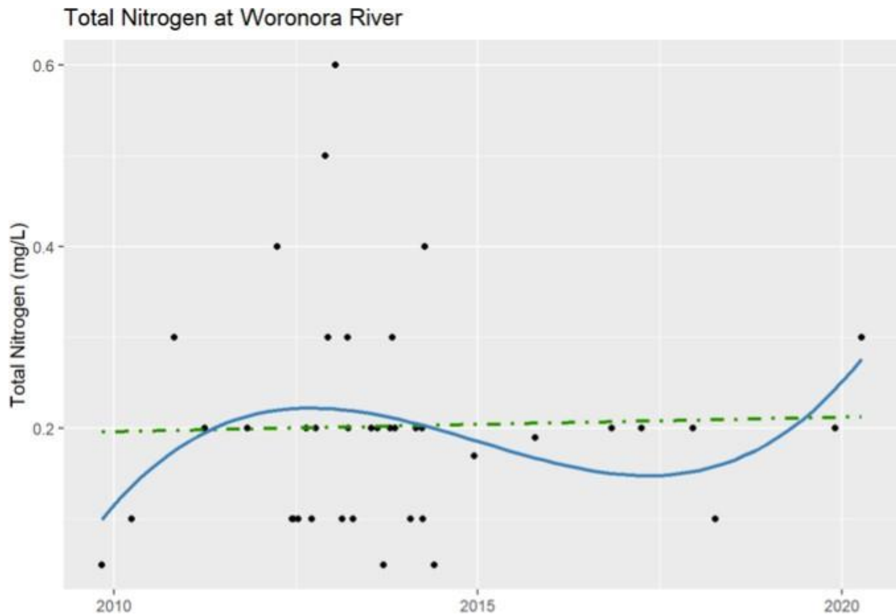


Figure 19: The total nitrogen values collected at Woronora River from 2009 to 2021. The line of best fit and 3rd degree polynomials had R-squared values of 0.00099 and 0.074, respectively. The outlier of 3.0 (mg/L) from 24/05/2012 was dropped.

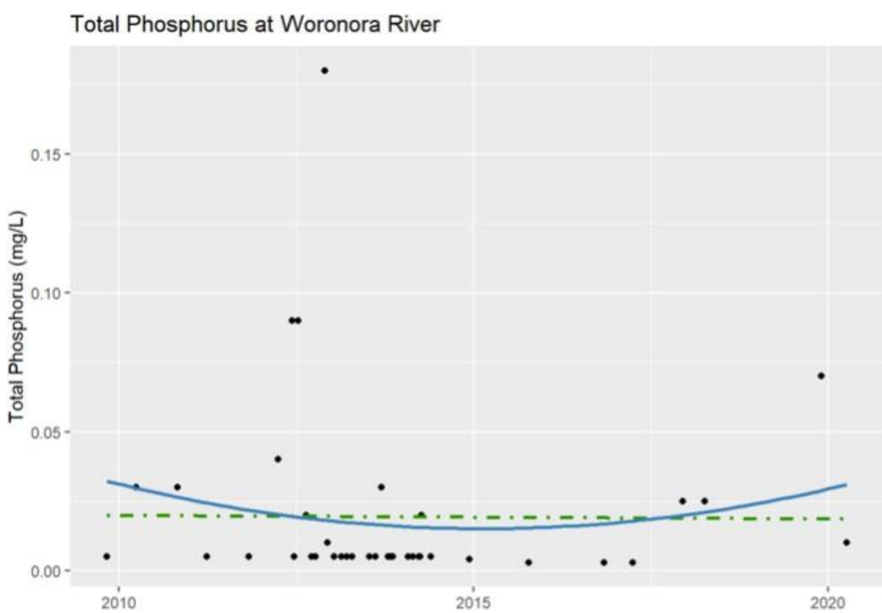


Figure 20: The total phosphorus values collected at Woronora River from 2009 to 2021. The line of best fit and 3rd degree polynomials had R-squared values of 7.47 and 0.018, respectively. The outlier dropped from this data set was 2.80 (mg/L) from 24/05/2012.

5. Discussion

Temporal Trends

Turbidity

Turbidity is a measure of the clarity of the water. It is affected by the amount of suspended solids in the water and the flow rate of the water itself. Total suspended solids in the water can be increased by erosion, pollution, algae growth and plankton. Flow rate is increased by heavy rainfall as well as the shape of the stream and gradient of the slope the stream flows along. It is unlikely that erosion would have affected the results as the process takes place over a much longer period of time than our graphs show. A higher flow rate allows larger solids to become suspended within the stream, The turbidity outliers in our graphs are most likely due to periods of increased rainfall in the area of the sites (Bureau of Meteorology 2021; Russell 2016).

Electrical Conductivity

Electrical conductivity is affected by temperature and rainfall. An increase in temperature in turn increases the conductivity of the water. Since rain is pure water, rainfall dilutes the stream thus lowering the electrical conductivity, however a lack of rainfall leads to evaporation, increasing the concentration of charged particles in the water and thus increasing the conductivity. It is likely that the conductivity results are mainly influenced by the temperature and amount of rainfall at the sites (Russell 2016).

Total Nitrogen

Total nitrogen can be affected by agricultural processes, industrial wastewater, animal waste and car exhaust (Russell 2016). In addition to animal waste, the sites may also be affected by car exhaust; most of them are all either within national parks or near campsites. Tourists travelling to these locations by car may possibly be contributing to the total nitrogen levels. Some of the sites also have farms in the area which might cause a change, however there is no direct passage of water between the farms and these sites so this is unlikely.

Total Phosphorus

Similar to nitrogen, the total phosphorus can be affected by agricultural runoff as well as animal waste, it also exists naturally in the soil in small amounts so erosion can also potentially increase the total amount of phosphorus (Russell 2016). Together, phosphorus and nitrogen act as nutrients for algae and aquatic plants which in turn could potentially affect turbidity.

The results of the analysis show only very slight trends in the quality of the water. Since these trends are so slight it is likely that the contributing factors are mostly natural and remain relatively consistent over time. Woronora river is the only one of these sites that is in close proximity to an urban environment and so human influence could possibly be greater at this site than the others.

The only site with unusual results was Stokes Creek which while still showed slight trends in the variables seemed to have almost sporadic outliers. According to the Bureau of Meteorology average rainfall per year in the area decreased from 2010 to 2020, this coupled with rising average temperatures due to global warming explains the increase in Electrical conductivity. The rise in turbidity is harder to explain. Since the rainfall had decreased, turbidity would be expected to decrease as well, however this is not the case. Since rainfall does not explain the turbidity there must have been an increase in suspended solids in the stream. There is a coal mine in the town of Appin relatively nearby to the stream however the report "Appin North - South 32 pollution reduction program 20 - Aquatic health monitoring report 2015" states that the mines impact on the surrounding bodies of water is minimal.

Literature Review

A long-term water analysis study was conducted by Biswas and Mosley (2019) on the Murray River from 1978 to 2015 with data being collected at least monthly. This dataset is likely as large or if not far larger than that of the Georges River water data. The approach that was taken in this study for the analysis of the data set was box and whisker plots for visualization of the data followed by an analysis of trends using the non-parametric Mann-Kendall test. This is used to identify whether the data is trending upwards or downwards. This is useful in identifying general trends that may indicate deteriorating or improving water quality within the Georges River. Wang et al. (2020) identify some shortcomings of the Mann-Kendall test however they identify that an increased significance level and increasing the number of data points are able to improve the power of the Mann-Kendall test.

Kruskal-Wallis tests followed by Dunn's post hoc pairwise comparison was used to compare between sites at the Bargo and Nepean Rivers (Fleming et al. 2021) and were useful in identifying significant differences between water quality measurements. Euclidean distance matrices were used by Hanford et al. (2020) to analyse water quality. The way in which this was done is not provided and may require further investigation to its application for future water quality studies

Macroinvertebrates are good indicators of overall stream health and pollution. Alongside existing datasets of primarily insect larvae, sentinel organisms such as fresh and estuarine bivalve molluscs could be analysed to allow for toxins such as metals and organic compounds and be included in the dataset. This may help provide estuary pollution data and identify sources or instances of pollution (Gagné and Burgeot 2013).

Pozza et al. (2019) used bivariate linear mixed models in the monitoring of heavy metals at a site with one historical and one current measurement. This approach could be utilised for water quality data where there are large gaps between measurements. It is able to determine the significance of change between two separate measurements. It can be used to predict emerging trends and can incorporate predictor variables such as land use datasets. The Wald test was also conducted which determines if explanatory variables within a model are significant. Once a trend has been identified, determining the cause of it could be made easier through the incorporation of Wald tests in the analysis. The Lagrange multiplier test and likelihood ratio test are two similar tests which may be more applicable than the Wald test depending on data properties and constraints.

R programming language (R Team 2021) was used by Pozza et al. (2019) to conduct the bivariate linear mixed model analysis. This programming language and associated libraries of functions were used to conduct all analyses in this study. It is useful in the handling and automation of the analysis of large datasets. Additionally, Tableau (Beard & Aghassibake 2021) is a data visualisation tool which also supports automation and can be linked directly to datasets in excel. In doing so, graphs can be generated in real time as data is entered making the visualisation of all future reports already available when it is required.

Whilst not applicable to the forested sites that were included in this study, the literature review has identified a water quality and water balance modelling system called HowLeaky (Queensland Government 2019). This modelling system links management practices, soil types, climate and land use types to water quality and hydrology. It is able to more easily connect agriculture and land management to water quality and catchment health. There are several sub-models that would be of particular interest based on the variables that are analysed in this study. Soil erosion can be calculated by HowLeaky using the daily amount of runoff and ground cover. Loss of phosphorous from paddocks can also be modelled with HowLeaky. It is able to estimate the amount of dissolved, bioavailable and total phosphorous lost with a similar model being developed for nitrogen. This can be helpful for stakeholders to improve the efficiency of their land management while simultaneously minimising harmful impacts on the waterways. Incorporating the data that landholders generate using HowLeaky or similar modelling programs into analysis of water quality in the catchment would be useful for identifying causes behind changes in water quality.

6. Alternative analyses and recommendations

Alternative Analyses - How it was conducted

To statistically assess whether a variable of interest has an upward or downward monotonic trend, the Mann-Kendall test was performed. This is useful when data may not be linear and would be particularly useful in this case as there is no clear linear trend. This is a non parametric test and does not involve any underlying assumptions about the data itself and can work for all distributions (your data may not comply with the assumptions of normality).

Due to the lack of data collection, many sites did not have a clear trend when linear regression was performed so the Mann-Kendall test is particularly useful in this scenario.

The null hypothesis is that there exists no monotonic trend, the alternative hypothesis is that it exists, this can be positive, negative or non-null.

Where the data did follow a normal distribution and other formal tests could be conducted, we performed the Pearson and Spearman correlation tests to analyse and measure the statistical relationship between different variables. To enable this, a test for normality was needed. This can be done with a normal-QQ plot and by plotting the residuals vs fitted values for a quick and visual identification of a normal distribution. While this was done for better understanding of the data, it was not included in the R markdown file used to interpret the results and a formal test, the Shapiro-Wilk test was used for detecting departures from normality.

Although correlation does not apply causation, we wished to analyse any interesting correlations between the variables contributing to the river health and investigate whether that was consistent over all sites to make bolstered claims about how the variables interact with one another. As mentioned, Pearson and Spearman correlation tests were chosen for this analysis. Pearson correlation coefficient tells us whether there is a linear relationship between the variables whereas Spearman correlation coefficient tells us whether there is a monotonic relationship (based on ranks of data as opposed to the raw data used by Pearson correlation).

The statistical analyses and the results along with the R code can be found here:
AlternativetestsRmarkdown.pdf

Results

Electrical conductivity at a 0.05 significance level did not show consistent patterns with Mann-Kendall test for the six sites analysed. Five Sites showed that there was no trend, however, one site heavily rejected the null hypothesis and indicated that a trend did exist. Similar patterns were observed for the other variables and no consistent patterns detected to make substantial claims about the temporal trends using the Mann-Kendall test.

Overall, no signs of correlation between different variables was detected. No anomalies existed across different sites and the results were quite consistent. At a 0.05 significance level, there was no evidence to reject the null hypothesis from the correlation tests conducted (i.e that a correlation exists). This tells us that the different variables analysed are independent and do not influence each other.

Recommendations

It was noted that data collection was inconsistent and the lack of data made interpretations difficult and less robust. Perhaps a larger amount of data with consistent collection dates would make the alternative tests more useful and accurate. We would still recommend conducting these tests in the future, but would heavily emphasize on frequent collection of data. A good idea would be to contact schools near each site and have students involved in the data collection process. This would help educate them and get the local community involved.

Using the R programming language in conjunction with RStudio for statistical analysis may be something to consider moving forward. Tableau is another potential software which may be implemented which will streamline the reporting process through the real time generation of graphs from datasheets.

Look into the existing use of 'HowLeaky' by land holders within the catchment area as a source of additional data for water quality analysis and potential future collaboration with land holders through the 'HowLeaky' platform.

Recommendations of statistical tests to consider in future reports in addition to those used in 2016:

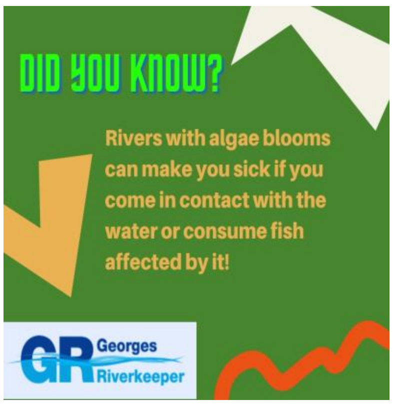
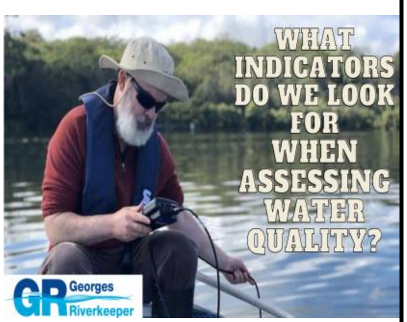
- Mann-Kendall Test
- Pearson correlation Test
- Spearman correlation Test
- Other tests and plots to better understand the data itself (Shapiro-Wilk Test, QQ-plots, residual vs fitted plots etc)

Social Media

In order to boost the social media presence that Georges Riverkeeper has along with aiming to get a wider audience, there are a number of strategies that can be implemented. One of these would be to use hashtags within the "captions" of posts, along with using widely followed and popular relevant hashtags. Some of these hashtags could include the words: Australia, New South Wales, NSW parks, NSW coast, environment, and South Sydney. We also recommend that on both Instagram and Facebook the use of the "story" feature is used more frequently, this could include showing pictures of the Georges River, the nature surrounding it, question and answer sessions, or environmental tips. Whilst the Georges Riverkeeper Instagram and Facebook frequently post, some post suggestions have been made within Table 3. These posts could be used for either Facebook or Instagram.

A consideration would be to create a TikTok account for Georges Riverkeeper. This would allow for Georges Riverkeeper to reach a wider audience and a different platform of people. Whilst this is an unlikely platform to use, it has a great opportunity to allow for the education of young people, and can be used to inspire young people about environmental awareness. Through doing videos such as “Day in the life of a Scientist”, environmental tips, and environmental Question and Answers, would enable Georges Riverkeeper to educate and promote environmental health to a diverse and larger audience.

Table 3: Three suggestions of posts to be made for social media platforms Facebook and Instagram, with the inclusion of captions and hashtags to be included in the posts.

Image	Caption	Hashtags
	Did you know that high levels of both nitrogen and phosphorus can cause algae blooms within rivers? Algae harms the water quality, and decreases the food and oxygen available to fish and other aquatic life. If algae blooms are severe they can even cause sickness in people if they come in contact with polluted water via drinking contaminated water, eating fish from these waterways or swimming. Here at Georges Riverkeeper we actively monitor the nitrogen and phosphorus levels in our waterways to ensure that none of this happens!!	#NSW #NSWcoast #NSWrivers #waterhealth #environment #SouthSydney #GeorgesRiverkeeper
	There are many different aspects that affect the quality of our waterways. Water quality is typically affected by: sediment in the water, bacteria and other microorganisms, algae and nutrients such as nitrogen and phosphorus. How do you think these pollutants get into our waterways?	#environment #water #riverhealth #NSWwater #nature #keepaustraliaclean #pollution #GeorgesRiverkeeper
	We love spending our weekends relaxing along Georges River, fishing, swimming or doing some of the walks through the national parks. Find out ways in which you can help us keep our Georges River beautiful- see the link in our bio!! (or link to the Georges Riverkeeper website here)	#NSW #NSWcoast #NSWparks #rivers #nature #naturalbeauty #SouthSydney #GeorgesRiverkeeper

Social Media Advertising Costs

If advertising is within budget constraints, advertising posts on Facebook, Instagram and Facebook Messenger costs:

- $22/day (373-1.1K per day reach)
- $100/day (1.7K-4.8K reach per day)

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