Historical Data Deep Dive

Long-Term Trends in Freshwater Catchment Health across Hornsby Shire

A comparative assessment of the Berowra Creek and Cowan Creek catchments



HORNSBY SHIRE COUNCIL



source: Hornsby Shire Council

ENVS8544 | Sustainability Consultancy Work Practice

This report is the work of post graduate students from Macquarie University who have undertaken a unit ENVS8544 Sustainability Consultancy Work Practice as part of a master's degree.

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Contents

Executive Summary **4**
1. Introduction **5**
1.1 Background and Importance of Freshwater Catchment Health 5
1.2 Hornsby Shire Council's Monitoring Program 5
1.3 Project Context and Client Needs 5
1.4 Research Problem and Knowledge Gaps 6
1.5 Project Aim and Specific Objectives 6
2. Study Area and Catchment Characteristics **7**
2.1 Hornsby Shire overview 7
2.2 Berowra Creek catchment 7
2.3 Cowan Creek catchment 8
2.4 Selection of monitoring Sites 012 and 013 9
2.5 Land-use composition and catchment characteristics 9
3. Data and Methods **10**
3.1 Data sources and monitoring period 10
3.2 GIS mapping and land-use analysis 11
3.3 Water-quality parameters and units 11
3.4 Data preparation, annual averages and trend graphs 11
3.5 Benchmarks and biological indicators 12
3.6 Limitations and interpretation approach 12
4. Results **13**
4.1 Catchment characteristics and land-use composition 13
4.2 Historical water-quality trends at Site 012: Hornsby Creek 13
4.3 Historical water-quality trends at Site 013: Sams Creek 14
4.4 Comparative summary of long-term water-quality results 15
4.5 Biological indicators 16
4.6 Integrated comparison 17
5. Discussion **18**
5.1 Interpretation of observed water-quality patterns 18
5.2 Electrical conductivity and catchment conditions 18
5.3 Turbidity and sediment-related pressures 19
5.4 Dissolved oxygen and aquatic ecosystem health 20
5.5 pH and freshwater chemistry 21
5.6 Nitrogen and phosphorus enrichment 21
5.7 Potential influence of land use and urbanisation 22
5.8 Biological indicators and ecological implications 23
5.9 Comparison with Published Scientific Literature 24
6. Recommendations and Management Implications **24**
6.1 Nutrient-source investigations 25
6.2 Stormwater and sediment monitoring 25
6.3 Improvements to long-term monitoring 26
6.4 Integration of biological monitoring 26
6.5 Targeted GIS and upstream catchment assessment 27
6.6 Prioritised recommendations for Council 27
7. Limitations **28**
7.1 Unequal sampling frequency 28

7.2 Incomplete 2026 observations 29
7.3 Missing values and extreme observations 29
7.4 Limitations of annual averages 30
7.5 One monitoring site per catchment 30
7.6 Limitations of biological and land-use datasets 30
7.7 Absence of statistical significance testing 30
8. Conclusion 31
References 33
Appendix A. Active freshwater sites with at least 300 records in the two catchments 36

Executive Summary

Hornsby Shire Council has conducted freshwater monitoring since 1994, establishing a valuable historical dataset for assessing environmental conditions and identifying long-term water-quality patterns. This report, *Historical Data Deep Dive: Long-Term Trends in Freshwater Catchment Health across Hornsby Shire*, examines changes in freshwater quality within the Berowra Creek and Cowan Creek catchments to support evidence-based environmental monitoring and catchment management.

The assessment focused on two long-term freshwater monitoring locations: Site 013 (Sams Creek, Mt Ku-ring-gai) in the Berowra Creek catchment and Site 012 (Hornsby Creek, Hornsby) in the Cowan Creek catchment. Water-quality records from 1994 to 2026 were analysed descriptively using 12 annual-average graphs covering six parameters: electrical conductivity (EC), turbidity, dissolved oxygen (DO), pH, total nitrogen (TN) and total phosphorus (TP). The assessment also incorporated GIS-derived land-use information, available biological monitoring records and comparisons with Hornsby Shire Council's Regional Environmental Health Values (REHVs).

The results indicated that recent average concentrations of several water-quality parameters were lower than those recorded during the earlier monitoring period. Mean turbidity decreased from 35.17 to 10.59 NTU at Site 013 and from 20.57 to 9.41 NTU at Site 012. Electrical conductivity and nutrient concentrations also showed lower recent averages at both locations, while pH remained relatively stable. Dissolved oxygen concentrations differed between sites, with generally higher values recorded at Site 012.

Despite these encouraging patterns, nutrient enrichment and sediment-related pressures remained important concerns. Total nitrogen exceeded the regional screening benchmark in 89.3% of valid observations at Site 013 and 100% at Site 012, while total phosphorus exceeded its benchmark in more than 96% of observations at both sites. Turbidity exceeded the applicable benchmark in approximately 42% of observations at each location. These findings indicate that lower recent average concentrations did not necessarily correspond to the achievement of regional freshwater health objectives.

The GIS assessment showed that the two catchments differed substantially in area but had similar broad land-use characteristics, with approximately 69% bushland and 23% urban land in each. Nevertheless, differences in water-quality conditions between the selected monitoring sites suggested that catchment-wide land-use proportions alone were insufficient to explain local freshwater conditions. The available biological monitoring data provided additional ecological context, although their limited temporal coverage and unresolved data inconsistencies restricted reliable interpretation of long-term ecological change.

The study was limited by unequal sampling frequency, incomplete 2026 observations, missing values and the selection of only one monitoring site per catchment. Furthermore, no formal statistical significance tests were undertaken. Therefore, the findings describe observed historical patterns rather than statistically confirmed trends or causal relationships.

1. Introduction

1.1 Background and Importance of Freshwater Catchment Health

Freshwater ecosystems are essential for maintaining biodiversity, supporting aquatic habitats, regulating nutrient cycling and providing important environmental and social benefits. Rivers and streams are influenced by interactions between natural catchment characteristics and human activities, making them sensitive indicators of environmental change. Land-use modification, urbanisation, sediment transport and nutrient enrichment can alter freshwater quality and affect aquatic ecosystem functioning (Allan and Castillo, 2007; Paul and Meyer, 2001).

Urbanisation is a significant pressure on freshwater ecosystems because increased impervious surfaces, modified drainage networks and stormwater runoff can change natural streamflow patterns and introduce pollutants. These changes may influence water chemistry, sediment dynamics and aquatic biological communities, contributing to the degradation of urban streams (Walsh et al., 2005). Nutrient enrichment is another important concern, as excessive nitrogen and phosphorus can promote eutrophication and disrupt ecological processes (Dodds and Smith, 2016).

Long-term water-quality monitoring is therefore important for understanding environmental variability, identifying recurring pressures and supporting catchment-management decisions. Historical monitoring records provide opportunities to examine changes over time, although their interpretation requires consideration of rainfall, hydrology, sampling frequency and other environmental influences (Durance and Ormerod, 2009).

Within Hornsby Shire, freshwater waterways occur across urban, rural and bushland environments. Understanding how water quality has varied across these settings is important for protecting aquatic ecosystems and supporting sustainable catchment management.

1.2 Hornsby Shire Council's Monitoring Program

Hornsby Shire Council has conducted water-quality monitoring since 1994, collecting long-term physicochemical and biological data to assess freshwater conditions (Hornsby Shire Council, 2012). Key parameters include electrical conductivity (EC), turbidity, dissolved oxygen (DO), pH, total nitrogen (TN) and total phosphorus (TP).

The Council also monitors aquatic macroinvertebrates and diatoms using biological indicators such as SIGNAL2 and the Trophic Diatom Index (TDI) to assess ecological conditions (Chessman, 2003; Kelly and Whitton, 1995). Regional Environmental Health Values (REHVs) provide benchmarks for identifying potential water-quality concerns. Together, these datasets support the assessment of historical patterns and inform catchment management.

1.3 Project Context and Client Needs

This report was prepared by Macquarie University postgraduate students undertaking ENVS8544 Sustainability Consultancy Work Practice for Hornsby Shire Council. The project, *Historical Data Deep Dive: Long-Term Trends in Freshwater Catchment Health across Hornsby Shire*, examines historical water-quality conditions in the Berowra Creek and Cowan Creek catchments.

The assessment focuses on Site 013 (Sams Creek) and Site 012 (Hornsby Creek), using monitoring records from 1994 to 2026. Twelve annual-average graphs illustrate historical patterns across six

water-quality parameters, supported by regional benchmark comparisons and GIS-derived land-use information.

The project aims to provide Council with a clear interpretation of historical water-quality patterns, identify potential environmental concerns and recommend priorities for future monitoring and catchment management.

1.4 Research Problem and Knowledge Gaps

Although long-term monitoring datasets provide valuable environmental information, their interpretation can be challenging because freshwater conditions are influenced by multiple interacting processes. Rainfall variability, streamflow, land use, pollution inputs and ecological activity can affect water-quality measurements, making it difficult to distinguish natural variability from changes associated with human activities (Bunn and Arthington, 2002; Durance and Ormerod, 2009).

A central problem addressed by this study was the need to convert extensive historical monitoring records into a coherent description of freshwater water-quality patterns. Individual observations provide information about conditions at specific sampling times, but they do not readily communicate how conditions have varied over several decades.

Several knowledge gaps were identified within the available assessment framework.

First, the historical water-quality records required consistent graphical presentation to illustrate temporal patterns across the six selected parameters and two monitoring sites. Second, differences in monitoring frequency, missing observations and incomplete recent records created uncertainty when comparing annual averages.

Third, the relationship between catchment land use and water quality remained insufficiently understood. Although urbanisation can influence freshwater ecosystems through altered runoff and pollutant transport, catchment-wide land-use percentages may not adequately represent environmental pressures affecting individual monitoring locations (Paul and Meyer, 2001; Walsh et al., 2005).

Finally, the available biological monitoring records were collected less frequently than physicochemical measurements. Their uneven temporal coverage and limited site-specific interpretation restricted the ability to assess whether observed water-quality patterns corresponded with changes in aquatic biological communities.

These gaps highlighted the need for an integrated but appropriately cautious assessment combining historical water-quality graphs, regional benchmarks, land-use information and available ecological evidence.

1.5 Project Aim and Specific Objectives

Project aim

The aim of this study was to assess observed long-term freshwater water-quality patterns at two selected monitoring locations within Hornsby Shire between 1994 and 2026 and to interpret these patterns in relation to regional environmental benchmarks, catchment land use and relevant scientific literature.

Specific objectives

The study addressed the following objectives:

1. **Examine historical water-quality patterns:** Present annual-average observations of electrical conductivity, turbidity, dissolved oxygen, pH, total nitrogen and total phosphorus for Sites 012 and 013 from 1994 to 2026 using 12 historical trend graphs.
2. **Compare the selected monitoring locations:** Identify similarities and differences in observed water-quality patterns between Hornsby Creek and Sams Creek, including periods of elevated concentrations and variation over time.
3. **Assess regional water-quality conditions:** Compare relevant monitoring observations with Hornsby Shire Council's Regional Environmental Health Values to identify recurring benchmark exceedances and potential environmental concerns.
4. **Examine catchment land-use characteristics:** Use GIS-derived land-use information to describe the environmental setting of the Berowra Creek and Cowan Creek catchments and consider possible relationships with observed water-quality conditions.
5. **Consider biological evidence:** Review the availability and relevance of macroinvertebrate and diatom monitoring indicators, including SIGNAL2 and TDI, to support the interpretation of freshwater ecological condition where reliable data are available.
6. **Identify management implications:** Integrate the descriptive findings with published scientific literature to identify evidence-based priorities for future monitoring, targeted investigation and freshwater catchment management.

2. Study Area and Catchment Characteristics

2.1 Hornsby Shire overview

Hornsby Shire is situated in northern metropolitan Sydney, New South Wales, and includes a combination of developed suburbs, waterways, bushland and conservation areas. Its freshwater drainage networks connect urban and less-developed landscapes with larger receiving waters, making catchment condition relevant to both local stream health and downstream environments. The present assessment focuses on the Berowra Creek and Cowan Creek catchments, which provide contrasting catchment areas but broadly similar proportions of urban and bushland land cover (NSW Government, 2017; Hornsby Shire Council, 2012).

Land-use distribution provides useful context for interpreting water-quality monitoring, although catchment-wide categories cannot identify individual pollutant sources. Runoff pathways, local drainage connections, rainfall and stream conditions may all influence measurements at a particular site (Paul and Meyer, 2001; Walsh et al., 2005).

2.2 Berowra Creek catchment

The Berowra Creek catchment is the larger study area, covering approximately 305.45 km² according to the project GIS analysis. It extends from more developed areas around Hornsby towards the Hawkesbury River. Urban land is concentrated mainly in the southern and central parts, while extensive bushland and conservation areas occupy much of the catchment. The 2017 land-use classification indicates 69.54% bushland, 22.95% urban land, 2.86% rural land, 4.51% water-related areas and 0.15% other land (NSW Government, 2017).

The project site metadata identify 31 water-quality monitoring locations across the Berowra Creek catchment, encompassing freshwater and estuarine settings. Site 013 at Sams Creek, Mt Ku-ring-gai, was selected for the current freshwater comparison because of its long monitoring record and consistent site classification. Sams Creek drains towards Berowra Creek and ultimately the Hawkesbury River.

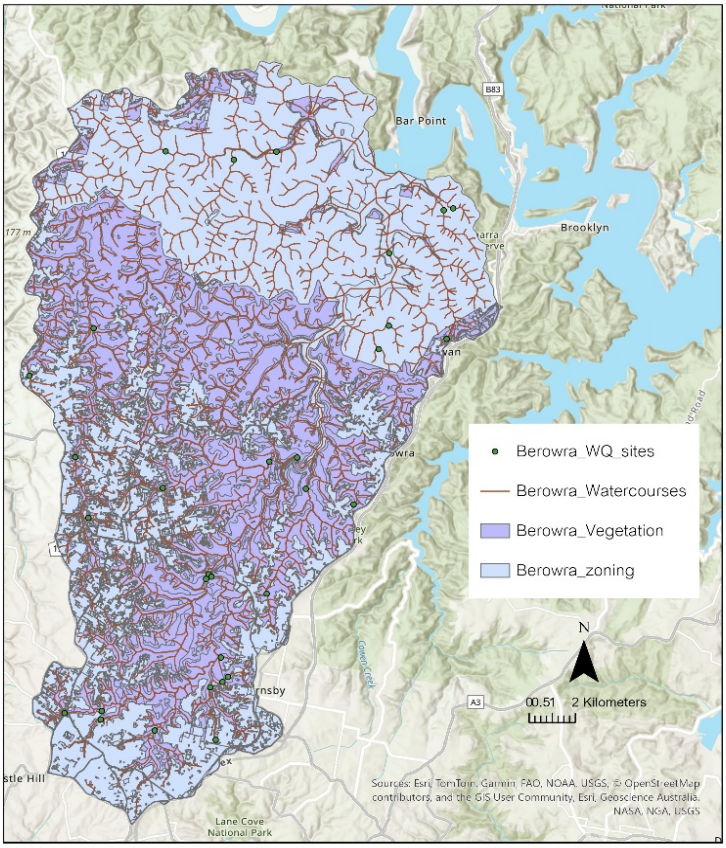


Figure 1. Berowra Creek catchment: land use, vegetation, waterways and water-quality monitoring site

Source: Authors' GIS analysis using NSW Government SEED spatial datasets (2017) and Hornsby Shire Council water-quality monitoring data.

2.3 Cowan Creek catchment

The Cowan Creek catchment covers approximately 37.67 km² in the project GIS analysis. It extends from developed areas near Hornsby towards the Hawkesbury River and is substantially smaller than Berowra Creek. Bushland and conservation areas dominate much of the catchment, while urban land is concentrated towards its southern end. The 2017 land-use classification indicates 69.26% bushland, 22.89% urban land, 0.02% rural land, 7.81% water-related areas and 0.02% other land (NSW Government, 2017).

The monitoring-site metadata identify seven water-quality locations in the Cowan Creek catchment. Site 012 at Hornsby Creek, Hornsby, was selected for its long-term freshwater record. Hornsby Creek drains through Cockle Creek into the Cowan Creek system. The catchment's relatively high share of water-related land reflects the mapped classification and should not be interpreted as a measure of freshwater habitat quality.

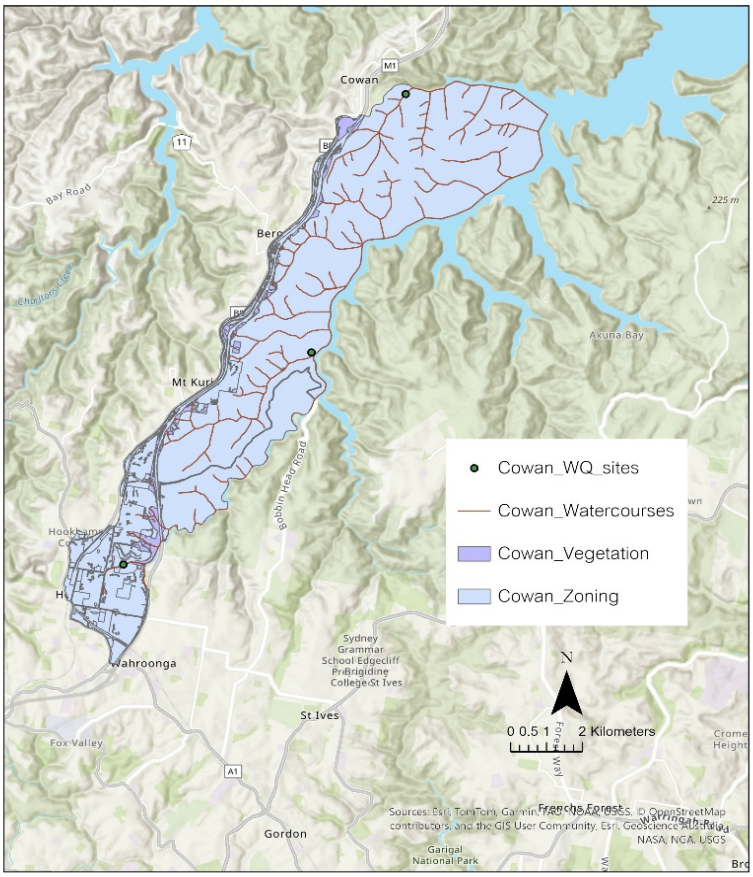


Figure 2. Cowan Creek catchment: land use, vegetation, waterways and water-quality monitoring sites

Source: Authors' GIS analysis using NSW Government SEED spatial datasets (2017) and Hornsby Shire Council water-quality monitoring data.

2.4 Selection of monitoring Sites 012 and 013

One freshwater monitoring site was selected in each catchment: Site 013 (Sams Creek, Mt Ku-ring-gai) in Berowra Creek and Site 012 (Hornsby Creek, Hornsby) in Cowan Creek. Both were classified as active freshwater sites with an industrial monitoring purpose in the project metadata. Site 013 has records beginning in March 1994 and Site 012 in October 1994. Their long records support a consistent descriptive presentation of annual average electrical conductivity, turbidity, dissolved oxygen, pH, total nitrogen and total phosphorus through the available 2026 observations.

The sites were chosen to compare observed water-quality patterns across two catchments with markedly different total areas but similar broad land-use proportions. This is a site-level comparison: one location cannot represent every tributary or land-use setting within an entire catchment. No formal statistical trend or significance testing was undertaken.

2.5 Land-use composition and catchment characteristics

Land-use composition was derived in the project GIS analysis by clipping the NSW Land Use 2017 v1.5 spatial dataset to the two catchment boundaries and grouping secondary land-use classes into urban, rural, bushland, water and other categories. Table 2.1 summarises the resulting areas and percentages. Bushland accounted for approximately 69% and urban land for approximately 23% in

both catchments. Berowra Creek had a larger rural component, whereas Cowan Creek had a higher proportion of mapped water-related land.

Table 1: Provisional land-use composition of the two study catchments Source: GIS analysis of the NSW Land Use 2017 v1.5 dataset downloaded from the SEED Data Portal.

Catchment	Area (km²)	Urban (%)	Rural (%)	Bushland / National Park (%)	Water (%)	Other (%)
Berowra Creek	305.5	23.0	2.9	69.5	4.5	0.2
Cowan Creek	37.7	22.9	0.0	69.3	7.8	0.0

The similar overall proportions do not imply identical environmental pressures at the selected sites. The location of urban development, the size of upstream contributing areas, connected stormwater infrastructure and local stream conditions may affect measured water quality. Furthermore, the 2017 land-use layer represents a single mapping period and cannot demonstrate land-use changes across the 1994–2026 water-quality record. Land use is therefore used here as contextual information rather than evidence of a causal relationship with the observed trends (Paul and Meyer, 2001; Walsh et al., 2005).

3. Data and Methods

3.1 Data sources and monitoring period

This study used four complementary data sources to assess long-term freshwater catchment health in Berowra Creek and Cowan Creek. Water-quality records were obtained from the Hornsby Shire Council master water-quality database for Site 013 (Sams Creek, Mt Ku-ring-gai) and Site 012 (Hornsby Creek, Hornsby). The available water-quality records covered approximately 1994 to 2026.

Spatial data, including catchment boundaries, water-quality monitoring sites and related GIS layers, were obtained from Hornsby Shire Council. Land-use composition was assessed using the NSW Land Use 2017 v1.5 dataset downloaded from the SEED Data Portal (NSW Government, 2017). Biological data were obtained from the Council's macroinvertebrate and diatom databases. These records covered selected sampling periods between 2002–2007, 2011 and 2023–2024, rather than continuous annual monitoring.

The analysis was restricted to freshwater environments. The Hawkesbury River catchment was excluded from the final comparison because most of its monitoring sites were classified as estuarine. The final analysis therefore focused on Berowra Creek and Cowan Creek, using one selected long-term freshwater monitoring site in each catchment.

Table 4. Summary of Council biological monitoring datasets

Dataset	Indicators	Records	Sites	Years sampled
Macroinvertebrates	SIGNAL2 score; EPT % abundance	257	38	2002–2007, 2011, 2023–2024
Diatoms	Trophic Diatom Index (TDI)	258	39	2002–2007, 2011, 2023–2024

Source: Hornsby Shire Council Macro_Invert_Master_DB_v1 and Diatom_Master_DB_v1.

3.2 GIS mapping and land-use analysis

GIS processing was conducted in ArcGIS Pro to delineate the study catchments, locate water-quality monitoring sites and quantify land-use composition. Catchment boundaries were derived from the Sub_catchments_HSC layer. Sub-catchment polygons were selected using the catchment-name attribute and exported to create the final Berowra Creek and Cowan Creek boundary layers.

Water-quality monitoring sites were reviewed spatially and through their attribute tables to confirm their site IDs, catchment allocation and monitoring status. Site 013 was selected for the Berowra Creek analysis and Site 012 was selected for the Cowan Creek analysis because both were active freshwater monitoring sites with long-term records.

For the land-use analysis, the NSW Land Use 2017 v1.5 dataset was downloaded from the SEED Data Portal and clipped separately to the Berowra Creek and Cowan Creek boundaries. The clipped layers were then grouped into broader land-use categories using the Secondary land-use field. The categories were Urban, Rural, Bushland/national park, Water and Other.

Because the original area field represented the area of the source polygons before clipping, new geometry-based area fields were calculated after clipping. The geodesic area of each clipped polygon was calculated in hectares using the Calculate Geometry Attributes tool. Summary Statistics were then used to calculate the total area of each land-use category. Areas were converted from hectares to square kilometres, and percentages were calculated using the total clipped catchment area as the denominator.

This workflow ensured that the reported land-use percentages represented the actual area of each land-use polygon within the study catchments rather than the area of the original un-clipped source polygons (NSW Government, 2017).

3.3 Water-quality parameters and units

The water-quality parameters considered in this study were electrical conductivity, turbidity, dissolved oxygen, pH, total nitrogen and total phosphorus. Electrical conductivity was recorded in mS/cm, turbidity in NTU, dissolved oxygen in mg/L, pH in pH units, and total nitrogen and total phosphorus in mg/L.

The number of valid observations varied between parameters and monitoring sites because not all parameters were measured during every sampling event and some records contained missing values. Only valid observations were retained for the relevant parameter analysis.

3.4 Data preparation, annual averages and trend graphs

The extracted water-quality datasets were checked and prepared before analysis. Records were filtered by site ID for Site 012 and Site 013, and the relevant water-quality fields were retained for analysis. Missing values were excluded only from the calculation of the corresponding parameter, while valid observations were retained.

The number of records varied between parameters because not all parameters were measured during every sampling event. Repeated sampling dates were retained where they represented separate database records. Annual averages were calculated by grouping valid observations by calendar year and calculating the arithmetic mean for each parameter and site. No values were imputed for missing observations.

The GIS site metadata reported 598 records for Site 013 and 612 records for Site 012, whereas the extracted master database contained 606 rows for Site 013 and 614 rows for Site 012. The GIS metadata totals were retained in Table 2 because they describe the monitoring-site metadata. The extracted row counts were used to describe the datasets used for the water-quality analysis. Differences between these totals may reflect differences in database counting methods, repeated sampling records and missing parameter values.

The 2026 annual averages were treated as incomplete because the available dataset covered only part of the year. Therefore, comparisons involving 2026 were interpreted cautiously.

3.5 Benchmarks and biological indicators

Historical trend graphs were prepared using the annual average values calculated for Site 012 and Site 013. Separate figures were produced for each monitoring site, with the six water-quality parameters presented in the same order: electrical conductivity, turbidity, dissolved oxygen, pH, total nitrogen and total phosphorus.

Each graph used year as the horizontal axis and the relevant parameter measurement as the vertical axis. Axis labels included the parameter name and its corresponding unit. The graphs were formatted consistently to support comparison between the two monitoring sites. Where a directly comparable benchmark was available, the relevant REHV was shown as a reference line.

The graphs were used to describe changes in annual average values over time. Any fitted lines were interpreted as descriptive visual summaries rather than formal statistical trend tests. The incomplete 2026 data were retained in the figures but interpreted cautiously.

3.6 Limitations and interpretation approach

Water-quality results were compared with Hornsby Shire Council's Regional Environmental Health Values (REHVs) for freshwater sites, as reported in the 2012 HSC Companion Technical Report – Report Card (Hornsby Shire Council, 2012). These REHVs were developed specifically for the Hornsby Shire region and were used as regional screening benchmarks.

The applicable benchmarks for electrical conductivity, turbidity, pH, total nitrogen and total phosphorus are summarised in Table 5. Where no directly comparable REHV was available, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) were considered as a supporting reference.

Table 5. Water-quality variables and applicable regional benchmarks

Parameter	Unit	Applicable benchmark
electrical conductivity	mS/cm	< 0.32 mS/cm
turbidity	NTU	< 8 NTU
dissolved oxygen	mg/L	No directly comparable REHV; the REHV is expressed as 75–118% saturation
pH	pH Unit	4.8–7.0
total Nitrogen	mg/L	< 0.32 mg/L
total Phosphorus	mg/L	< 0.01 mg/L

Dissolved oxygen was recorded in mg/L in the master database, whereas the Hornsby REHV is expressed as percentage saturation. Because the dataset did not provide the temperature and pressure information required to reliably convert mg/L to percentage saturation, dissolved oxygen was not directly assessed against the REHV benchmark. Instead, dissolved oxygen patterns were described comparatively between sites and over time, without assigning a compliance status.

4. Results

4.1 Catchment characteristics and land-use composition

The GIS analysis showed that Berowra Creek and Cowan Creek differed substantially in catchment size but had similar broad land-use composition (Table 1). Berowra Creek covered approximately 305.5 km², while Cowan Creek covered approximately 37.7 km².

Bushland and national park areas dominated both catchments, accounting for 69.5% of Berowra Creek and 69.3% of Cowan Creek. Urban land accounted for 23.0% of Berowra Creek and 22.9% of Cowan Creek. Berowra Creek had a larger rural component than Cowan Creek, whereas Cowan Creek had a higher proportion of water-related areas. The spatial distribution of these land-use categories and monitoring sites is presented in Figures 1 and 2 in Section 2.

Overall, the two catchments had similar proportions of urban and bushland areas despite their different sizes. The land-use comparison chart in this section further illustrates the similarity in broad land-use composition, while also showing the greater rural component in Berowra Creek and the higher water-related proportion in Cowan Creek (NSW Government, 2017).

4.2 Historical water-quality trends at Site 012: Hornsby Creek

Figure 3 presents the annual average water-quality trends at Site 012 from 1994 to 2026. Electrical conductivity, turbidity and total phosphorus generally declined over the monitoring period, although intermittent peaks occurred. Dissolved oxygen and pH were comparatively stable, while total nitrogen remained variable and included an isolated later-period peak. These patterns are interpreted descriptively because the number of valid observations varied among parameters and years.

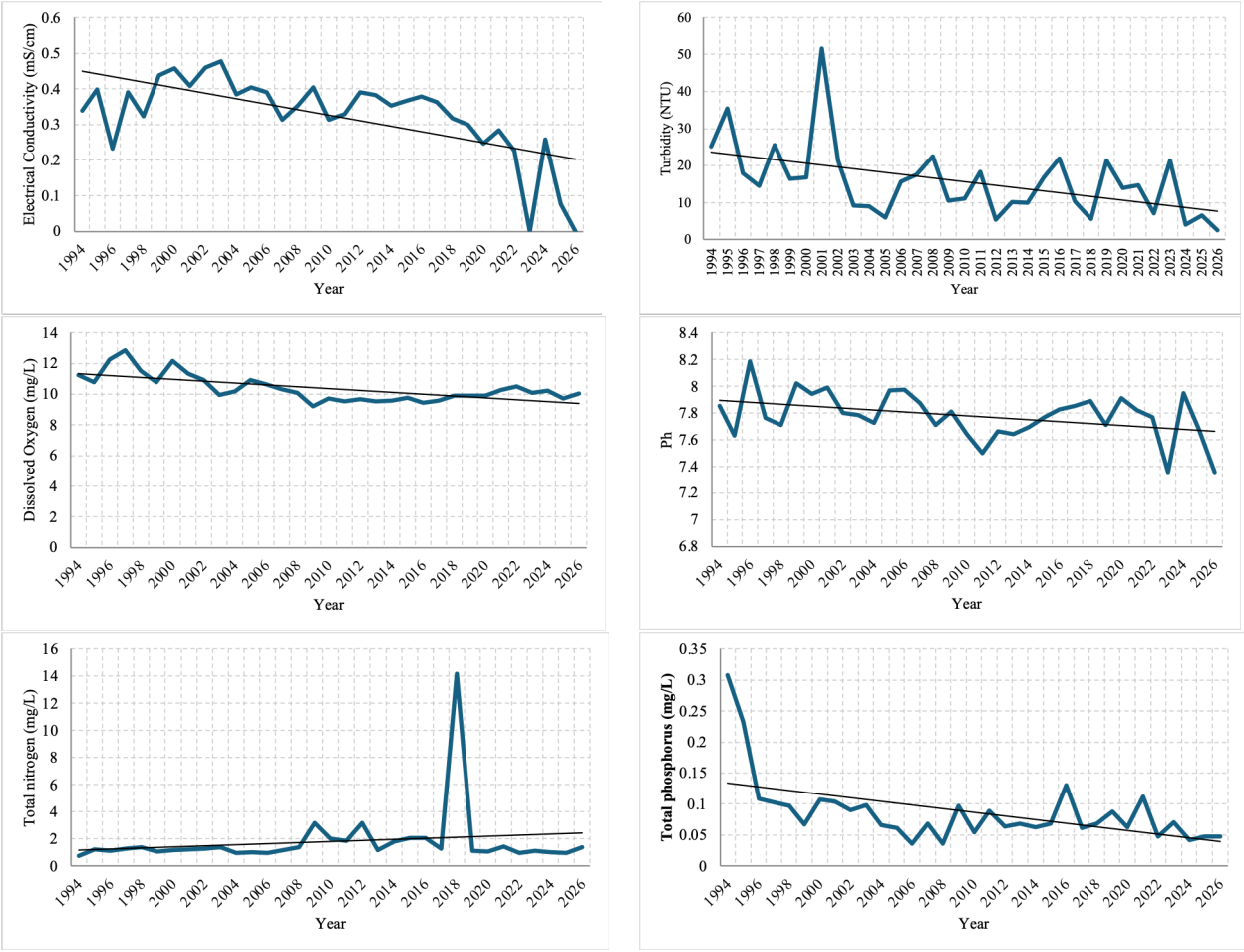
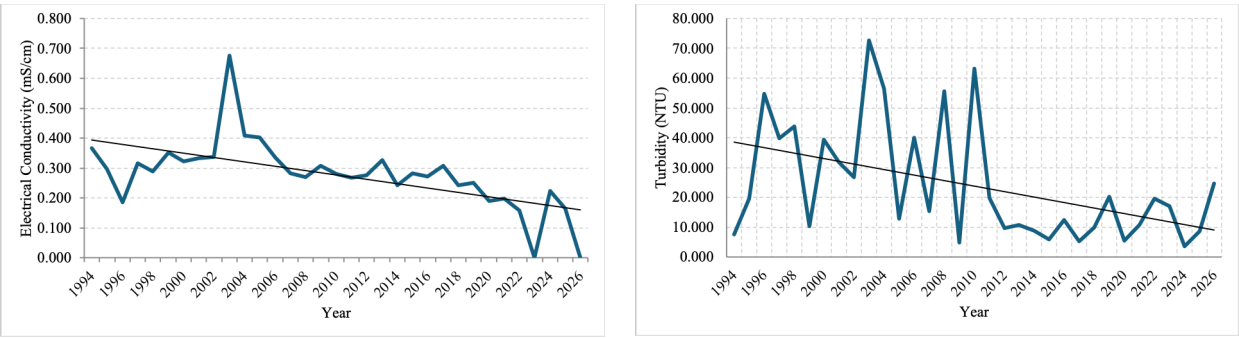


Figure 3. Annual average water-quality trends at Site 012 (Hornsby Creek), 1994–2026.

4.3 Historical water-quality trends at Site 013: Sams Creek

Figure 4 presents the annual average water-quality trends at Site 013 from 1994 to 2026. Electrical conductivity and total phosphorus showed overall declines, while turbidity and total nitrogen were characterised by intermittent peaks. Dissolved oxygen declined from higher early-period values before becoming more stable, and pH remained within a relatively narrow range. The trends should be interpreted cautiously because sampling effort and valid observations varied between years.



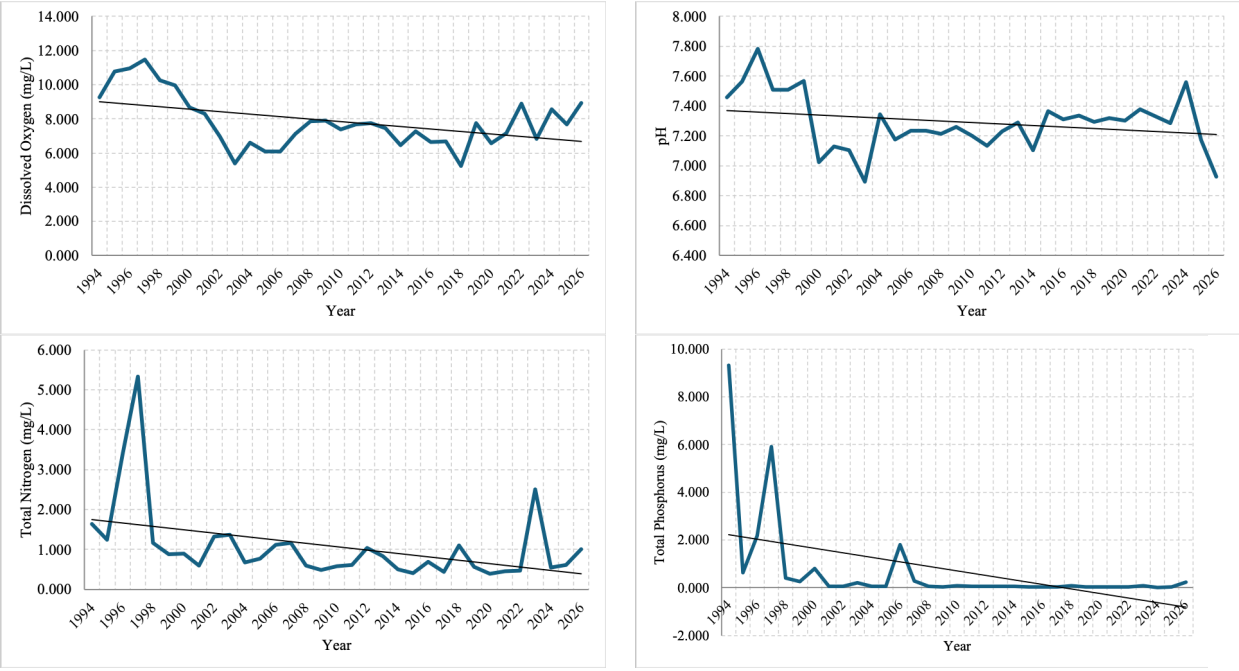


Figure 4. Annual average water-quality trends at Site 013 (Sams Creek), 1994–2026.

4.4 Comparative summary of long-term water-quality results

Table 6. Summary of long-term water-quality results

Parameter	Unit	Site 013		Site 012	
		1994–2007	2023–2026	1994–2007	2023–2026
Electrical Conductivity	mS/cm	0.348	0.138	0.389	0.153
Turbidity	NTU	35.17	10.59	20.57	9.41
Dissolved oxygen	mg/L	8.49	7.93	11.18	10.05
pH	Unitless	7.32	7.30	7.87	7.67
Total Nitrogen	mg/L	1.53	1.11	1.16	1.03
Total Phosphorus	mg/L	1.12	0.044	0.101	0.051

Table 6 summarises the mean water-quality conditions during the earlier and recent monitoring periods. Electrical conductivity and turbidity were lower during the recent period at both sites. Dissolved oxygen was consistently higher at Site 012 than at Site 013, while pH remained relatively stable at both sites.

Total nitrogen and total phosphorus generally decreased during the recent period. However, extreme observations, particularly for total nitrogen and total phosphorus at Site 013, influenced some mean

values. These results should therefore be interpreted together with the annual trend graphs rather than from mean values alone.

Screening against the Hornsby Shire Council Regional Environmental Health Values showed frequent exceedances for electrical conductivity, turbidity, total nitrogen and total phosphorus. Dissolved oxygen was not directly compared with the REHV because the database reports it in mg/L, whereas the benchmark is expressed as percentage saturation. Overall, the results indicate persistent water-quality pressures at both sites, with greater variability at Site 013.

4.5 Biological indicators

Biological indicators were used to provide supporting evidence of ecological condition. SIGNAL2 and EPT percentage abundance generally reflect the presence of pollution-sensitive macroinvertebrate communities, while higher TDI values generally indicate greater nutrient enrichment. The available datasets and their interpretation are summarised in Table 7.

Table 7. Summary of ecological indicators

Dataset	Indicator	Records/sites	Sampling periods	Interpretation
Macroinvertebrates	SIGNAL2	257 records from 38 sites	2002–2007, 2011, 2023–2024	Higher values generally indicate more pollution-sensitive communities
Macroinvertebrates	EPT % abundance	257 records from 38 sites	2002–2007, 2011, 2023–2024	Higher values generally indicate better ecological condition
Diatoms	Trophic Diatom Index	258 records from 39 sites	2002–2007, 2011, 2023–2024	Higher values generally indicate greater nutrient enrichment

Biological sampling was less frequent than water-quality monitoring, with records concentrated in 2002–2007, 2011 and 2023–2024. The 2011 TDI values were unusually low, at approximately 3 compared with values of approximately 50–70 in other periods. This difference was treated cautiously because it may reflect differences in sampling, data processing or data entry. Therefore, the biological indicators were used as supporting context rather than as evidence of continuous long-term trends.

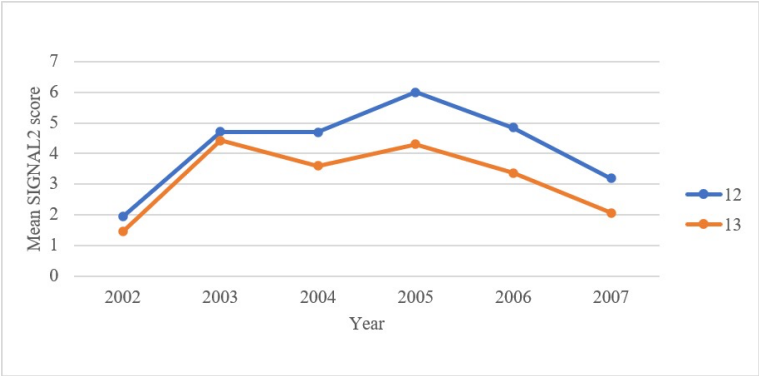


Figure 5. Available annual mean SIGNAL2 scores at Sites 012 and 013, 2002–2007.

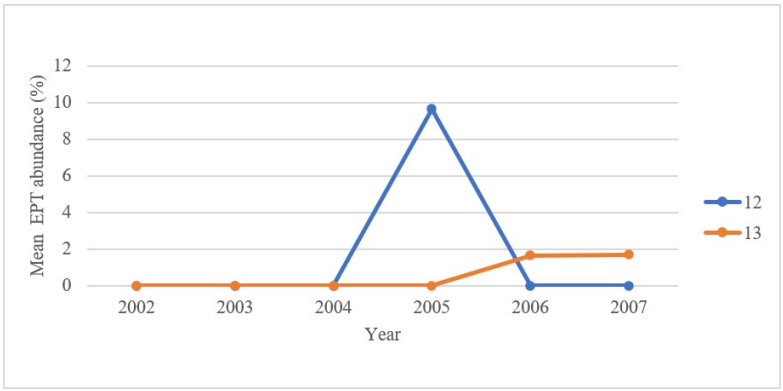


Figure 6. Available annual mean EPT abundance at Sites 012 and 013, 2002–2007.

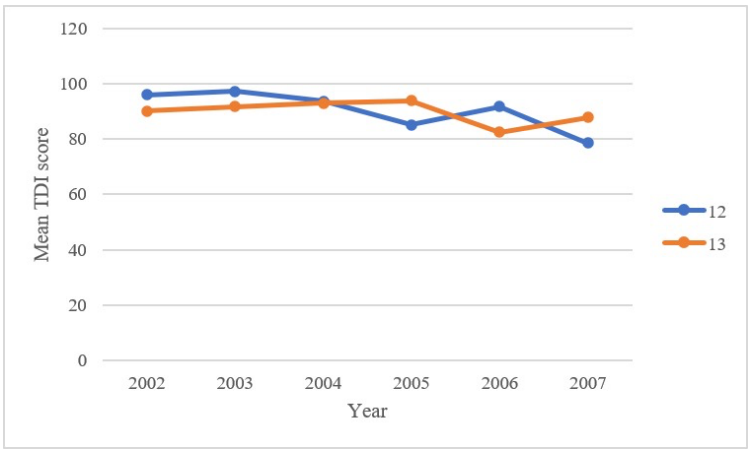


Figure 7. Available annual mean TDI scores at Sites 012 and 013, 2002–2007.

Figures 5–7 show the available annual mean values for Sites 012 and 013 during 2002–2007. Additional biological records were available for other sampling periods but were not sufficient for continuous annual comparison.

4.6 Integrated comparison

Table 8. Integrated comparison of the two catchments and monitoring sites

Aspect	Berowra Creek (Site 013)	Cowan Creek (Site 012)
Catchment setting	Larger and more mixed land-use pattern	Smaller, with extensive bushland and national park
Urban context	Urban development mainly in southern and central areas	Urban development concentrated in the southern part
Electrical conductivity	Lower overall mean than Site 012	Higher overall mean than Site 013
Turbidity	Higher mean, influenced by extreme observations	Similar median but lower mean
Dissolved oxygen	Lower than Site 012	Higher than Site 013
pH	Lower overall mean	Higher overall mean
Nutrients	Higher total phosphorus mean, influenced by extreme values	Higher total nitrogen mean
Interpretation	More variable water-quality profile	Different water-quality profile despite greater bushland context

Overall, the two catchments differed in land-use setting and several water-quality characteristics. However, the results indicate association rather than direct causation. Differences in sampling effort, extreme observations, incomplete recent records and the use of one selected monitoring site per catchment limit the strength of catchment-wide conclusions.

5. Discussion

5.1 Interpretation of observed water-quality patterns

The historical water-quality records from 1994 to 2026 provide an opportunity to examine how freshwater conditions have varied at two monitoring locations within Hornsby Shire: Site 012 (Cowan Creek catchment) and Site 013 (Berowra Creek catchment). The annual average graphs indicate substantial temporal variability in several physicochemical parameters, with differences in both the magnitude and direction of observed changes. These patterns demonstrate the value of long-term environmental monitoring for identifying persistent pressures, periods of elevated concentrations and possible changes in freshwater condition.

The comparison between earlier observations (1994–2007) and recent observations (2023–2026) suggests that average electrical conductivity and turbidity were lower in the recent period at both sites. Total nitrogen and total phosphorus also showed lower recent mean concentrations, although the magnitude of the differences varied between parameters and monitoring locations. In contrast, pH remained relatively stable, while dissolved oxygen showed comparatively modest changes. These differences indicate that freshwater quality cannot be adequately characterised through a single indicator, because individual parameters respond to different environmental processes.

Long-term freshwater monitoring must be interpreted within the context of natural environmental variability. Stream chemistry and physical conditions are influenced by rainfall, discharge, catchment

geology, temperature, biological activity and episodic disturbance. Durance and Ormerod (2009) demonstrated that changes in river water quality and discharge can complicate the interpretation of long-term ecological responses to environmental change. Similarly, Bunn and Arthington (2002) highlighted the importance of natural flow regimes in maintaining aquatic ecosystem structure and functioning. Consequently, observed differences between monitoring periods should not automatically be attributed to catchment management or land-use change.

An important finding is that lower recent average concentrations did not necessarily indicate that regional freshwater health objectives had been achieved. In the original analysis, total nitrogen, total phosphorus and turbidity frequently exceeded the applicable Hornsby Shire Council Regional Environmental Health Values (REHVs). These exceedances indicate continuing water-quality concerns, even where recent mean values were lower than historical averages. However, REHVs are screening benchmarks, and exceedances should prompt further investigation rather than automatically being interpreted as evidence of ecological damage (Hornsby Shire Council, 2012; Australian and New Zealand Governments, 2018).

Overall, the annual-average graphs provide descriptive evidence of historical water-quality variability and differences between the selected monitoring locations. Because the analysis does not include formal statistical trend testing, the findings are interpreted as observed temporal patterns rather than statistically demonstrated improvements or deterioration.

5.2 Electrical conductivity and catchment conditions

Electrical conductivity (EC) is an indicator of the concentration of dissolved ions in water and is commonly used to characterise freshwater salinity and changes in dissolved mineral content. Conductivity can be influenced by catchment geology, groundwater contributions, evaporation, rainfall dilution and anthropogenic inputs. Therefore, changes in EC may reflect several interacting processes rather than a single pollution source (Allan and Castillo, 2007).

The historical comparison showed lower recent EC means at both monitoring sites. At Site 013, mean conductivity decreased from approximately 0.348 mS/cm during 1994–2007 to 0.138 mS/cm during 2023–2026. At Site 012, the corresponding values were approximately 0.389 and 0.153 mS/cm. These differences suggest that the ionic composition of the monitored waters varied substantially between the two periods. Nevertheless, annual-average differences alone cannot determine whether the change was gradual, episodic or associated with particular hydrological conditions.

The similarity in the direction of the observed changes at both sites raises the possibility of shared environmental influences. Rainfall variability and changes in streamflow can affect conductivity through dilution and alterations in the relative contributions of surface water and groundwater. In urban catchments, stormwater and wastewater-related inputs may also influence dissolved-ion concentrations. Walsh et al. (2005) described how urbanisation modifies stream hydrology and water chemistry through interconnected changes in runoff pathways, drainage infrastructure and pollutant delivery.

Despite lower recent EC means, the original dataset analysis identified conductivity exceedances of the Council's 0.32 mS/cm screening value at both sites, with a higher reported frequency at Site 012. This suggests that elevated conductivity has occurred repeatedly within the historical monitoring record. However, the frequency of exceedances should be interpreted alongside seasonal conditions, sampling frequency and the environmental context of individual observations.

The findings indicate that conductivity remains a useful indicator for future monitoring, particularly when interpreted together with rainfall, streamflow and major-ion chemistry. Where elevated conductivity is repeatedly observed, targeted investigation of upstream drainage inputs and groundwater contributions would help determine whether natural processes or anthropogenic sources are responsible.

5.3 Turbidity and sediment-related pressures

Turbidity describes the extent to which suspended particles reduce water clarity and is an important indicator of sediment-related pressure in freshwater ecosystems. Elevated turbidity may result from soil erosion, streambank instability, stormwater runoff, sediment resuspension and disturbance associated with catchment activities. Suspended particles can reduce light penetration, influence primary production and affect aquatic habitats, particularly when high concentrations persist or coincide with sediment deposition (Bilotta and Brazier, 2008).

The historical analysis identified lower recent mean turbidity at both monitoring sites. At Site 013, the mean declined from 35.17 NTU in 1994–2007 to 10.59 NTU in 2023–2026. At Site 012, the corresponding values were 20.57 and 9.41 NTU. These differences are consistent with lower turbidity in the recent monitoring period, although they do not establish the causes of the change.

The annual-average graphs should be interpreted carefully because turbidity is often strongly influenced by individual rainfall events. A relatively small number of high-turbidity observations can substantially increase annual or period means. Consequently, differences in the timing of sampling relative to rainfall may influence comparisons between years. Bilotta and Brazier (2008) emphasised that the ecological effects of suspended sediment depend on its concentration, duration, particle characteristics and the sensitivity of affected organisms.

Despite the lower recent averages, approximately 42% of valid observations at both sites exceeded the Council's 8 NTU screening value in the original analysis. This indicates that elevated turbidity remained a recurring feature of the monitoring record. The persistence of exceedances is important because intermittent sediment pulses may affect freshwater habitats even where annual average turbidity appears comparatively low.

Urban development may contribute to sediment-related pressures by increasing impervious surfaces, accelerating runoff and modifying stream channels. Walsh et al. (2005) identified altered runoff regimes and associated physical habitat changes as central components of urban stream degradation. However, the current study does not include event-based rainfall, streamflow or sediment-source information sufficient to attribute the observed turbidity patterns to urban stormwater or particular land-use activities.

For Hornsby Shire Council, the findings support further investigation of sediment transport during rainfall events and the identification of potential erosion-prone locations upstream of the monitoring sites. Such investigations would provide a stronger basis for determining whether sediment-control measures or targeted riparian management are required.

5.4 Dissolved oxygen and aquatic ecosystem health

Dissolved oxygen (DO) is essential for aerobic aquatic organisms and is influenced by temperature, atmospheric exchange, stream turbulence, photosynthesis, respiration and the decomposition of organic matter. Low dissolved oxygen concentrations can place physiological stress on aquatic

organisms, while substantial daily fluctuations may indicate changes in ecosystem metabolism or other environmental conditions (Allan and Castillo, 2007).

The historical records showed differences in DO between the two monitoring sites. Site 012 generally recorded higher average concentrations than Site 013. During 1994–2007, mean DO was approximately 11.18 mg/L at Site 012 compared with 8.49 mg/L at Site 013. In the recent period, the corresponding values were 10.05 and 7.93 mg/L. Although recent mean concentrations were somewhat lower at both sites, the available analysis does not establish whether these differences reflect persistent environmental changes.

The difference between monitoring locations may be associated with variation in water temperature, stream morphology, turbulence, shading or biological activity. For example, turbulent reaches may promote atmospheric oxygen exchange, while warmer or slower-moving water may have lower oxygen concentrations. Organic matter decomposition can also increase oxygen demand. These mechanisms are well established in freshwater ecology, but the current dataset does not provide sufficient supporting measurements to identify their relative importance at either site.

An important methodological consideration is that the Council's dissolved oxygen REHV is expressed as percentage saturation, whereas the historical database records DO in mg/L. These measurements are related but are not directly interchangeable without additional information, particularly water temperature and atmospheric pressure. Therefore, the recorded concentrations should not be directly assessed against the percentage-saturation benchmark (Hornsby Shire Council, 2012).

The observed DO patterns should consequently be interpreted descriptively. Future monitoring would benefit from recording water temperature and percentage saturation alongside DO concentration, preferably with consistent sampling times. This would improve the assessment of oxygen conditions and strengthen comparisons between monitoring periods.

5.5 pH and freshwater chemistry

pH is a fundamental water-quality parameter that reflects the acidity or alkalinity of freshwater. It influences chemical speciation, nutrient availability, biological processes and the potential toxicity of certain substances. Natural pH conditions vary according to catchment geology, dissolved carbon dioxide, organic acids and biological activity. Consequently, pH values should be interpreted in relation to local freshwater characteristics rather than assuming that neutral conditions are universally optimal (Australian and New Zealand Governments, 2018).

The historical monitoring records indicated comparatively stable mean pH values at both sites. Site 013 recorded mean values of approximately 7.32 in the early period and 7.30 in the recent period, while Site 012 recorded values of approximately 7.87 and 7.67, respectively. These results suggest that Site 012 generally exhibited more alkaline conditions than Site 013 during the periods compared.

The differences between sites may reflect natural variation in catchment geology, groundwater chemistry and biological processes. Urban runoff can also affect stream chemistry through the transport of dissolved substances and interactions with constructed drainage infrastructure. However, the available data do not establish which factors account for the observed differences.

The Council's freshwater REHV range of pH 4.8–7.0 provides a regional screening reference. Mean pH values above the upper boundary should be examined in their local environmental context rather than automatically classified as harmful. In particular, ecological interpretation requires consideration

of natural background conditions, the duration and magnitude of departures from expected ranges, and the sensitivity of local aquatic communities (Australian and New Zealand Governments, 2018).

The relative stability of average pH compared with other parameters suggests that the two sites may have maintained broadly consistent acid-base characteristics over the monitoring periods examined. Nevertheless, this does not exclude shorter-term fluctuations or episodic chemical disturbances. Continued monitoring remains important, particularly where unusual pH observations coincide with changes in conductivity, nutrient concentrations or dissolved oxygen.

5.6 Nitrogen and phosphorus enrichment

Nitrogen and phosphorus are essential nutrients for aquatic primary production, but excessive concentrations can contribute to eutrophication and changes in freshwater ecosystem structure. Nutrient enrichment may stimulate algal and microbial growth, alter biological communities and contribute to oxygen-related stress under suitable environmental conditions. The ecological consequences depend on nutrient availability, light, temperature, hydrology and the characteristics of the receiving waterbody (Smith, Tilman and Nekola, 1999; Dodds and Smith, 2016).

The historical comparison indicated lower recent mean total nitrogen (TN) concentrations at both sites. Site 013 declined from approximately 1.53 mg/L during 1994–2007 to 1.11 mg/L during 2023–2026, while Site 012 declined from approximately 1.16 to 1.03 mg/L. Total phosphorus (TP) also showed lower recent mean values. At Site 013, the early mean was approximately 1.12 mg/L compared with 0.044 mg/L in the recent period, whereas Site 012 recorded approximately 0.101 and 0.051 mg/L, respectively.

The particularly large difference in mean TP at Site 013 requires careful interpretation because the original analysis identified extreme phosphorus observations that influenced historical averages. This illustrates the importance of examining the full distribution of nutrient concentrations rather than relying exclusively on mean values. Annual medians, sample counts and individual extreme observations can help determine whether an apparent change reflects a broad shift in typical conditions or the influence of a small number of unusually high measurements.

Despite the lower recent means, nutrient benchmark exceedances were widespread. The original analysis reported TN concentrations above the 0.32 mg/L REHV in 89.3% of valid observations at Site 013 and all valid observations at Site 012. TP concentrations exceeded the 0.01 mg/L screening value in more than 96% of valid observations at both sites. These results identify nutrient enrichment as a priority for further investigation, although exceedance frequencies alone do not establish ecological impairment.

Potential nutrient sources in urban and mixed-use catchments include stormwater runoff, wastewater infrastructure, fertilised landscapes, organic waste and sediment-associated nutrient transport. Walsh et al. (2005) identified altered nutrient and pollutant delivery as characteristic pressures in urban streams. However, the present analysis does not include nutrient-source tracing or sufficient information to distinguish among these potential contributors.

The ecological significance of nutrient concentrations should also be assessed through biological evidence. Dodds and Smith (2016) demonstrated that nutrient enrichment can affect freshwater ecosystem processes and community composition, but the response varies across systems. Consequently, the persistent nutrient exceedances observed in this study warrant further investigation using complementary indicators such as diatom assemblages, algal biomass, dissolved oxygen dynamics and nutrient-speciation measurements.

5.7 Potential influence of land use and urbanisation

Land use can influence freshwater ecosystems through changes in runoff generation, pollutant transport, vegetation cover, sediment delivery and stream-channel conditions. Urbanisation is particularly important because impervious surfaces and connected drainage networks can alter the frequency, magnitude and timing of stormwater inputs. These changes may affect stream chemistry, physical habitat and aquatic biological communities (Paul and Meyer, 2001; Walsh et al., 2005).

The GIS assessment identified substantial differences in catchment size but similar broad land-use proportions. Berowra Creek covered approximately 305.45 km², compared with 37.67 km² for Cowan Creek. Bushland accounted for approximately 69% of each catchment, while urban land represented approximately 23%. Despite these similarities, the selected monitoring sites displayed differences in conductivity, dissolved oxygen, pH and nutrient concentrations.

This contrast demonstrates an important limitation of catchment-wide land-use percentages. The proportion of urban land within an entire catchment does not necessarily describe the land-use conditions directly upstream of an individual monitoring location. The position of developed areas, drainage connectivity, impervious-surface distribution and local environmental characteristics may be more relevant to water quality at a particular site.

Paul and Meyer (2001) described how urban streams are affected by interconnected physical, chemical and biological changes. Walsh et al. (2005) further argued that urban stream degradation cannot be understood solely through the amount of urban land, because drainage connectivity and altered hydrological pathways strongly influence stream responses. These findings provide a scientific basis for investigating upstream contributing areas rather than relying exclusively on total catchment land-use composition.

However, the current GIS analysis uses the NSW Land Use 2017 v1.5 dataset, which represents a single period. It does not provide a historical sequence of land-use conditions between 1994 and 2026. Therefore, the study cannot determine whether urban expansion or particular developments caused the observed water-quality patterns.

Future spatial analysis should delineate the upstream drainage areas of Sites 012 and 013 and quantify land-use characteristics within those boundaries. Where available, historical land-use mapping, impervious-surface data, stormwater infrastructure and riparian vegetation information could provide a stronger basis for examining relationships between catchment development and freshwater condition.

5.8 Biological indicators and ecological implications

Biological monitoring provides an important complement to physicochemical water-quality measurements because aquatic organisms respond to environmental conditions over time. Whereas an individual water sample describes conditions at a particular sampling moment, biological communities may reflect the combined effects of water chemistry, habitat characteristics, hydrology and disturbance (Bonada et al., 2006).

The Council's biological monitoring datasets include macroinvertebrate and diatom records from selected years between 2002 and 2024. The original report identified SIGNAL2, EPT percentage abundance and the Trophic Diatom Index (TDI) as potentially relevant indicators. However, the available summary describes records across multiple monitoring sites rather than providing complete

site-specific biological results for Sites 012 and 013. Consequently, these datasets cannot presently support definitive conclusions about ecological trends at the two selected locations.

SIGNAL2, or Stream Invertebrate Grade Number Average Level, uses the pollution-sensitivity grades of aquatic macroinvertebrate taxa to provide an indication of biological condition. Higher scores generally indicate a greater representation of pollution-sensitive organisms, while lower scores may indicate communities dominated by more tolerant taxa. The index must be interpreted in relation to sampling methods, taxonomic resolution, habitat and regional environmental conditions (Chessman, 2003).

EPT metrics describe the representation of mayflies, stoneflies and caddisflies within macroinvertebrate communities. These groups often contain taxa sensitive to environmental disturbance, although their abundance and diversity also depend on habitat type, natural stream conditions and sampling methods. Therefore, EPT results should not be treated as universally applicable indicators without evaluating their suitability for the selected freshwater environments (Bonada et al., 2006).

The Trophic Diatom Index provides information about diatom community responses to nutrient enrichment. Diatoms are useful biological indicators because their community composition responds to environmental gradients, including nutrient availability. Kelly and Whitton (1995) established the TDI as an approach for monitoring eutrophication in rivers, although its application requires attention to the index methodology and ecological context.

The original report noted unusually low TDI values in 2011, approximately 3 compared with values around 50–70 in other sampled years. Such a large difference requires verification against the original biological records and calculation procedures before being interpreted as an ecological improvement. Differences in index scaling, data processing or sampling methods may influence comparability.

Although the water-quality results indicate persistent nutrient-related pressures, it would be inappropriate to conclude that these pressures caused changes in macroinvertebrate or diatom communities without site-specific biological evidence. The most defensible interpretation is that the biological datasets offer potential complementary evidence, but further validation and alignment with the selected monitoring locations are required before an integrated ecological assessment can be completed.

5.9 Comparison with Published Scientific Literature

The findings of this study are consistent with research showing that freshwater quality is influenced by land use, hydrological conditions, pollutant inputs and ecological processes. However, identifying the specific causes of long-term water-quality changes remains challenging.

Paul and Meyer (2001) demonstrated that urbanisation affects stream ecosystems through increased runoff, altered hydrology and pollutant inputs. These processes may influence water quality in the Berowra Creek and Cowan Creek catchments, although the present study cannot establish direct relationships between urban development and observed changes.

Similarly, Dodds and Smith (2016) highlighted the ecological consequences of nitrogen and phosphorus enrichment. The frequent exceedances of nutrient benchmarks at both monitoring sites suggest continuing nutrient-related pressures, although their biological effects remain uncertain.

Chessman (2003) demonstrated the usefulness of SIGNAL2 in assessing freshwater ecological condition while emphasising the influence of natural environmental variability. This supports integrating biological indicators with physicochemical measurements when evaluating stream health.

Overall, the literature suggests that lower recent pollutant concentrations do not necessarily indicate improved ecological condition. The findings highlight the importance of combining long-term water-quality monitoring, biological assessments and catchment-level information to better understand freshwater health in Hornsby Shire.

6. Recommendations and Management Implications

The following recommendations are based on the descriptive water-quality assessment, the GIS-derived catchment characteristics and the limitations of the available biological evidence. They are intended to identify priorities for further investigation and monitoring rather than prescribe specific engineering interventions before pollutant sources have been confirmed.

6.1 Nutrient-source investigations

Nutrient enrichment should be treated as a priority for further investigation because TN and TP concentrations frequently exceeded the applicable regional screening values at both monitoring locations. Although recent mean nutrient concentrations were generally lower than earlier values, the persistence of exceedances suggests that potential nutrient-related pressures have not been fully resolved.

Hornsby Shire Council should undertake targeted nutrient-source investigations within the upstream contributing areas of Sites 012 and 013. These investigations should consider urban stormwater drainage, wastewater infrastructure, fertilised landscapes, organic material and sediment-associated nutrient transport as potential sources. The importance of considering both nitrogen and phosphorus is supported by Dodds and Smith (2016), who demonstrated that both nutrients can influence stream ecosystem processes.

A staged investigation is recommended. Initial work should identify likely nutrient pathways using existing monitoring records, drainage maps and land-use information. Targeted field sampling could then be undertaken at selected upstream locations, including stormwater outlets and tributary junctions, to determine whether particular areas contribute disproportionately to nutrient concentrations.

Where significant sources are identified, Council could evaluate appropriate management responses, including source-control measures, stormwater treatment improvements and riparian management. Any proposed intervention should be supported by site-specific evidence and an assessment of feasibility, environmental benefit and maintenance requirements.

6.2 Stormwater and sediment monitoring

The recurring turbidity benchmark exceedances indicate a need to investigate sediment-related pressures at both monitoring sites. Although the recent mean turbidity values were lower than those recorded during the earlier monitoring period, episodic sediment inputs may remain environmentally important.

Council should consider supplementing routine monitoring with targeted sampling during and after rainfall events. Event-based monitoring would provide additional information about the relationship between runoff conditions and elevated turbidity. Where possible, turbidity observations should be accompanied by rainfall data, streamflow information and field observations of erosion or sediment deposition.

Potential sediment-contributing areas should be identified through inspections of drainage outlets, streambanks, construction-affected areas and other locations where runoff may transport sediment into receiving waterways.

The ecological importance of sediment monitoring is supported by Bilotta and Brazier (2008), who identified suspended sediment as a potential pressure on freshwater organisms and habitats. However, the appropriate management response should depend on the location, magnitude and nature of identified sediment sources.

Where evidence indicates significant sediment contributions, Council could investigate suitable erosion-control, stormwater-management or riparian-restoration measures. The effectiveness of implemented actions should subsequently be evaluated through consistent monitoring.

6.3 Improvements to long-term monitoring

The historical water-quality database represents a valuable environmental resource, but variations in sampling frequency, missing observations and differences in parameter coverage complicate comparisons between monitoring periods.

Council should maintain clearly documented monitoring procedures, including sampling frequency, field methods, laboratory analytical methods, detection limits, quality-assurance protocols and data-validation requirements. Consistent procedures would improve the comparability of future observations and strengthen the value of the historical record.

Monitoring records should also distinguish between missing measurements, values below detection limits, invalid observations and genuine zero values. These categories should not be treated interchangeably because they have different implications for data analysis.

Future monitoring should retain the six physicochemical parameters assessed in this study: EC, turbidity, DO, pH, TN and TP. Additional supporting measurements, particularly water temperature and DO percentage saturation, would improve ecological interpretation and allow more appropriate comparisons with relevant water-quality benchmarks.

Council should also maintain a centralised, quality-controlled database with consistent site identifiers, measurement units and metadata. Any changes in monitoring methods should be documented so that future analysts can determine whether observations remain comparable across years.

Finally, annual monitoring summaries should report sample counts alongside average values. This would make it easier to distinguish years with substantial monitoring coverage from years represented by relatively few observations.

6.4 Integration of biological monitoring

Biological monitoring should be more closely integrated with physicochemical water-quality monitoring to strengthen the assessment of freshwater ecosystem condition.

The existing macroinvertebrate and diatom datasets provide a potentially valuable source of ecological information. However, their intermittent temporal coverage and limited site-specific interpretation restrict their current usefulness for evaluating long-term changes at Sites 012 and 013.

Council should review the availability of biological observations at the selected monitoring locations and identify opportunities for consistent future sampling. Where feasible, biological surveys should be undertaken at comparable times of year and supported by water-quality measurements collected during the same monitoring periods.

SIGNAL2 could be retained as a macroinvertebrate indicator where sampling methods and taxonomic resolution are appropriate. Chessman (2003) demonstrated its usefulness for assessing pollution sensitivity in Australian rivers while emphasising the importance of local environmental context. Diatom assessments could provide complementary evidence of nutrient-related ecological responses, subject to the suitability and consistency of the index methodology.

The unusually low 2011 TDI observations should be reviewed against the original records and calculation procedures before they are incorporated into future assessments.

An integrated monitoring program would enable Council to evaluate whether observed changes in water chemistry are accompanied by changes in aquatic communities. This would provide a stronger basis for assessing ecological condition than physicochemical measurements alone.

6.5 Targeted GIS and upstream catchment assessment

Future GIS investigations should focus on the upstream contributing drainage areas of individual monitoring sites rather than relying exclusively on the overall land-use composition of the Berowra Creek and Cowan Creek catchments.

Although both catchments contain approximately 69% bushland and 23% urban land, these broad percentages do not indicate the location of urban development relative to the selected monitoring sites. The environmental influence of developed areas may depend on drainage connectivity, impervious-surface distribution, stream proximity and local catchment characteristics.

Council should therefore consider delineating the contributing subcatchments of Sites 012 and 013 using appropriate hydrological and spatial datasets. Land-use composition could then be calculated within these upstream areas to provide a more relevant spatial context for interpreting water quality.

Additional datasets could include impervious-surface coverage, riparian vegetation condition, stormwater infrastructure, wastewater networks and historical development records. Where suitable historical land-use information is available, changes in catchment characteristics could be examined alongside the monitoring record.

This recommendation is consistent with Paul and Meyer (2001) and Walsh et al. (2005), who demonstrated the importance of urban hydrology and drainage connectivity in influencing stream condition.

The resulting spatial analysis would help Council identify priority locations for further investigation and support more targeted catchment-management decisions.

6.6 Prioritised recommendations for Council

The recommendations should be implemented through a staged approach that reflects the strength of the available evidence, practical feasibility and the potential benefits for freshwater management.

Table 9. Proposed management and monitoring priorities for Hornsby Shire Council

Recommendation	Priority	Proposed timeframe	Suggested performance indicator
Investigate potential nutrient sources upstream of both sites	High	Short term: 0–12 months	Completion of source investigation and identification of priority locations
Improve monitoring of rainfall-related turbidity events	High	Short term: 0–12 months	Number of event-based sampling occasions and associated rainfall records
Standardise monitoring metadata and quality assurance	High	Short term: 0–12 months	Consistent units, sampling records and documented validation procedures
Review biological datasets and verify the 2011 TDI anomaly	High	Short term: 0–12 months	Completion of biological data audit
Delineate upstream contributing areas using GIS	Medium–High	Medium term: 1–2 years	Verified upstream catchment maps and land-use summaries
Integrate biological and physicochemical monitoring	Medium–High	Medium term: 1–3 years	Number of comparable paired biological and water-quality sampling events
Establish periodic integrated freshwater condition reporting	Medium	Ongoing	Publication of consistent monitoring summaries and management reviews

The highest immediate priority should be improving the evidence available for nutrient-source assessment, sediment monitoring and data reliability. These activities would provide a stronger foundation for evaluating future management interventions.

A periodic review process should be established so that monitoring results can inform subsequent decisions. Performance indicators should include data completeness, pollutant concentrations, benchmark exceedance frequencies and biological condition where reliable observations are available.

This approach would allow Council to refine management priorities as additional evidence becomes available, rather than relying on assumptions about the causes of historical water-quality changes.

7. Limitations

7.1 Unequal sampling frequency

Although the water-quality records extend from 1994 to 2026, the number of monitoring observations varied between years. Sampling frequency was generally greater during some earlier periods, while several recent years contained fewer observations.

Unequal sampling effort may influence the representativeness of annual average values. Years with relatively few samples may not adequately capture seasonal variability or short-duration pollution

events. Consequently, annual averages based on different numbers of observations are not necessarily equally reliable.

This limitation is particularly important when comparing historical and recent monitoring periods. Apparent differences may partly reflect changes in monitoring coverage rather than environmental conditions alone.

To improve transparency, annual sample counts should be presented alongside the trend graphs or in the supporting appendices.

7.2 Incomplete 2026 observations

The 2026 monitoring data represent only part of the calendar year. The original extracted datasets extend to May 2026 for Site 012 and June 2026 for Site 013.

Consequently, the 2026 annual averages do not represent complete calendar-year conditions. Seasonal differences in rainfall, streamflow, temperature and biological activity may affect water-quality measurements, meaning that partial-year averages may not be directly comparable with complete-year averages.

The 2026 observations have been retained to present the most recent available information, but they should be clearly identified as provisional in the trend graphs and supporting tables.

Any interpretation of recent changes should acknowledge that the final 2026 annual averages may differ once a complete year of monitoring data becomes available.

7.3 Missing values and extreme observations

Not all six water-quality parameters were measured during every sampling event. Consequently, the number of valid observations differed between parameters and years.

Missing observations were excluded from the relevant annual-average calculations rather than being treated as zero. However, differences in parameter coverage may affect comparisons between monitoring periods.

The original analysis also identified extreme turbidity and total phosphorus observations, particularly at Site 013. These observations may strongly influence arithmetic means, producing annual averages that are substantially higher than typical measurements.

Extreme values may represent genuine environmental events, analytical errors or unusual sampling conditions. Without additional verification, they should not automatically be removed from the dataset.

The inclusion of annual medians, sample counts and supplementary raw-data tables would improve transparency and help readers evaluate the influence of extreme observations.

7.4 Limitations of annual averages

Annual averages provide a straightforward method for summarising long-term water-quality records and presenting historical patterns graphically. However, they simplify complex environmental variability and may conceal important differences between individual sampling events.

For example, an annual average may remain relatively low despite several short-duration pollution events. Conversely, a single extreme observation may increase the annual mean even when most measurements fall within a narrower range.

Annual averages also do not account for the duration of exposure to elevated pollutant concentrations. Consequently, they cannot independently determine the ecological consequences of observed water-quality conditions.

The graphs should therefore be interpreted as descriptive summaries of available measurements rather than complete representations of freshwater ecosystem condition.

Where appropriate, future analysis could incorporate seasonal summaries, medians and event-based observations to provide a more detailed understanding of water-quality variability.

7.5 One monitoring site per catchment

The study assessed one selected freshwater monitoring location in each catchment: Site 012 in Cowan Creek and Site 013 in Berowra Creek.

Although these locations provide valuable long-term records, they cannot represent the full spatial variability of water quality throughout their respective catchments.

Both locations are classified as industrial monitoring sites in the Council metadata. Their water-quality characteristics may therefore reflect local environmental pressures that differ from conditions at other monitoring locations.

The findings should consequently be interpreted as comparisons between the two selected sites rather than comprehensive assessments of freshwater condition across the entire Berowra Creek and Cowan Creek catchments.

Future assessments could incorporate additional monitoring sites, including appropriately selected reference locations, to improve spatial representativeness.

7.6 Limitations of biological and land-use datasets

The biological monitoring datasets cover selected years rather than providing continuous observations throughout 1994–2026. In addition, the original biological summaries describe records collected across multiple Council monitoring locations rather than complete site-specific datasets for Sites 012 and 013.

These limitations prevent a reliable assessment of continuous biological trends at the selected sites. The unusually low 2011 TDI observations also require verification before being used to interpret ecological change.

The land-use assessment has a separate temporal limitation. It was based on the NSW Land Use 2017 v1.5 dataset, which represents one period within the much longer water-quality monitoring record.

Therefore, the GIS analysis cannot establish how land use changed between 1994 and 2026. It also uses overall catchment land-use percentages rather than the land-use composition of the upstream contributing areas of individual monitoring sites.

These limitations restrict the ability to explain observed water-quality patterns through historical development or specific land-use activities.

7.7 Absence of statistical significance testing

The present study used descriptive analysis of historical monitoring records, including annual averages, graphical comparisons and selected comparisons between earlier and recent monitoring periods.

No formal statistical significance tests were undertaken. Consequently, the study cannot determine whether observed changes represent statistically significant temporal trends or differences between monitoring periods.

Similarly, the analysis does not quantify uncertainty around annual means or account formally for temporal dependence, seasonality or differences in sampling effort.

The observed changes should therefore be described as patterns within the available monitoring records rather than statistically demonstrated long-term trends.

The absence of formal statistical testing does not eliminate the value of the analysis. The historical graphs remain useful for identifying periods of elevated concentrations, describing variation and highlighting issues that warrant further investigation.

However, future studies could apply suitable statistical methods where the monitoring data and research objectives justify their use. Such analysis would strengthen the evaluation of long-term environmental change and improve confidence in comparisons between monitoring locations.

8. Conclusion

This study examined historical freshwater water-quality conditions within Hornsby Shire through a descriptive comparison of Site 012 (Hornsby Creek, Cowan Creek catchment) and Site 013 (Sams Creek, Berowra Creek catchment). Monitoring records from 1994 to 2026 were used to assess temporal patterns in electrical conductivity, turbidity, dissolved oxygen, pH, total nitrogen and total phosphorus. The assessment also considered GIS-derived land-use characteristics and the availability of biological monitoring information.

The annual-average comparisons indicated that recent mean electrical conductivity, turbidity and nutrient concentrations were generally lower than those recorded during the earlier monitoring period. pH remained comparatively stable, while dissolved oxygen showed differences between sites and modest changes between the selected periods. These findings demonstrate that individual water-quality parameters have varied differently over the historical monitoring record.

Despite lower recent mean values for several parameters, frequent exceedances of the regional screening benchmarks for total nitrogen, total phosphorus and turbidity indicate that water-quality pressures remain relevant at both monitoring locations. Lower average concentrations should therefore not be interpreted as evidence that freshwater ecosystem health objectives have been achieved.

The GIS assessment demonstrated that Berowra Creek and Cowan Creek differed substantially in catchment size but contained similar broad proportions of bushland and urban land. Nevertheless, the selected monitoring sites exhibited different water-quality characteristics. This indicates that

catchment-wide land-use percentages alone are insufficient to explain local freshwater conditions and supports further investigation of upstream drainage areas and potential pollutant sources.

Biological monitoring offers an important opportunity to strengthen ecological interpretation, but the available records do not provide sufficient verified site-specific evidence to establish continuous biological trends at the two selected locations. More consistent integration of biological and physicochemical monitoring would improve future assessments.

The study is limited by unequal sampling frequency, incomplete 2026 observations, missing values, extreme measurements, the selection of one site per catchment and the absence of formal statistical testing. Consequently, the findings describe observed historical patterns rather than statistically significant trends or proven causal relationships.

For Hornsby Shire Council, the principal priorities are targeted nutrient-source investigations, improved understanding of sediment-related pressures, consistent long-term monitoring, verification of biological datasets and more detailed upstream GIS analysis.

Overall, the study demonstrates the value of Hornsby Shire Council's long-term monitoring records as a foundation for evidence-informed freshwater management. By combining consistent future monitoring with targeted investigations and integrated ecological assessment, Council can strengthen its understanding of catchment condition and better evaluate the effectiveness of future management actions.

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Appendix A. Active freshwater sites with at least 300 records in the two catchments

A full list of active freshwater sites with at least 300 records is provided in Appendix A.

Catchment	Site ID	Location	First record	Records	Primary purpose
Berowra Creek	**013**	**Sams Ck, Mt Ku-ring-gai**	**Mar 1994**	**598**	**Industrial**
Berowra Creek	010	Larool Ck, Thornleigh	Oct 1994	577	Industrial
Berowra Creek	CALN2	Calna Ck, Walls Gully, Hornsby Heights	Nov 1995	450	Ecohealth
Berowra Creek	BERO4	Berowra Ck, Galston Gorge, downstream road bridge	Oct 1994	366	Ecohealth
Berowra Creek	BERO6	Fishponds, Berowra Ck, Hornsby	Oct 1994	357	Ecohealth
Berowra Creek	BERO7	Berowra Ck, Westleigh	Oct 1994	326	Ecohealth
Berowra Creek	COLA2	Colah Ck, Glenorie	Oct 1994	325	Ecohealth
Berowra Creek	SMUG1	Smugglers Ck, Marramarra NP	Jan 1995	322	Ecohealth
Berowra Creek	TUNK1	Tunks Ck, Galson Gorge	Oct 1994	320	Ecohealth
Berowra Creek	STIL2	Still Ck, Galston	Oct 1994	318	Ecohealth
Berowra Creek	GEOR1	Georges Ck, Dural	Oct 1994	313	Ecohealth
Berowra Creek	PYES1	Pyes Ck, Cherrybrook	Oct 1994	312	Ecohealth
Berowra Creek	JOEC1	Joe Crafts Ck, Muogamarra NR	Oct 1994	312	Ecohealth
Berowra Creek	CALN1	Calna Ck, Lyrebird Gully	Oct 1994	300	Ecohealth

Cowan Creek	**012**	**Hornsby Ck, Hornsby**	**Oct 1994**	**612**	**Industrial**
Cowan Creek	MAN D1	Murray Anderson Ck, Kuring-Gai Chase NP	Jan 1995	330	Ecohealth

Source: GIS water-quality site metadata (WQ_sites_2026) and the Council master water-quality database.