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Water Quality and Biological Assessment, Te Puru Stream Tributary, Beachlands
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Cover Illustration: Site C, Farm Pond Tributary of the Te Puru Stream, Beachlands (31 January 2024)

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EXECUTIVE SUMMARY

A survey of the upper Te Puru Stream catchment was undertaken on behalf of Watercare Services Limited (Watercare), as a comparative study of water quality and biological condition upstream and downstream of the Beachlands wastewater treatment plant discharge point. This report presents the results of the water quality and biological survey undertaken at ten sites over the period 31st of January, and 1st and 2nd of February 2024, to determine the effects of the existing discharge of highly treated effluent from the treatment facility on the water quality and biology of the receiving waters.

Overall water quality and biological health of the Te Puru stream tributaries were relatively poor throughout both reference and impact sites, reflecting in part the pastoral catchment in which the Te Puru Stream tributaries are located.

In terms of water quality, conductivity was elevated below the discharge point and continued to be substantially elevated beyond the lowest site surveyed. pH and carbonaceous biochemical oxygen demand did not appear to be influenced by the discharge.

Bioavailable nutrients (nitrogen and phosphorus) increased below the discharge point. Nutrient concentrations tended to decrease with increasing distance downstream; however, some parameters such as total nitrogen, dissolved inorganic nitrogen, total phosphorus, and dissolved reactive phosphorus continued to be elevated until the furthest downstream site, approximately 1.5 km downstream of the discharge pond. Ammonia, which can be toxic to aquatic fauna at elevated concentrations, increased markedly downstream of the discharge pond, however returned to reference levels by the most downstream site. All of the sites surveyed recorded ammoniacal nitrogen below both these acute and chronic guidelines.

There was no evidence of bacterial contamination by the discharge, with some very high values for faecal coliforms and enterococci bacteria recorded at both reference and effects sites, which was attributed to the presence of livestock and birds within the catchment.

Macroinvertebrate communities were generally indicative of fair/good quality habitat at reference sites and poor/fair quality habitat across effects sites and sensitive macroinvertebrate taxa tended to be absent from effects sites. Macroinvertebrate indices at the most downstream sites did show some recovery, indicating localised adverse effects from the discharge on macroinvertebrate communities.

Fish communities appeared to be influenced by the discharge, with reductions in native species diversity and abundance observed downstream of the discharge pond. Juvenile eels and juvenile banded kōkopu were recorded in the upstream reference site, indicating that fish are able to migrate upstream of the discharge.

Macrophytes increased in cover and diversity downstream of the discharge, with a diverse range of both introduced and native species present, dominated by Nitella, followed by filamentous algae. Due to differences in shading, flow rate and bioavailable nutrient levels between reference and effects sites, the differences observed in macrophyte and periphyton growth were attributed to these range of factors.

Overall comparison with the results of the previous surveys since 2000 (Bioresearches 2002, 2010, 2016, 2019 and 2022), shows that water quality and ecological conditions in the upper Te Puru Stream tributaries surveyed were broadly similar in the present survey. Ammonia showed substantial decreases at effects sites compared to 2022 data; however, are still considered to be markedly higher than that at reference sites. Macrophytes and macroinvertebrate communities appeared to be negatively influenced at effects sites surveyed over 31 January – 2 February 2024, specifically noting a decline in sensitive macroinvertebrates species and an increase in macrophyte species at effects sites. Native fish were still able to migrate beyond the farm pond, as found previously. Conductivity levels below the discharge were very high and remained high throughout the Te Puru Tributary. The elevated levels of conductivity require further consideration, both in terms of whether these levels can be reduced in the discharge and the extent the elevated levels are present downstream of the survey sites.

While the overall quality of the Te Puru Stream tributaries is determined principally by the land use of the adjacent catchment, the results of the survey indicate that the wastewater treatment plant discharge influences the quality of the habitat of the Te Puru Stream Tributary for a distance of at least 200 m downstream of the farm pond, with some water quality parameters such as conductivity and bioavailable nutrients affected for a greater distance (observed at lowest monitoring site, Site C). Fish populations, sensitive macroinvertebrates and filamentous algae also appeared to be affected for some distance downstream of the discharge (observed up to the lowest monitoring site, Site C), although eels and banded kōkopu were able to migrate upstream past the discharge.

1. INTRODUCTION

Watercare operates the wastewater treatment plant (WWTP) at Beachlands, Auckland, and regular monitoring of the effects of the discharge on water quality and stream biology is required. The WTP discharges highly treated effluent through pipes and then through a trickle system through a vegetated area, then into a large farm pond, which discharges to a tributary of the Te Puru Stream in Beachlands.

This water quality and biological assessment of selected Te Puru Stream tributaries is a repeat of the water quality and biological surveys carried out for Manukau Water in 1997, 1999, 2002 and 2010, and for Watercare in 2016, 2019 and 2022 (Bioresearches 1997, 1999, 2002, 2010, 2016, 2019 and 2022). Monitoring is usually undertaken every three years; however, the most recent monitoring in January-February 2024 which is described in this report was carried out only two years after the previous (2022) monitoring to inform Watercare's understanding of the potential effects of an increased discharge of treated effluent into the tributary of the Te Puru Stream, as part of its application to Auckland Council to renew its current discharge consent.

The Te Puru Stream is located in the Beachlands area, near the east coast, south of Auckland. The stream is approximately four kilometres long and flows through moderately steep pastoral land before discharging into the ocean at Kelly's Beach. The highly treated effluent from the WTP is discharged into a farm pond on a tributary of the Te Puru Stream located approximately 4.5 km inland from the stream mouth.

Analysing water and sediment quality can give an indication of the presence and extent of nutrient enrichment/contaminants from influences such as wastewater discharges, urban areas and pastoral land use. Parameters such as nitrogen and phosphorous compounds and bacteria are often measured when analysing water and sediment quality. The biological characteristics of stream ecosystems can give indications of stream health and the effects that factors such as a wastewater discharge may have on freshwater communities.

Sampling was undertaken in two main tributaries adjacent to Okaroro Road, referred to as the Reference Tributary and Te Puru Stream Tributary. A side tributary of the main tributary, which included the farm pond into which the treated wastewater is held for final polishing, was referred to as the Farm Pond Tributary (Figure 1).

Water quality samples were taken at seven sites from the two tributaries, including three reference sites, and sediment quality samples were taken at four sites. Biological samples included fish and macroinvertebrates, taken from six sites, and macrophytes, which were evaluated at eight sites. Site names and locations correspond to those used in previous Te Puru Stream monitoring surveys (Bioresearches 1997, 1999, 2002, 2010, 2016, 2019 and 2022). This report presents the results of the water quality and biological assessments carried out on the 31st of January, and 1st and 2nd of February 2024.

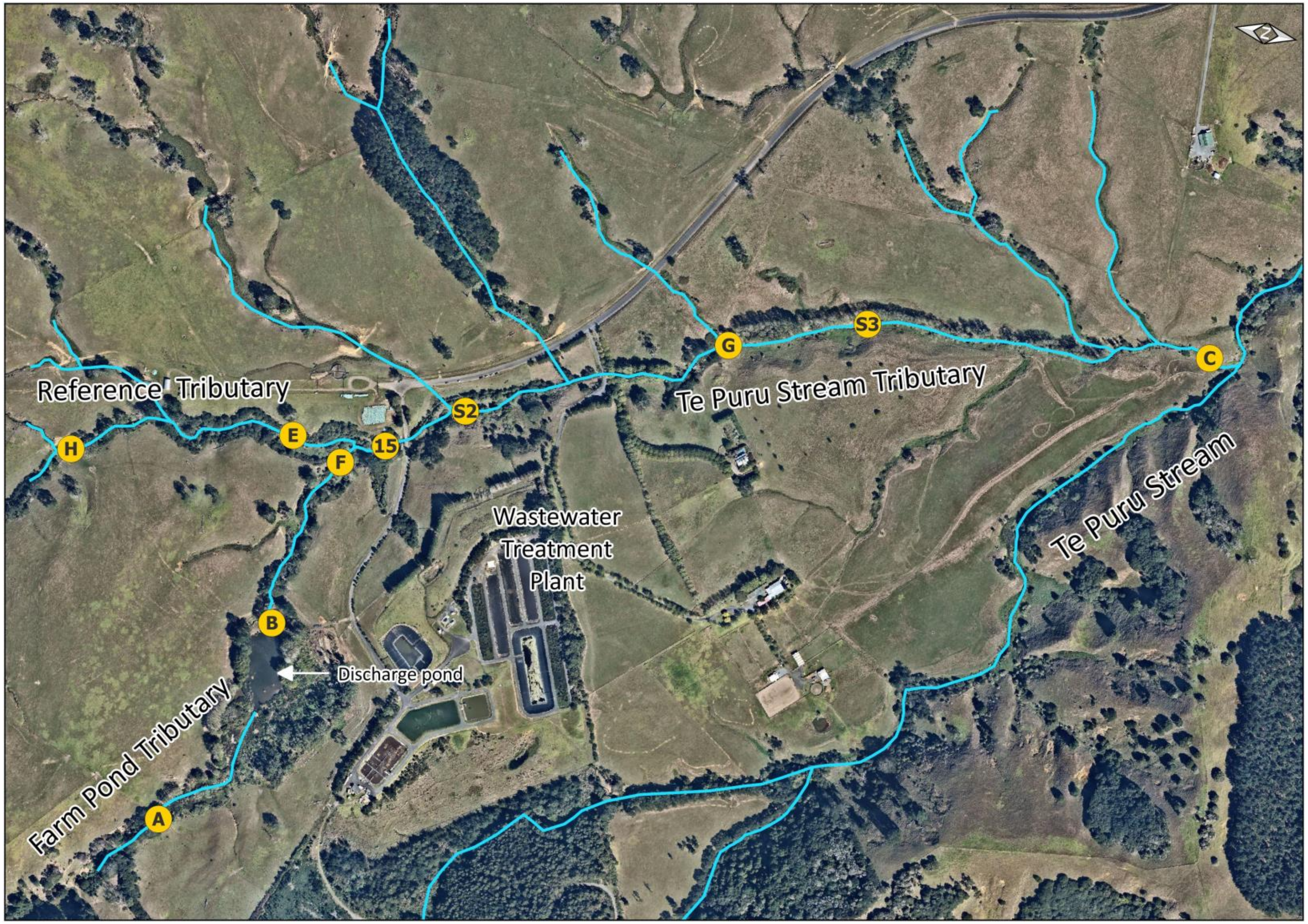

Figure 1. ***Sampling site locations in Te Puru Stream tributaries (blue lines – Reference Tributary, Farm Pond Tributary and Te Puru Stream Tributary), site locations (yellow circles) and the location of the wastewater treatment plant.***

2. METHODOLOGY

2.1 Site Locations

Locations of sampling sites for the water quality and biological surveys were the same as in the previous monitoring surveys (Table 1 and Table 2).

Table 1. Sampling site locations.

Site	Description	Tributary	Location (NZTM)
A	Reference site, upstream of the farm pond.	Farm Pond Tributary	E1781181.11 N5912504.77
B	Effect site, immediately downstream of the farm pond discharge.	Farm Pond Tributary	E1780823.81 N5912650.06
F	Effect site, approximately 200m downstream of the farm pond and immediately upstream of the Te Puru Stream Tributary confluence.	Farm Pond Tributary	E1780640.75 N5912676.69
H	Reference site, upstream of E in the headwaters of the Reference Tributary	Reference Tributary	E1780642.45 N5912324.68
E	Reference site, downstream of H and just upstream of the confluence with the Farm Pond Tributary, Te Puru Stream Tributary	Reference Tributary	E1780549.89 N5912604.50
15	Effect site, immediately downstream of the confluence of the of the Farm Pond Tributary and the Reference Tributary	Te Puru Stream Tributary	E1780548.57 N5912764.51
S2	Effect site, approximately 200m downstream of the Farm Pond Tributary and Reference Tributary confluence, within replanted area.	Te Puru Stream Tributary	E1780445.25 N5912920.30
G	Effect site, approximately 600m downstream of the Farm Pond Tributary and Reference Tributary confluence.	Te Puru Stream Tributary	E1780300.63 N5913226.02
S3	Effect site, approximately 800m downstream of the Farm Pond Tributary and Reference Tributary confluence.	Te Puru Stream Tributary	E1780236.26 N5913406.90
C	Effect site, approximately 100m upstream of the confluence with the mainstem Te Puru Stream	Te Puru Stream Tributary	E1780186.32 N5913871.81

Table 2. Sample types taken at each site.

Site	Sample Types
A	Water Quality, Macroinvertebrates and Fish, Macrophytes
B	Water Quality
F	Water Quality, Sediment, Quality, Macroinvertebrates and Fish, Macrophytes
H	Macroinvertebrates and Fish, Macrophytes
E	Water Quality, Sediment Quality, Macroinvertebrates and Fish Macrophytes
15	Water Quality
S2	Macrophytes
G	Water Quality, Sediment Quality, Macroinvertebrates and Fish, Macrophytes
S3	Macrophytes
C	Water Quality, Sediment Quality, Macroinvertebrates and Fish, Macrophytes

2.2 Water and Sediment Quality

Water quality sampling was undertaken on the 31st of January 2024, after a period of settled weather and under late summer low-flow conditions. Water samples were collected from Sites A, B, C, E, F, G & 15 (Figure 1). The water samples were chilled and delivered to the laboratory (Hills Laboratories, Hamilton) within 24-29 hours of collection. These samples were analysed for the following parameters:

- Conductivity – the total ionic strength of the water and an indication of nutrient enrichment;
- pH – the concentration of hydrogen ions in the water showing the strength of acid present;
- Total Suspended Solids – suspended particles that are not dissolved in the water;
- Carbonaceous Biochemical Oxygen Demand ($CBOD_5$) – the oxygen used by bacteria for the biochemical degradation of organic matter;
- Chlorophyll-α – a measure of the phytoplankton biomass;
- Total Ammoniacal Nitrogen (NH_4-N) – an indicator of nutrient enrichment, often from point source discharges such as sewage or dairy effluent;
- Total Nitrogen – the sum of all organic and inorganic forms of nitrogen, an indicator of nutrient enrichment;
- Nitrate Nitrogen (NO_3-N) – a common nutrient in urban and rural areas and an indicator of nutrient enrichment;
- Nitrite Nitrogen (NO_2-N) – a less common form of nitrogen and an indicator of nutrient enrichment;
- Total Kjeldahl Nitrogen (TKN) – a measure of nitrogen in the trivalent state (NH_4-N, protein N and non-protein-N), an indicator of nutrient enrichment;
- Dissolved Inorganic Nitrogen (DIN) – a measure of nitrite, nitrate and ammonium, an indicator of nutrient enrichment;
- Total Phosphorus – all phosphorus concentrations (dissolved, solid or bound to sediment), an indicator of nutrient enrichment;
- Dissolved Reactive Phosphorus (DRP) – a measure of the dissolved phosphorus compounds that are readily available for use by plants and algae, an indicator of a waterbody's ability to support algae/plant growth;
- Faecal Coliform Bacteria – predominantly found in the gut of humans and animals, an indicator of faecal contamination; and
- Enterococci – a faecal coliform bacteria species that naturally occurs in the gut of humans and animals (including birds, fish and reptiles), an indicator of faecal contamination.

Spot measurements of basic water quality parameters (temperature, dissolved oxygen and conductivity) were also taken using a Yellow Springs Instrument (YSI) Professional Series meter and water clarity was measured using a turbidity tube at each site.

Water quality results were compared to the Australia and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC Guidelines – ANZG 2018, ANZECC and ARMCANZ 2000); the New Zealand National Policy Statement for Freshwater Management (NPS-FM) criteria for protecting aquatic ecosystems, (Ministry for the Environment (MfE) 2020); habitat indicators of stream health from the National Institute of Water and Atmosphere (NIWA) (Hickey 2001, 2014 and Biggs *et al*. 2002); and sewage fungus growth (Quinn 2009). The raw water quality data are presented in Appendix 1.

Composite sediment samples were collected at Sites C, E, F and G on the 31st of January 2024. Six sediment cores (80mm x 100mm) were collected from each site (two from true left bank, two from true right bank, two from centre of tributary) and combined. A representative sub-sample was taken from this composite sample and sent to Hills Laboratories, Hamilton for analyses of the following parameters:

- % Dry Weight – the amount of organic matter in a sample;
- Total Phosphorus – an indicator of nutrient enrichment;
- Total Nitrogen – an indicator of nutrient enrichment and of sources of organic matter input;
- Total Carbon – an indicator of sources of organic matter input;
- Carbon: Nitrogen Ratio – an indicator of the relative sources of organic matter; and
- Ammonium-Nitrogen – an indicator of nutrient enrichment.

Stream velocity measurements were undertaken on the 31st of January and the 1st of February 2024 at sites within all three tributaries. The width of the stream was measured, and depth and velocity readings were taken at proportional intervals across a transect – at 10%, 30% 50%, 70% and 90% of the stream width. This enabled flow to be calculated. While a pygmy flow meter was the preferred instrument to take the stream velocity measurements, the high electrical conductivity in the water meant the instrument was not able to perform as required. As such, stream velocity was recorded by measuring the amount of time it took for an object to travel a certain distance. Other limitations with once-off flow measurements include:

- A Lack of temporal variability: A single flow measurement may not capture the temporal variability in flow patterns, which can affect habitat conditions and the distribution of aquatic organisms over time;
- Inadequate representation: Flow measurements taken at a single point at the various sites in time may not adequately represent the range of flow conditions experienced by aquatic organisms throughout different seasons or hydrological events (high flows, low flows etc.);
- Inaccuracy in habitat assessment: Flow data collected at a single time point may not accurately reflect the range of habitats available to aquatic organisms, particularly if flow conditions vary significantly over the various seasons;
- Without multiple flow measurements over time, it is challenging to assess long-term trends in flow patterns and its effects on aquatic ecosystems;
- Without repeated flow measurements, it is difficult to develop a comprehensive understanding of the relationships between flow dynamics and ecological responses in the Te Puru stream and tributaries; and
- Limited ability to evaluate management interventions: Single flow measurements may not provide sufficient data to evaluate the effectiveness of management interventions aimed at mitigating the impacts of altered flow regimes on aquatic ecosystems.

2.3 Biological Surveys

Biological assessments were undertaken on the 31st of January, and 1st and 2nd of February 2024. Six sites were sampled for macroinvertebrates and fish, and macrophytes were sampled at eight sites (Figure 1 and Table 2).

Macroinvertebrates were sampled from instream habitats to obtain semi-quantitative data in accordance with the Ministry for the Environment's current "Protocols for Sampling Macroinvertebrates in Wadeable Streams" (Stark *et al*. 2001). Sampling was undertaken using protocol 'C1: hard-bottomed, semi-quantitative' where the majority of the substrate was hard bottomed (Sites H and E), and protocol 'C2: soft-bottomed, semi-quantitative' where the site was predominantly soft bottomed (Sites A, F, G and C). The macroinvertebrate sample was preserved in 70% ethyl alcohol (ethanol), returned to the laboratory and sorted (using protocol 'P3: full count with sub-sampling option' (Stark *et al*. 2001)). Macroinvertebrates were then identified to the lowest practicable level and counted to enable biotic indices to be calculated.

Several biotic indices were calculated, namely the number of taxa, the number and percentage of Ephemeroptera (mayflies); Plecoptera (stoneflies) and Trichoptera (caddisflies) recorded in a sample (%EPT), the Macroinvertebrate Community Index (MCI) and the Semi-Quantitative Macroinvertebrate Community Index (SQMCI) (Stark & Maxted, 2007a). EPT are three orders of insects that are generally sensitive to organic or nutrient enrichment but exclude *Oxyethira* and *Paroxyethira* as these taxa are not sensitive and can proliferate in degraded habitats. The MCI and SQMCI are based on the average sensitivity score for individual taxa recorded within a sample; although the SQMCI is calculated using coded abundances instead of actual scores. The raw macroinvertebrate data are presented in Appendix 2. For the MCI and SQMCI, respectively, scores of:

- ≥ 120 and ≥ 6.0 are indicative of excellent habitat quality,
- 100 – 119 and 5.0 – 5.9 are indicative of good habitat quality,
- 80 – 99 and 4.0 – 4.9 are indicative of fair habitat quality and
- < 80 and < 4.0 are indicative of poor habitat quality (Stark & Maxted, 2007b).

The Auckland Unitary Plan (AUP), Chapter E1.3, provides additional MCI values criteria, AUP Table E1.3.10, for freshwater ecosystem health associated with various land uses within catchments (Table 3). Policy E1.3(2) mandates the management of discharges that could potentially impact freshwater systems to maintain or improve water quality, flow rates, stream channels, margins, and other freshwater values. This policy applies when the current condition is either above (for maintenance) or below (for enhancement) the National Policy Statement for Freshwater Management (NPS-FM) National Bottom Lines and the relevant MCI guidelines.

Table 3. MCI guideline for Auckland rivers and streams as per AUP Policy E1.3(2)

Land use	MCI guideline
Native forest	123
Exotic forest	111
***Rural areas**	94
Urban areas	68

*MCI guideline applicable to the Te Puru catchment

Fish communities can be good indicators of stream ecosystem health. Freshwater fish were sampled using three baited Gee's minnow traps which were deployed overnight at each site. Electric fishing was also intended to be carried out at each site using an electric fishing machine (EFM) 300 backpack. Electric fishing was only effective at Sites A, H and E as the high conductivity at sites downstream of the pond prevented effective operation of the machine. The electric fishing machine temporarily stuns the fish, allowing them to be captured. All fish captured were identified and counted, and their size estimated before being returned to their habitats. A Fish Index of Biotic Integrity (IBI) for the Auckland Region was calculated for each site based on fish species present, altitude and distance inland (Joy and Henderson 2004). New Zealand Freshwater Fish Database (NZFFD, NIWA) forms were completed for each site. The raw freshwater fish data are presented in Appendix 3.

At each site the percentage cover (proportion of the total line width impinged) of algae and/or macrophytes was recorded along twelve random replicate transects which ran from bank to bank. Transect locations were determined using a random number table. From the centre of the site, six transects were completed in an upstream direction at random intervals in metres determined by the table, followed by six transects returning in a downstream direction. At each transect the stream width, and the length of the transect impinged by the plant taxa were recorded and converted to percentage plant cover. Incidental species present at the site but not recorded along the transects were also noted. The raw macrophyte survey results are present in Appendix 5.

2.4 Results Comparison

All results were compared to guideline values, where applicable. Guideline values for water quality can give an indication as to the relevant concentrations of nutrients and toxicants above or below which possible adverse effects are known to occur.

Results from 2024 were also compared to the most recent three-yearly survey (Bioresearches, 2022). Any large deviations in results from what was found in 2019 and 2022 was also reported.

3. RESULTS

3.1 Physical Characteristics

The physical characteristics of Te Puru Stream tributary sites are summarised in Table 4 and photographs of each site are shown in Photos 1 to 10.

The average width at each stream site varied between 1.74 m (Site H) to 2.69 m (Site S3) wide, and the average stream width across all sites was 2.11 m. Average depth at most sites was relatively shallow and ranged between 0.12 m (Site F and S2) and 0.51 m (Site S3).

Substrate was predominantly made up of silt, with the exception of Sites H and S2, where bedrock and cobbles were dominant. Cobble and gravels were also common at all sites. Fish habitat/cover types observed during the survey comprised macrophytes, instream debris (e.g. wood), undercut banks and bankside vegetation.

Stream flow varied substantially across the sites. Flow was highest at Site G (66.39 L/s) and lowest at Site E (10.24 L/s), and generally increased with distance downstream.

One thing to note, monitoring of reference Site A was shifted 10 m upstream due to the abundant growth of wetland plants within the previous monitoring site. This is further discussed in Section 4.1.1

Table 4. *Summary of the physical characteristics and biological survey results of the Te Puru Stream sites, 31st of January to the 2nd of February 2024.*

	Reference Tributary		Farm Pond Tributary			Te Puru Stream Tributary		
Site	**H**	**E**	**A**	**F**	**S2**	**G**	**S3**	**C**
Date	31 Jan 2024	31 Jan 2024	31 Jan 2024	31 Jan 2024	31 Jan 2024	31 Jan 2024	31 Jan 2024	31 Jan 2024
Habitat								
Average Width (m)	1.74	2.16	1.61	2.36	2.36	2.17	2.69	1.82
Average Depth (m)	0.24	0.23	0.19	0.12	0.12	0.25	0.51	0.27
Flow (L/s)	Not assessed	10.24	Not assessed	15.8	31.73	49.24	38.66	40.49
Dominant substrate	Bedrock with small cobble	Silt and cobble	Small gravel on top of soft sediments	Thick layer of fine organic material and silt	Bedrock, cobble	Silt, cobble and gravel	Silt, cobble and gravel	Silt, cobble and gravel
Fish Cover	Instream debris, Undercut banks	Macrophytes, instream debris, undercut banks, bank vegetation	Macrophytes, instream debris, undercut banks, bank vegetation	Macrophytes, instream debris, bank vegetation	Instream debris, bank vegetation	Macrophytes, instream debris, bank vegetation	Instream debris, bank vegetation, undercut banks	Macrophytes, instream debris, undercut banks, bank vegetation
Macrophytes and Algae								
No. of Taxa	1	8	3	7	4	9	7	7
Average Percent Cover	5	11	7	43	9	53	60	72
Species Recorded	Water celery	Willow weed, curly pondweed, water celery, buttercup, forget me knot, *Nitella*, green mat and filaments.	Willow weed, red ludwigia, and green filaments.	Willow weed, watercress, duck weed, Starwort, forget me knot, brown mat, green filaments.	Forget me not, Nitella, brown mat, brown filaments.	Willow weed, watercress, duck weed, curly pondweed, water celery, buttercup, forget me not, *Nitella*, green filaments	Willow weed, watercress, duck weed, curly pondweed, buttercup, *Nitella*, green mat	Willow weed, watercress, water celery, oxygen weed, *forget me not*, *Nitella*, green filaments

Site	H	E	A	F	S2	G	S3	C
Macroinvertebrates								
No. of Taxa	15	22	21	3	Not assessed	12	Not assessed	12
Dominant taxon	*Potymopyrgus*	*Potymopyrgus*	*Paracalliope fluviatilis*	*Potymopyrgus*		*Potymopyrgus*		*Paracalliope fluviatilis*
%EPT	20	30	22	0		0		0
MCI	101.3 - Good	98.2 - Good	104.7 - Fair	63.3 - Poor		81.7 - Fair		67.3 - Poor
SQMCI	4.78 - Fair	4.46 - Fair	6.01 - Excellent	2.13 - Poor		4.49 - Fair		4.83 - Fair
Large invertebrates	*Paratya* shrimp, kōura	*Paratya* shrimp, kōura	kōura			*Paratya* shrimp		*Paratya* shrimp, kōura
Fish								
No. of species	4	3	4	1	Not assessed	3	Not assessed	4
No. of fish	36	19	21	1		25		14
Fish IBI	34 - Fair	26 - Poor	34 - Fair	14 – Very Poor		26 - Poor		26 - Poor
Species recorded	Kōura, Cran's bully, Common bully, Banded kokopu	Common bully, unidentified eel, kōura	Banded kokopu, kōura, common bully, unidentified eel	Unidentified eel		Mosquito fish, common bully, longfin eel		Common bully, mosquito fish, longfin eel, unidentified eel

*HB = hard-bottomed, SB = soft-bottomed

Photo 1. Site A – reference site, Farm Pond Tributary.

Photo 2. Site H – reference site, Reference Tributary.

Photo 3. Site E – reference site, Reference Tributary.

Photo 4. Site B – effect site, Farm Pond Tributary.

Photo 5. Site F – effect site, Farm Pond Tributary.

Photo 6. Site 15 – effect site, Te Puru Stream Tributary

Photo 7. ***Site S2 – effect site, Te Puru Stream Tributary***

Photo 8. ***Site S3 – effect site, Te Puru Stream Tributary***

Photo 9. *Site G – effect site, Te Puru Stream Tributary*

Photo 10. *Site C – effect site, Te Puru Stream Tributary*

3.2 Water Quality

Water quality results are presented in Table 5 and Figures 2 to 6.

Small amounts of nutrients such as nitrogen and phosphorus in freshwater are important for plant growth, however excess concentrations can lead to nuisance aquatic plant growth, algal blooms, eutrophication of freshwater ecosystems and some compounds are toxic to aquatic life at high concentrations. Faecal bacteria associated with wastewater discharges can indicate a risk to human health.

Water quality results were compared to freshwater guideline values for the protection of aquatic ecosystems, where values for the water quality component were available and relevant. Guideline values used were all New Zealand based data (ANZG 2018; ANZECC and ARMCANZ 2000; Ministry for the Environment 2020; Quinn 2009; Biggs *et al.* 2002, Hickey 2014) and NIWA site specific data (Hickey 2001). These guidelines give the concentrations of nutrients and toxicants above or below which possible adverse effects are known to occur.

The ANZG (2018), which succeeded ANZECC (2000), provides generic default guideline values (DGVs) for toxicants and physical and chemical stressors in waterways. Physical and chemical DGVs are available for both high and low values:

- High indicates the stressor is harmful at high values (80th percentile); and
- Low indicates the stressor is harmful at low values (20th percentile).

DGVs for physical and chemical stressors were derived for a low elevation river in a warm-dry climate, based on the River Environmental Classification (REC) of Te Puru stream and tributaries (NIWA 2004)[1].

Guidelines from the National Policy Statement for Freshwater Management (NPS-FM – Ministry for the Environment 2020) include several attribute states, the lowest being Attribute State D (significant, persistent stress on aquatic organisms, high risk of local extinctions of keystone species and loss of ecological integrity) to the highest of Attribute State A (no stress caused by the indicator on 99% aquatic organisms at pristine (reference) sites). Attribute State B refers to lakes and rivers impacted by land use practices and/or provides for 95% species protection level (i.e. starting to impact occasionally on the 5% most sensitive species). As the surrounding catchment has been cleared and the dominant land use is farming this report mainly refers to the Attribute State B guideline values.

Habitat indicators of stream health from Biggs *et al*. (2002) do not provide specific guideline values, however, they do provide ranges of some water quality components that would indicate ‘poor’, ‘fair’, ‘good’ and ‘excellent’ stream health and these ranges were used where appropriate.

[1] Since 2019, the monitoring report used DGVs for a REC of low elevation river in a warm-wet climate. This change in classification does not impact on the outcome of this study, as the updated classification refers to specific guidelines to which the most recent water quality analysis is compared to.

Specific guideline values for carbonaceous biochemical oxygen demand ($cBOD_5$) were not available for New Zealand river systems. Evidence presented by Quinn (2009) at a hearing relating to water quality in the Horizons region presents professional opinion regarding the concentration of BOD to protect river systems from sewage fungus. This evidence has been cited and utilised as a guideline value when reporting on water quality previously (Mott MacDonald 2017). Chlorophyll α concentrations in lake ecosystems from the NPS-FM (MfE 2020) were used as guideline values in this report, however, should be reviewed with some caution due to the differing ecosystem types.

Table 5. Water quality results for the Te Puru Stream sites, sampled January/February 2024. Bold text corresponds to values not meeting the guideline.

	Reference Tributary	Farm Pond Tributary			Te Puru Stream Tributary			Guideline	
	E	**A**	**B**	**F**	**15**	**G**	**C**	**Low/High***	**Value**
Time (hrs, NZDST)	15:00	10:40	11:25	12:05	13:10	15:40	9:10		
Temperature (°C)	19.9	18.2	24.5	24.2	22.4	22	20.6	H	20 [5]
Dissolved Oxygen (mg/L)	6.8	6	**7.7**	**4.6**	6.5	7.00	5.3	L	5.0 - 7.5 [4]
Oxygen Saturation (%)	**76**	**65**	**94**	**56.0**	**76**	**81**	**61**	L and H	82 - 100 [1]
Conductivity (µS/cm)	**158.9**	**149.8**	**1964**	**1944**	**1297**	**1166**	**1188**	H	86 [1]
Conductivity (mS/m)	15.89	14.98	196.4	194.4	129.7	116.6	118.8	H	
Salinity (ppt)	0.08	0.08	1.01	1	0.68	0.62	0.65		
Visual Clarity (m)	**0.7**	0.47	**0.76**	**0.75**	**0.72**	**0.8**	**0.78**	L	0.7 [1]
pH (pH unit)	7.4	**7.1**	7.7	7.8	7.5	7.7	7.5	L and H	7.27 - 7.8 [1]
Total Suspended Solids (g/m^3)	< 3	**6**	**7**	**6**	**10**	< 3	< 3	H	4.6 [1]
Carbonaceous Biochemical Oxygen Demand (g O_2/m^3)	< 2[#1]	< 2[#1]	< 2[#1]	< 2[#1]	< 2[#1]	< 2[#1]	< 2[#1]	H	2 [3]
Chlorophyll α (g/m^3)	< 0.003	< 0.003	0.006	< 0.003	< 0.003	< 0.003	< 0.003	H	0.05 - 0.12 [4]
Total Ammoniacal Nitrogen (g/m^3)	0.011	0.029	0.167	0.057	0.022	0.011	0.01	H	3 [6]
Total Nitrogen (g/m^3)	0.23	0.25	**3.5**	**3.5**	2.4	2	2.1	H	3 [6]
Nitrate-N (g/m^3)	0.115	0.099	**2.4**	**2.5**	**1.69**	**1.51**	**1.47**	H	0.195 [1]
Nitrite-N (g/m^3)	0.002	< 0.002	0.173	0.094	0.036	0.017	0.013	H	0.444 [2]
Nitrate-N + Nitrite-N (g/m^3)	0.117	0.101	2.6	2.6	1.73	1.52	1.49	-	
Total Kjeldahl Nitrogen (g/m^3)	0.11	0.15	0.95	0.87	0.63	0.52	0.57	-	
Dissolved Inorganic Nitrogen (g/m^3)	0.128	0.13	2.7	2.7	1.75	1.53	1.5	-	
Total Phosphorous (g/m^3)	**0.04**	**0.029**	**0.69**	**0.61**	**0.45**	**0.32**	**0.28**	H	0.023 [1]
Dissolved Reactive Phosphorous (g/m^3)	**0.015**	0.005	**0.51**	**0.48**	**0.29**	**0.24**	**0.2**	H	0.007 [1]
Faecal Coliforms (cfu / 100mL)	**460**	**560**	**540**	**410**	**340**	**1800[#2]**	**1300[#2]**	H	150 [2]
Enterococci (MPN / 100mL)	**1,986**	461	166	549	517	**1,203**	461	H	700 [2]

*L = harmful at low values; H = harmful at high values, [1] ANZG (2018), [2] ANZECC (2000), [3] Quinn (2009), [4]Ministry for the Environment (2020), [5] Biggs *et al*. (2002), [6]Hickey 2011, 2014) specific guideline for Te Puru derived from ANZECC (2000); Ammoniacal nitrogen guideline used as Total N is the sum of nitrate, nitrite, organic nitrogen and ammonia.

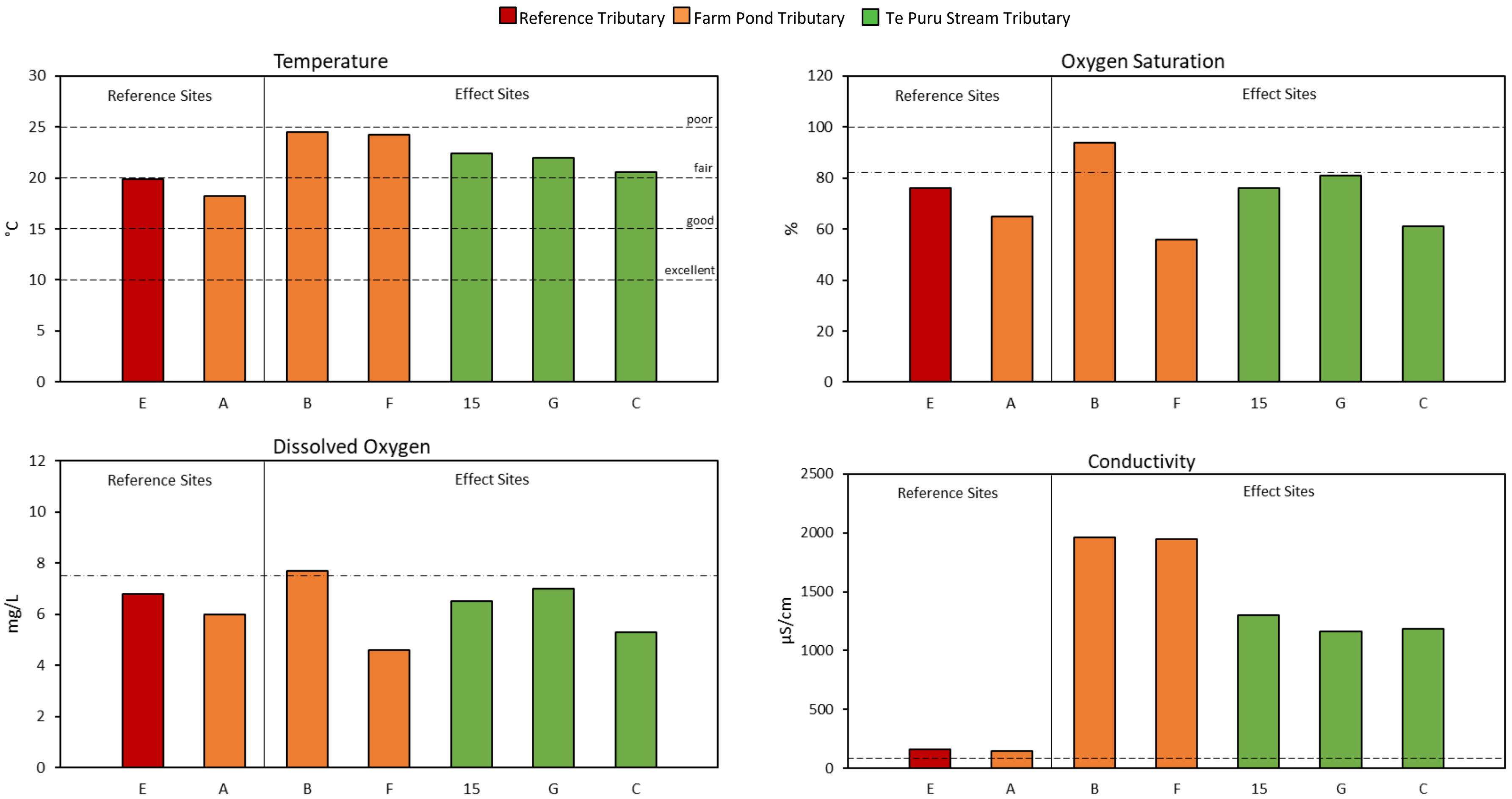

Figure 2. ***Water quality results for temperature, oxygen saturation, dissolved oxygen and conductivity for the Te Puru Stream tributaries. Dashed lines represent upper guideline values and dot-dashed lines represent lower guideline values.***

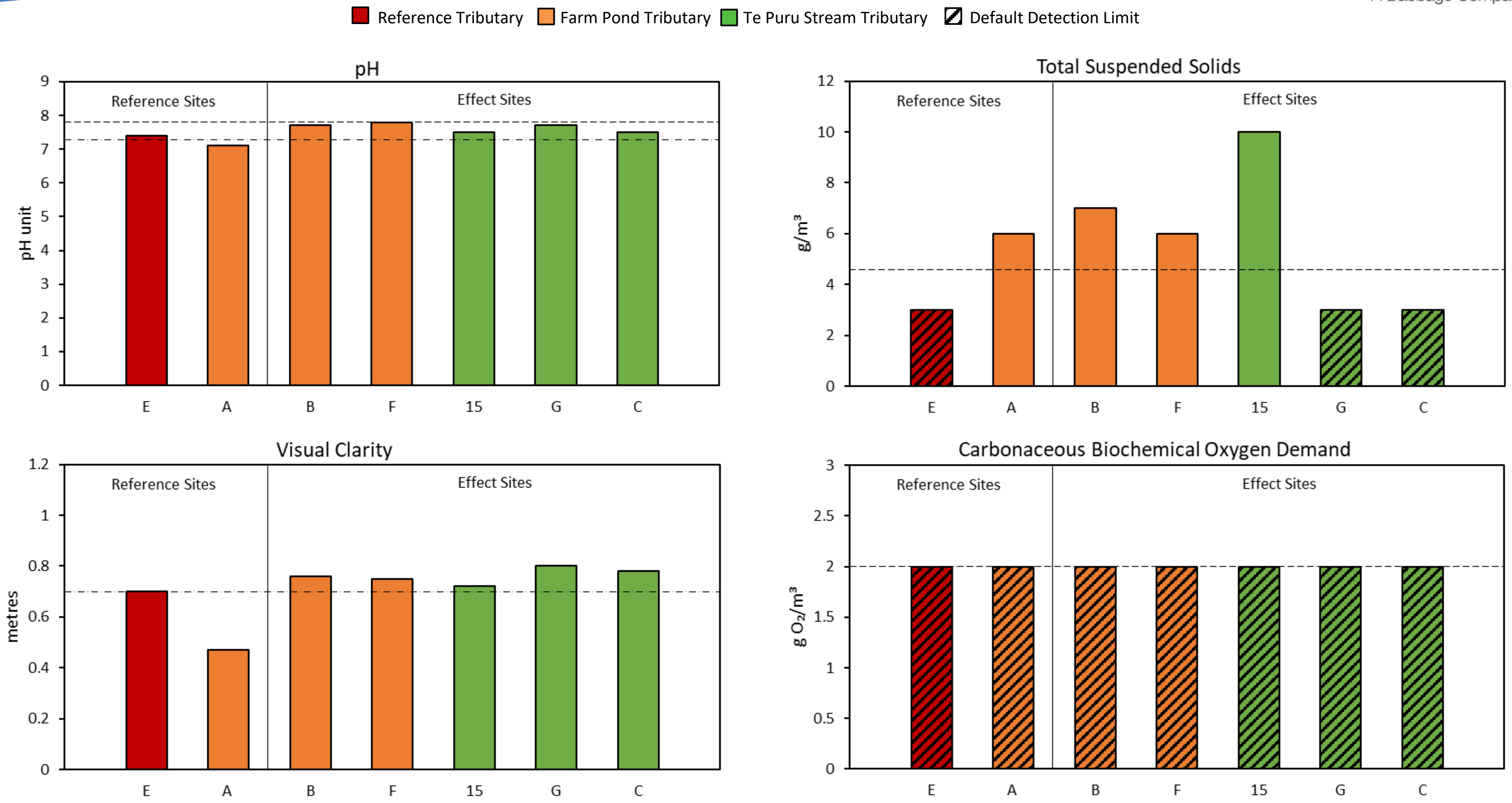

Figure 3. ***Water quality results for pH, total suspended solids, visual clarity and carbonaceous biochemical oxygen demand for the Te Puru Stream tributaries. Dashed lines represent upper guideline values and dot-dashed lines represent lower guideline values. Hashed fill represents values below the detection limit[2].***

[2] A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes.

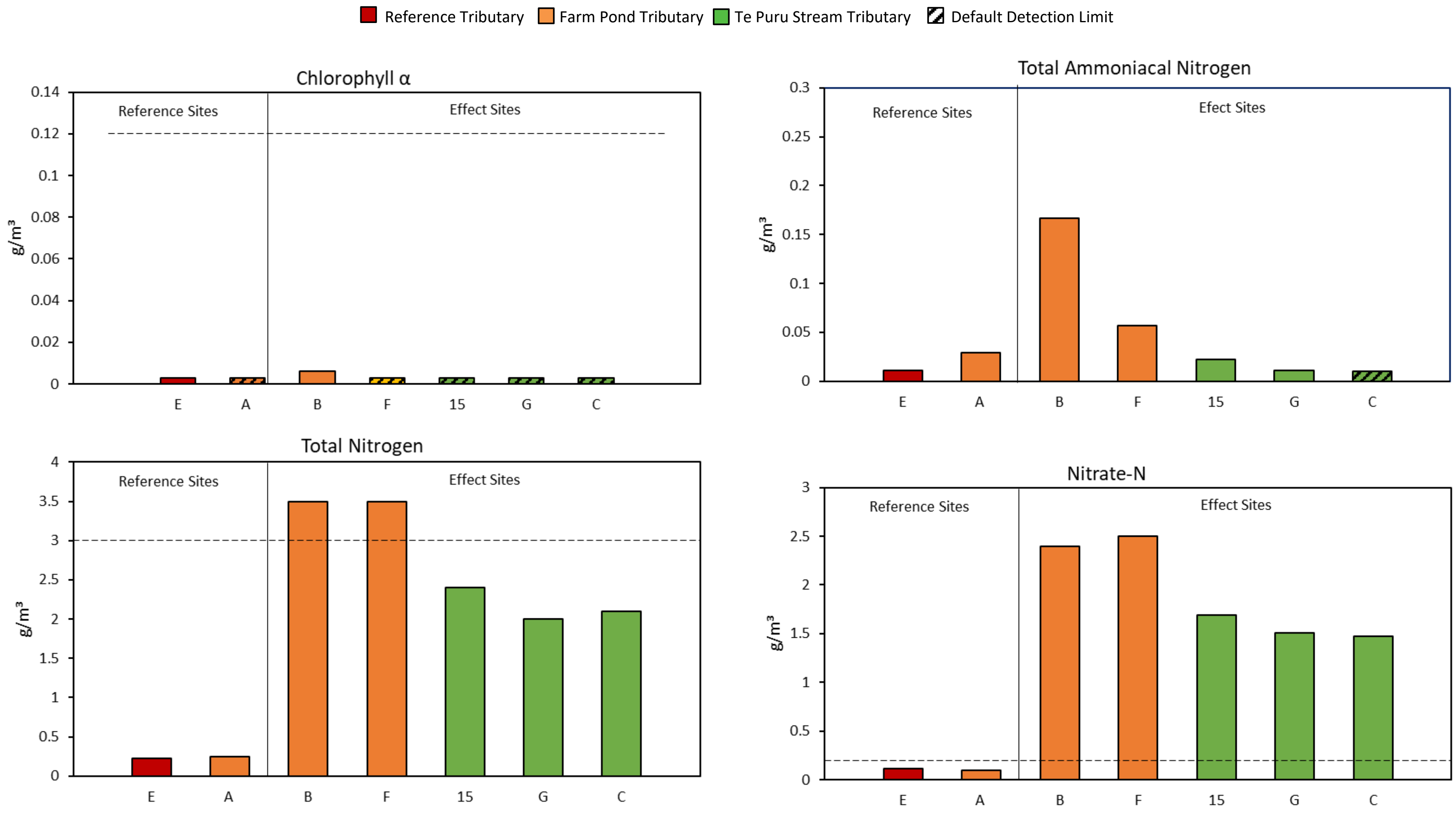

Figure 4. ***Water quality results for chlorophyll α, total ammoniacal nitrogen, total nitrogen and nitrate nitrogen for the Te Puru Stream tributaries. Dashed lines represent upper guideline values. Note that the guideline value of Total Ammoniacal Nitrogen is set at 3 g/m3, which far exceeds the measured concentrations, and thus also the scale of the graph.***

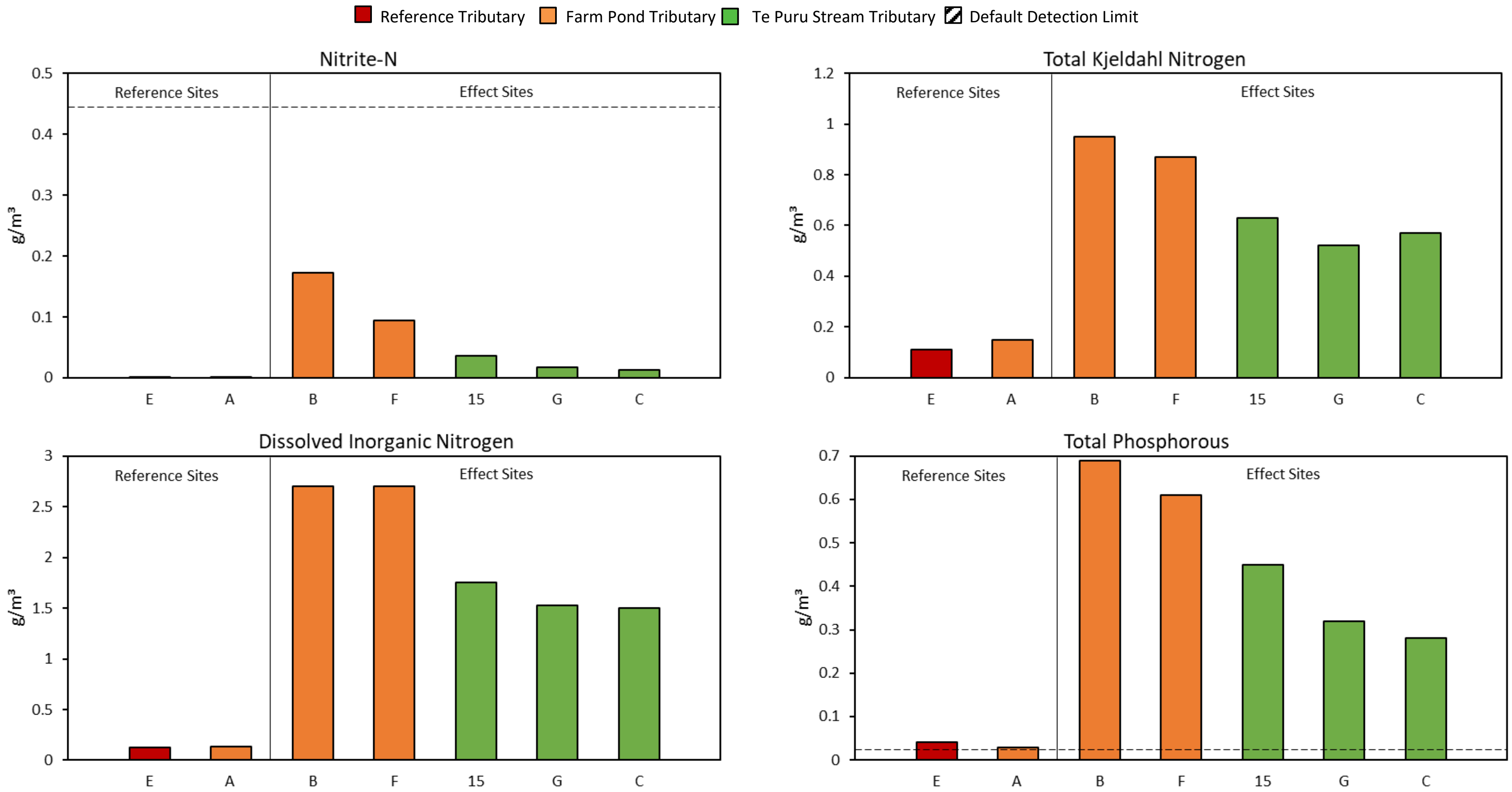

Figure 5. ***Water quality results for nitrite nitrogen, total Kjeldahl nitrogen, dissolved inorganic nitrogen and total phosphorus for the Te Puru Stream tributaries. Dashed lines represent upper guideline values. Note that Total Kjeldahl Nitrogen and Dissolved Inorganic Nitrogen does not have set guideline values.***

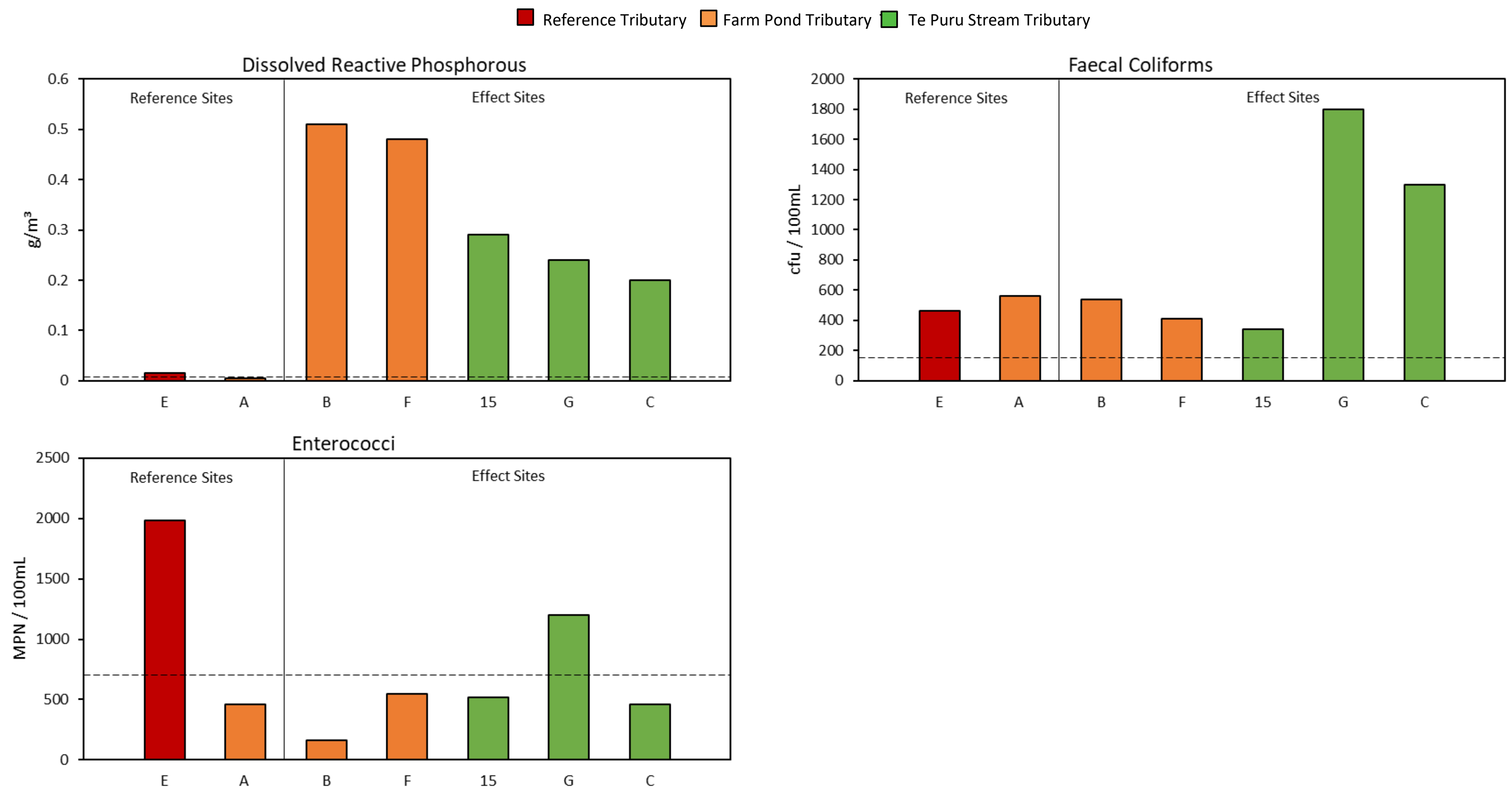

Figure 6. ***Water quality results for dissolved reactive phosphorus, faecal coliforms and enterococci for the Te Puru Stream tributaries. Dashed lines represent upper guideline values.***

3.2.1 Temperature

Elevated water temperatures can adversely affect the physiological processes of aquatic fauna, particularly more sensitive species. Water temperatures are heavily influenced by the shading provided by riparian vegetation both at the site and more importantly the catchment upstream of the site.

The temperature ranged between 18.2 °C (Site A) and 24.5 °C (Site B). The lowest temperatures were recorded at sites upstream of the farm pond, peaking immediately downstream of it, and gradually decreasing further downstream (Figure 2). The higher temperature recorded at Site B, the discharge point from the farm pond, was not unexpected during summer as the pond is very large and mostly unshaded, and ponds such as this develop thermoclines in summer with a layer of much warmer surface water overlying the deeper cooler water. This would have influenced the temperature of the impact sites, particularly the upper impact sites. Although all effect sites exhibited higher water temperatures compared to the reference sites, Site C, the downstream impact site was very similar to the upstream reference site, both near 20 °C

Temperature guideline ranges from Biggs *et al.* (2002) indicate that the reference sites (Sites E and A) registered temperatures indicative of 'good' stream health (ranging from 15 °C to 19.9 °C), although reaching a level where temperatures begin to stress some invertebrates (e.g., stoneflies). In contrast, all effect sites recorded temperatures above 20 °C, falling within the range indicative of 'fair' stream health (20°C to 24.9°C).

3.2.2 Dissolved Oxygen

Dissolved oxygen is required by aquatic fauna for respiration. Low dissolved oxygen can be a stressor, providing insufficient oxygen to maintain stream health, however high levels of dissolved oxygen can also indicate excess plant/algal growth, which can lead to super-saturation with associated lethal and sub-lethal effects on fish.

Both dissolved oxygen saturation (%) and concentration (mg/L) were measured at all water quality sites (Figure 2). No clear trend was observed in dissolved oxygen saturation, with the lowest and highest values recorded at effect sites, ranging between 56 % (Site F) and 94 % (Site B).

According to ANZG (2018) guidelines, most sites (A, C, E, F, G, and 15) had oxygen saturation levels below the DGV range (82%), with only Site B falling within this range. Site G, with an oxygen saturation of 81%, was just below the DGV range. Dissolved oxygen concentrations at Sites B and G were classified under Attribute State B (≥7 and <8 mg/L), while all other sites fell under prescribed Attribute State C (≥5 and <7 mg/L), yet all remained above the National bottom line (MfE, 2020).

Dissolved oxygen concentrations mirrored the general pattern observed in oxygen saturation, with the lowest concentration recorded at Site F, where the water was barely flowing (averaging 0.02 m/s i.e. 50 seconds to travel a metre), and the highest at Site B, where the water was flowing much faster (averaging 0.24 m/s i.e. 4 seconds to travel a metre) as it exited the pond.

3.2.3 Conductivity

Conductivity is a measure of the free ions in the water and indicates the amount of mineral salts in the water, which is often an indicator of the presence of dissolved nutrients, salt water or pollution. There was a very large difference in conductivity between reference and effect sites, with a notable increase immediately downstream of the discharge point, followed by a decline at sites further downstream (Figure 2). Even at the most downstream effect site (Site C), conductivity remained approximately eight times higher than that of any reference site. Site A exhibited the lowest conductivity at 149.8 µS/cm, while Site B recorded the highest at 1964 µS/cm.

All sites had conductivity measurements higher than the ANZG (2018) guideline value of 86 µS/cm, indicating the conductivity at all sites could have potential adverse effects. Reference site A's conductivity reading hovered at the borderline of the 'good' range (Biggs *et al.,* 2002), which extends from 50 to 149 µS/cm. Reference site E's conductivity fell within the 'fair' range (Biggs et al., 2002), indicating slightly enriched water. Conversely, all effect sites fell within the 'poor' range (Biggs *et al.,* 2002), suggesting either highly enriched waters or other contaminants (e.g. dissolved salts).

3.2.4 pH

pH is a measure of the acidity or alkalinity of water (and hence the strength of acid present), with neutral pH at 7. With increasingly acid waters, numbers of species and individuals of aquatic organisms decrease (Biggs *et al.,* 2002).

At the sampling sites, pH levels ranged from 7.1 (Site A) to 7.8 (Site F), with Sites A and E (reference sites) exhibiting the lowest pH readings, while all other effect sites ranged between 7.5 to 7.8. The majority of pH values fell within the guideline range (Figure 3), except for Site A, which marginally fell outside the lower guideline range. The pH level recorded at Site F (7.8) reached the upper limit of the guideline value. Deviations from the recommended pH range can result in negative consequences, affecting the health and functioning of the freshwater ecosystem, but the pH of all the Te Puru tributary sites were circum-neutral and well within the range of pH usual in New Zealand streams (6.5 -8.0, LAWA, 2024).

3.2.5 Total Suspended Solids

Total Suspended Solids (TSS) are particles less than 2 microns found in the water sample and includes anything drifting in the water from sediment/silt to planktonic algae. TSS was below the detectable limit at Site E, G and C (< 3g/m^3). TSS were highest at effect Site 15. In comparing the two reference sites, TSS levels were twice as high at Site A compared to Site E. TSS increased slightly at effect Site B (immediately after the farm pond), but subsequently decreased at the following site (Site F), reaching levels similar to those at Site A. Downstream of Effect Sites B and F, Site 15 showed an increase in TSS, which indicated a source of TSS downstream of Site F. Following the elevated TSS levels at Site 15, concentrations dropped to below detectable values at the most downstream effect sites (Sites G and C). High suspended solids can result in adverse effects on habitats through smothering and abrasion. With the exception of Sites E, G, and C (below the detectable level), all sites had TSS levels exceeding the ANZG (2018) guideline value of 4.6 g/m^3.

3.2.6 Visual Clarity

Water clarity refers to the degree of transparency or how clear the water appears, indicating how far light can penetrate through it. It is often inversely related to Total Suspended Solids (TSS), with low clarity typically associated with high TSS levels. Clarity can be indicative of potential adverse effects, particularly at low values.

Visual clarity was found to be lowest at the reference sites, particularly at Site A, whereas all effect sites exhibited higher clarity than the reference sites. At reference Site E, visual clarity was relatively high, attributed to relatively low TSS measures, in contrast to the high TSS measures at Site A, which corresponded to lower visual clarity. Interestingly, Site 15 displayed similar visual clarity to other effect sites despite having the highest measured TSS of all the sites.

The reference sites (Sites A and E) had clarity lower than the guideline value of 0.7 m (ANZG 2018), with all the effects sites having clarity above the guideline value.

3.2.7 Carbonaceous Biochemical Oxygen Demand

Carbonaceous biochemical oxygen demand ($cBOD_5$) measures the amount of oxygen consumed by microorganisms in decomposing organic matter in stream water. All values for $cBOD_5$ were below the detectable limit of 2 g O_2/m^3. This limit is also the guideline value (Quinn 2009), therefore no sites had $cBOD_5$ that would be indicative of adverse effects.

3.2.8 Chlorophyll α

Chlorophyll α serves as an indicator of the total algae present in water. The highest concentration of chlorophyll α was recorded at Site B, directly below the farm pond, at 0.006 g/m^3, with levels decreasing downstream of Site B to undetectable levels. Measurements of chlorophyll α at all other sites remained below the detectable limit. Importantly, all measurements, including those at Site B, were below the guideline value that could potentially harm freshwater ecosystems (MfE 2020).

3.2.9 Total Ammoniacal Nitrogen

In aqueous solutions, ammonia primarily exists in two forms, un-ionized ammonia (NH_3) and ammonium ion (NH_4^+), which are in equilibrium with each other. The un-ionized ammonia fraction is significantly more toxic than the ammonium ion, although under certain conditions, the ammonium ion can also contribute significantly to ammonia toxicity. The proportions of these fractions vary notably with temperature and pH.

When comparing the concentrations of ammoniacal nitrogen (total ammonia - NH_4-N) between the two reference sites, Site A exhibited a higher concentration (0.029 g/m^3) compared to Site E (0.011 g/m^3). Concentrations of ammoniacal nitrogen increased immediately downstream of the farm pond (Site B: 0.167 g/m^3), but subsequently, progressively decreased downstream, reaching a minimum of <0.010 g/m^3 at the most downstream site (Site C), falling below the detection limit (Figure 4).

As reported previously (Bioresearches 2010, 2016, 2019 and 2022), Hickey (2001) used the ANZECC (2000) and USEPA (1999) derivation procedures to derive ammonia toxicity guidelines specific to the Te Puru Stream Tributary. Acute values were based on USEPA (1999) and adjusted for New Zealand species present. An acute guideline of 3.0 g/m^3 NH_4-N or higher was derived for these sites based on the highest pH recorded during a previous study (pH 8.1 at Site B, Hickey 2001). A chronic guideline of 2.46 g/m^3 NH_4-N was derived by Hickey (2001) for banded kōkopu, the most sensitive fish species recorded in the Te Puru Stream. All of the sites surveyed recorded ammoniacal nitrogen below both these acute and chronic guidelines.

3.2.10 Total Nitrogen

The total nitrogen in water is composed of total Kjeldahl nitrogen, nitrate and nitrite. The concentration of Total Nitrogen (Total-N) was lowest at the two reference sites (Site E: 0.23 g/m^3 and Site A: 0.25 g/m^3). Concentrations substantially increased at the sites immediately below the farm pond, with the highest Total Nitrogen concentration observed at Site B and F (both at 3.5 g/m^3), before decreasing with distance from the discharge (Figure 4). The total nitrogen levels at Sites B and F exceeds the guideline value for the Te Puru Stream Tributary developed by NIWA (Hickey, 2001).

3.2.11 Nitrate-Nitrogen

Nitrate, primarily derived from nitrogen-fixing plants or through the complete oxidation of ammonium ions, represents the most common form of nitrogen in water. Nitrate nitrogen (Nitrate-N), a constituent of total nitrogen, exhibited a pattern similar to Total-N, with lowest concentrations observed at the reference sites (Site E: 0.12 g/m^3 and Site A: 0.1 g/m^3). Subsequently, concentrations increased substantially below the pond, reaching maximum values of 2.4 g/m^3 and 2.5 g/m^3 at Site B and F, respectively, before decreasing at sites further away from the farm pond (Figure 4). Notably, all effect sites (Sites B, F, 15, G, and C) exceeded the ANZG (2018) guideline of 0.195 g/m^3 for nitrate concentration.

3.2.12 Nitrite-Nitrogen

Nitrite, as the intermediate product of the nitrification process (the complete oxidation of ammonium ions to nitrate), constitutes Nitrite-N. Concentrations of Nitrite-N were consistently low across all sites, mirroring the patterns observed for Nitrate-N and Total-N. The lowest Nitrite-N concentrations were recorded at the reference sites, with increases noted at sites immediately below the farm pond. Concentrations decreased progressively as samples were taken further downstream from the discharge (Figure 5). Nitrite-N ranged between < 0.002 g/m^3 (Site A) to 0.173 g/m^3 (Site B). All Nitrite-N samples were below the ANZECC (2000) guideline value of 0.444 g/m^3.

3.2.13 Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) consists of both organic nitrogen and ammonia. The concentrations of TKN exhibited a similar overall pattern as total nitrogen and nitrate nitrogen, with typically low levels observed at both of the reference sites (Sites E and A). Concentrations increased immediately downstream of the farm pond (Site B) and subsequently decreased with increasing distance downstream (Figure 5). There are no specific guidelines for concentrations of TKN.

3.2.14 Dissolved Inorganic Nitrogen

Both nitrate and ammonia are considered biologically available to plants, comprising the dissolved inorganic nitrogen (DIN) content of freshwaters. Dissolved inorganic nitrogen (DIN), including ammonia and nitrate, is a crucial nutrient that fosters periphyton growth.

DIN concentrations ranged from 0.128 g/m^3 at Site E upstream of the farm pond to 2.7 g/m^3 downstream of the pond (both at Site B and F), subsequently decreasing with distance downstream to 1.5 g/m^3 at the lowest site, Site C. There are no specific guidelines for concentrations of DIN.

3.2.15 Total Phosphorus

Total phosphorus is a measure of all types of phosphorus present and includes the phosphate bound to sediment as well as dissolved reactive phosphorus. Phosphorus, being a key element necessary for plant growth, often acts as a growth-limiting nutrient. Excessive levels of phosphorus can stimulate excessive or nuisance growths of algae and other aquatic plants. Total phosphorus includes all forms of phosphorus likely to become available to support plant growth.

The general trend of Total-P concentrations followed a similar pattern to other stressors such as nitrogen, with both reference sites exhibiting lower concentrations (Site E: 0.04 g/m^3 and Site A: 0.029 g/m^3) compared to the effect sites. Total-P peaked at Site B (0.69 g/m^3) and decreased as sites moved further downstream from the discharge. However, Total-P at Site C, the effect site furthest from the discharge, remained seven to nine times higher than concentrations recorded at reference sites (Figure 5). Total-P at all sites exceed the guideline value (0.023 g/m^3), and all effects sites concentrations exceed the NPS-FM attribute D (i.e. > 0.05 g/m^3 as the national bottom line).

3.2.16 Dissolved Reactive Phosphorous

Dissolved reactive phosphorus (DRP) represents the form of phosphorus most readily available to plants. At the reference sites (Site E: 0.015 g/m^3 and Site A: 0.005 g/m^3), DRP concentrations were observed to be lowest. Concentrations exhibited a substantial increase at the Effect Sites, reaching 0.51 g/m^3 at Site B and 0.48 g/m^3 at Site F, before decreasing with increasing distance downstream. These higher values were more than 34 times higher than the DRP concentrations observed at the reference sites (Figure 6).

As sampling progressed downstream from Site F, DRP concentrations decreased, albeit remaining approximately 13 times higher than those recorded at the reference sites. The guideline value (0.007 g/m^3) from the ANZG (2018) was exceeded by all sites, with the exception of Site A, and all effects sites concentrations exceed the NPS-FM attribute D (i.e. > 0.018 as a median).

3.2.17 Faecal Coliforms

Faecal coliforms represent a defined bacterial group present in the faecal material of humans, livestock, and wildlife. Escherichia coli, the most common bacteria in this group, is consistently and exclusively associated with the faecal waste of warm-blooded animals.

Bacteria forming faecal coliforms were found to be abundant at all sites, without displaying a clear trend between either reference/effect sites or distance from the discharge (Figure 6). The concentration of faecal coliforms varied from 340 cfu/100mL at Site 15 to 1,800 cfu/100mL at Site G. Notably, Site A, a reference site, recorded the third-highest result with 560 cfu/100mL, only slightly higher than the immediately downstream effect site (Site B: 540 cfu/100mL). As the Te Puru Stream Tributary is actively farmed and stock were present, it is highly likely the suddenly elevated concentrations of faecal coliforms at the downstream sites resulted from livestock. The ANZECC (2000) guideline value for faecal coliforms of 150 cfu/100mL was exceeded at all sites that were sampled.

Note: These results should be interpreted with caution as samples were > 10 °C on receipt at the lab, which may result elevated levels of faecal coliforms.

3.2.18 Enterococci

Enterococci are also indicators of the presence of faecal material in water, and are used as an indicator of the possible presence of other bacteria and viruses that have the potential to cause disease or illness. Surveys at marine and freshwater bathing sites indicated that swimming related gastroenteritis is related directly to the quality of bathing water and that enterococci are the most efficient indicator of bathing water quality.

The number of enterococci varied between the two reference sites, with the highest count of 1986 MPN/100ml recorded at reference site E and reference site A recorded 461 MPN/100ml (Figure 6). The most upstream effect site, Site B, immediately downstream of the farm pond, recorded the lowest count of all the sites, 166 MPN/100mL. This then increased to 549 MPN/100mL and 517 MPN/100mL at the subsequent two downstream sites (Site F and G, respectively). Enterococci counts spiked at Site G (1203 MPN/100mL), followed by a decrease at Site C to 461 MPN/100mL.

The low concentrations of enterococci at the most upstream Effect Site, and the elevated concentrations at one of the Reference Sites and Effect Sites downstream in the catchment indicate that there are various sources of enterococci.

The ANZECC (2000) guideline values associated with enterococci are also related to primary and secondary contact recreation. These guideline values are based on a median value, but state that there should be a maximum of 60-100 organisms/100ml in any one sample for primary contact (i.e. full body immersion activities such as swimming) and 450-700 organisms/100ml in any one sample for secondary contact (i.e. activities where only limbs are in contact with water such as wading). All sites exceeded the upper primary guideline value of 100 MPN/100ml, with only reference site E and effect site G exceeding the secondary contact guideline value of 700 MPN/100mL. It's important to note that the Te Puru Stream tributaries are unlikely to be used for either primary or secondary contact recreation.

Note: these results should be interpreted with caution as samples were > 10 °C on receipt at the lab, which may result elevated levels of enterococci.

3.3 Sediment Quality

Sediment quality results are presented in Table 6 and Figure 7 and Figure 8. Components of sediment quality were tested at one reference site (Site E) and three effect sites (Sites F, G and C).

Sediment characteristics such as organic matter and relevant carbon/nutrient compositions can give an indication as to the sources of organic matter input the stream receives. Factors such as carbon and nitrogen can affect the primary production and eutrophication status of aquatic ecosystems.

Table 6. Sediment quality results summary for the Te Puru Stream tributaries. Site E is a reference site and sites F, G and C are effect sites.

	Reference Tributary	Farm Pond Tributary	Te Puru Stream Tributary	
	E	F	G	C
Dry Matter (% of sample)	46	37	43	54
Total Carbon (g/100g dry weight)	2.2	3.9	2.9	1.62
Total Nitrogen (g/100g dry weight)	0.12	0.26	0.2	0.12
C : N ratio	18	15	15	14
Ammonium-N (mg/kg dry weight)	24	148	11	18
Total Recoverable Phosphorous (mg/kg dry weight)	380	2,000	1,210	800

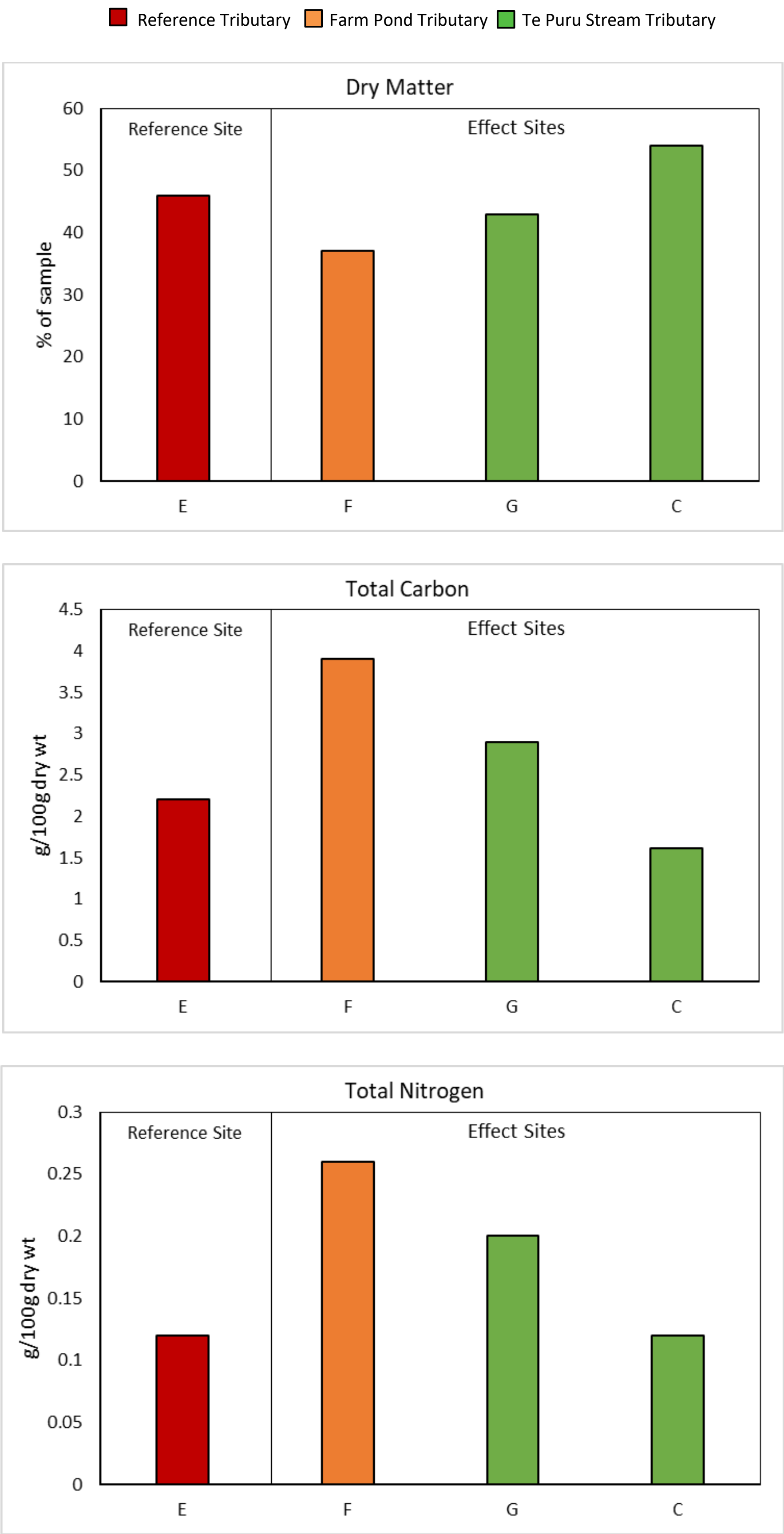

Figure 7. Sediment quality results for dry matter, total carbon and total nitrogen.

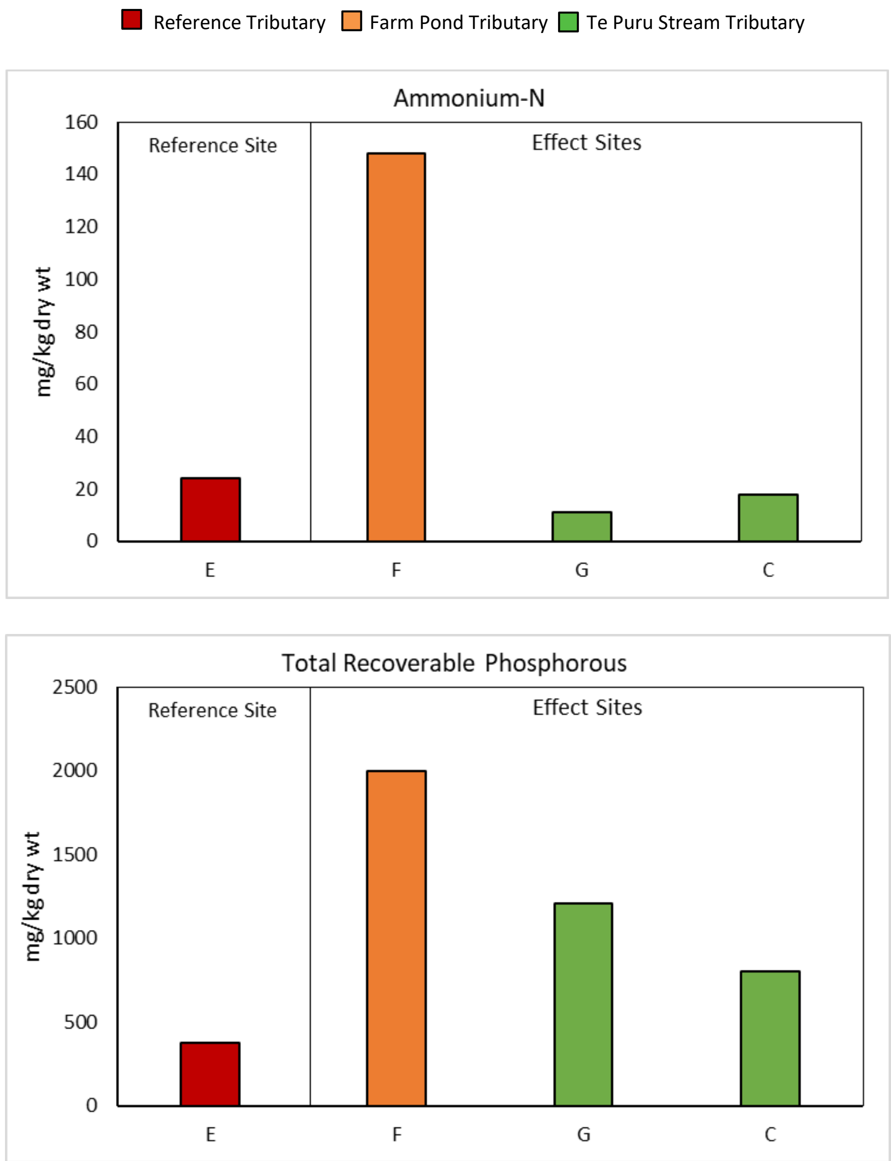

Figure 8. Sediment quality results for Ammonium – N and total recoverable phosphorous.

3.3.1 Dry Matter

The highest percentage of dry matter (organic matter) was found at the most downstream site (Site C: 54 %) and the most upstream site (Site E: 46 %). Site F, downstream of the discharge, had the lowest percentage of dry matter (37 %).

3.3.2 Total Carbon and Total Nitrogen

Both total carbon and total nitrogen showed very similar patterns, elevated downstream of the farm pond (Site F) compared to the reference site (Site E), decreasing at Site G, and even more so at the most downstream Site C. Both total carbon and total nitrogen decreased with distance downstream, within concentrations at the most downstream effects site (Site C), similar or lower than the reference site.

3.3.3 Carbon to Nitrogen Ratio

The carbon-to-nitrogen ratio was highest at reference Site E (18), followed by a ratio of 15 at both downstream effect Sites F and G. Downstream effect Site C had the lowest ratio (14).

3.3.4 Ammonium - Nitrogen

Ammonium nitrogen was highest at the most upstream effect site (Site F: 148 mg/kg dry weight), with substantially lower concentrations noted at all other sites. Reference Site E (24 mg/kg dry weight) measured higher concentrations of ammonium nitrogen than Sites G and C (11 mg/kg dry weight and 18 mg/kg dry weight, respectively) further downstream of the discharge.

3.3.5 Total Recoverable Phosphorous

Total Recoverable Phosphorus was lowest at the reference site (Site E: 380 mg/kg dry weight) and then increased substantially downstream of the discharge (Site F: 2000 mg/kg dry weight). Total Recoverable Phosphorus then showed decreasing concentrations with distance downstream.

3.4 Biological Survey

3.4.1 Macroinvertebrates

Macroinvertebrate results are presented in
Table 4 and Figure 9 and Figure 10.

Macroinvertebrate diversity, represented by the number of taxa present, showed considerable variability. The highest number of taxa was recorded at the headwaters of the tributaries above the WTP, with 21 taxa at Site A and 22 taxa at Site E. In contrast, the lowest number of taxa was observed at the site below the discharge pond (Site F), with only 3 taxa. Taxa numbers increased downstream in the Te Puru Stream tributary, reaching 12 taxa at both Site G and Site C.

With the exception of reference Site A and effect Site C, macroinvertebrates were dominated by the freshwater snail (*Potamopyrgus antipodarum*) This species constituted 28 % of individuals at Site H, 37 % at Site E, 98 % at Site F, and 59 % at Site G. Sites A and C were dominated by the freshwater amphipod (*Paracalliope fluviatilis*), comprising 63 % and 80 % of the individuals, respectively.

The lowest assessed site, Site C, had the most variability in abundance (1534 individuals), which was made of 80 % freshwater amphipod, followed by freshwater snail (17 %). The lowest abundance was noted at Site E.

The more sensitive EPT taxa were present in the headwaters of the tributaries, Sites A and E, comprising 21.9 % and 30.2 % of individuals respectively. No EPT taxa were noted at Site F (effect site downstream of the farm pond). The %EPT was negligible (0 or near 0) at effect Sites G and C further below the farm pond.

MCI scores ranged from 101 at Site H to 105 at Site A, indicating 'Good' quality habitat at both sites (Stark & Maxted, 2007b). Site E, on the reference tributary, had an MCI score of 98, reflecting 'Fair' quality habitat. The MCI score dropped to 63 at effect site F ('Poor' habitat quality), increased at Site

G (82, 'Fair' habitat quality), before dropping again to 67 ('Poor' habitat quality) at Site C. The low score on the reference tributary may have been influenced by low water levels and potentially a lack of aquatic habitat during the driest summer months. Only the MCI scores of the reference sites are above the AUP guideline value (94).

The Scores Quality Macroinvertebrate Community Index (SQMCI), which considers the relative abundance of taxa as well as the MCI score, was highest at the two headwater reference sites (Site A and Site H), recorded at 6.01 and 4.78, respectively. Site A fell within the 'Excellent' habitat quality band, while Site H fell within the 'Fair' habitat quality band. The SQMCI score at Reference Site E indicated 'Fair' habitat quality. Effect Site F, the first effect site below the farm pond, had the lowest SQMCI score, falling in the 'Poor' habitat quality band. However, SQMCI scores showed some improvement downstream, reaching 'Fair' habitat quality.

The presence of large macroinvertebrates, kōura (freshwater crayfish) and kākahi (freshwater mussels) were recorded. Kōura were recorded as present at reference Sites A, H and E, plus effect site C, and are therefore likely to be present in low numbers through the entire tributary. No live kākahi were recorded but shells were observed at Sites H and E (Photo 11 and Photo 12).

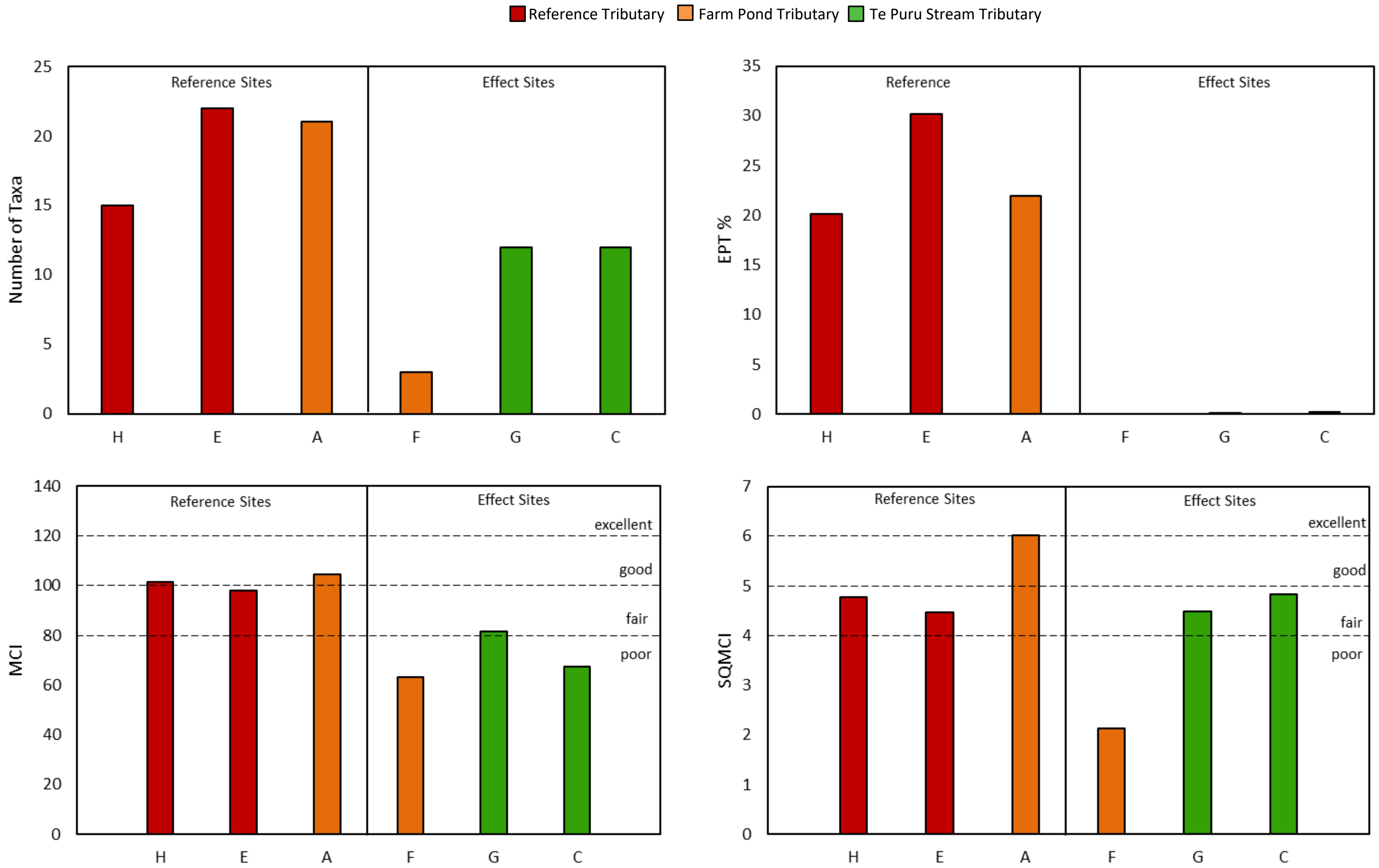

Figure 9. Macroinvertebrate community results – number of taxa, EPT%, MCI and SQMCI.

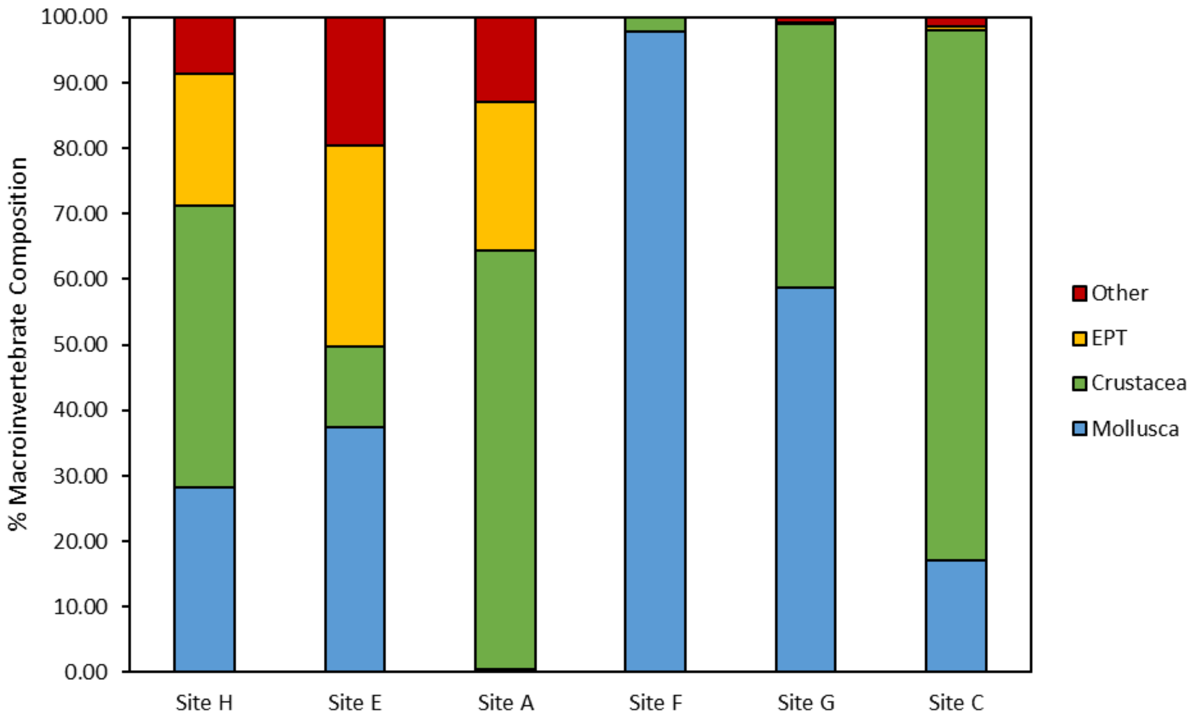

Figure 10. The percent composition of macroinvertebrate taxa at each Te Puru site.

3.4.2 Freshwater Fish

Fish species were sampled using electric fishing and gee minnow traps at the three reference sites (Sites H, E and A). Native fish species biodiversity and abundance was highest at Site H, with four species recorded and 36 individuals captured. At Sites E and A, three and four native species, respectively, were recorded. Reference site fish abundance was lowest at Site E, with 19 individuals caught. Native fish species recorded at the three reference sites included an unidentified eel species (*Anguilla spp.*), and three species listed as 'Not Threatened' - banded kōkopu (*Galaxias fasciatus*), common bully (*Gobiomorphus cotidianus*) and Cran's bully (*G. basalis*) (Dunn *et al*. 2017).

Electric fishing could not be undertaken downstream of the farm pond due to the very high electrical conductivity in the water, therefore only Gee's minnow traps and a hand net were used to sample native fish communities at Sites F, G and C. Both native fish species biodiversity and abundance decreased at the effect Sites C and F compared to the reference sites, with only common bully and eels (longfin eel and an unidentified eel at Site C; unidentified eel at Site F) caught. Site G, however, had a high abundance of common bully (21 individuals). Introduced 'mosquito fish' *Gambusia affinis* was also identified at Sites C and G.

The Fish IBI score for the upper Reference Tributary (Site H) was 34, indicative of 'Fair' species diversity in comparison to other Auckland streams, given the altitude and distance from the sea (Joy and Henderson 2004). Reference Sites IBI scores A and E were 34 and 26, respectively, indicative of 'Fair' and 'Poor' species diversity in comparison to other Auckland streams. The downstream sites are indicative of 'Poor' species diversity, and Site F specifically of 'Very Poor' species diversity.

To put the fish survey results into context of the wider catchment, a search of fish records from the New Zealand Freshwater Fish Database for the Te Puru Stream catchment was carried out, with the data collected between 1991 and 2022 (Table 7). Seven native and one introduced fish species (*Gambusia affinis*) have been recorded around the wider Te Puru Stream catchment, with the shortfin eel and common bully being the most commonly recorded species. Freshwater mussel and kōura were also recorded within the catchment. No additional species were recorded in the 2024 study. Based on these records, Cran's bully was last recorded in 1991, which was recorded at Site H in 2024.

Table 7. Fish previously recorded in the Te Puru Stream catchment, from the New Zealand Freshwater Fish Database (NIWA, sourced February 2024).

Genus	Scientific name	Common name	Number of Records	Year sampled*:
Galaxias	*fasciatus*	Banded kokopu	38	1997, 1998, 2001, 2002, 2005, 2010, 2016, 2022
Galaxias	*maculatus*	īnanga	4	2001, 2005
Gobiomorphus	*cotidianus*	Common bully	45	1991, 1997, 1998, 1999, 2001, 2002, 2005, 2010, 2016, 2019, 2022
Gobiomorphus	*basalis*	Crans bully	1	1991
Gobiomorphus	*huttoni*	Redfin bully	6	1998, 2005, 2016, 2019
Anguilla	*unidentified*	unidentified eel	17	19971999, 2002, 2005, 2010, 2022
Anguilla	*australis*	shortfin eel	43	1991, 1997, 1998, 1999, 2002, 2005, 2010, 2019, 2022
Anguilla	*dieffenbachii*	longfin eel	18	1991, 1997, 1998, 1999, 2002, 2005, 2010, 2016, 2022
Echydridella	*spp.*	freshwater mussel	5	2005, 2016
Paranephrops	*spp.*	kōura	30	1997, 1998, 1999, 2002, 2005, 2010, 2016, 2022
Paratya	*curvirostris*	Freshwater Shrimp	11	1991, 2002, 2005, 2016

*This column provides the listed years in which the corosponding species were sampled based on the recorded data available from NIWA. Those higlighted in red, have not since the listed date been recorded.

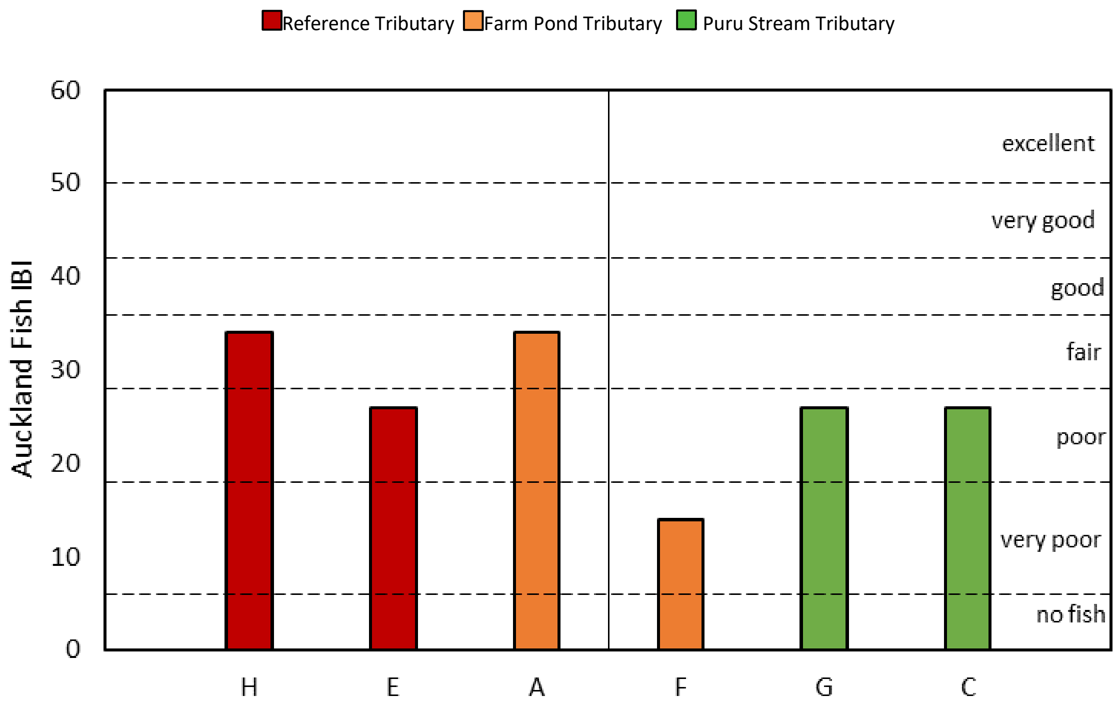

Figure 11. Auckland Fish IBI scores for sites on the Te Puru Stream Tributaries.

Photo 11. Freshwater mussel shells at Site E.

Photo 12. Kōura caught at Site A.

Photo 13. Banded kōkopu.

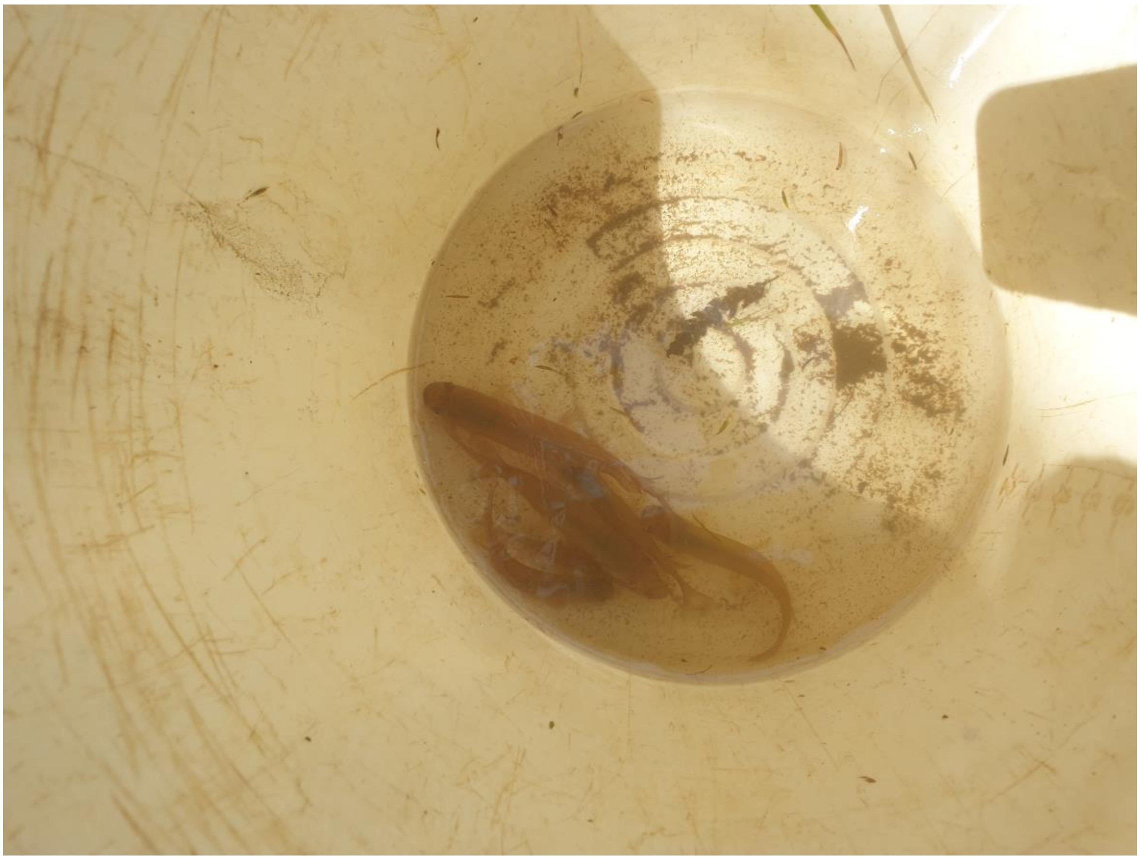

Photo 14. Native fish abundance and diversity was highest at Site A.

3.4.3 Macrophytes

Macrophyte diversity generally increased with distance downstream. Reference sites (Sites H and A) displayed the lowest diversity, ranging between zero and two species, while the highest diversity (seven species) was documented at Site G. Notably, Site F, situated downstream of the discharge point, also recorded seven species.

Among the macrophyte species surveyed, willow weed (*Persicaria* sp.) was the most prevalent, identified at six out of the eight sites, followed by water forget-me-not (*Myosotis laxa*) found at five sites, and watercress (*Nasturtium officinale*) and water celery (*Apium nodiflorum*), each present at four sites. Green and brown filamentous algae was observed at most sites (the exceptions being Site H and Site S3).

Differences in macrophyte/algae community composition were observed between reference and effect sites. For instance, Nitella was absent at Sites H and A (reference sites), whereas it constituted a significant proportion of total plant cover at Sites G, S3, and C (ranging from 12 % to 54 %). Filamentous algae were detected at only six sites, with Site F exhibiting the highest coverage at 23 % (Figure 12).

The percentage of macrophyte and algae cover generally increased downstream (Table 8), likely due to the effects sites having less shade. The highest percentage of bare substrate was recorded at Site H (94.9 %), followed by Site A (92.6 %). Notably, three out of the five sites downstream of the farm pond displayed macrophyte and algae cover exceeding 50 %, with Site C showcasing the highest coverage at 72 %. Nitella accounted for the highest percent cover among plant species, followed by filamentous algae (Figure 12).

Table 8. Average percent cover (n=12) and standard error (S.E.) at each site of macrophytes, algae and bare substrate.

Site	Total Macrophytes (%)		Total Algae / Iron Floc (%)		Bare Substrate (%)	
	Mean (n = 12)	S.E.	Mean (n = 12)	S.E.	Mean (n = 12)	S.E.
H	5.10	± 4.99	0.00	± 0.0	94.90	± 4.99
E	0.88	± 0.49	10.50	± 3.23	88.63	± 3.12
A	7.00	± 3.36	0.42	± 0.42	92.58	± 3.42
F	18.45	± 6.75	24.17	± 6.33	57.38	± 10.39
S2	5.00	± 2.38	3.67	± 1.83	91.33	± 2.66
G	23.68	± 6.73	29.08	± 6.8	47.24	± 8.88
S3	5.74	± 2.07	54.92	± 8.41	39.34	± 9.71
C	23.43	± 5.68	48.58	± 771	27.99	± 5.09

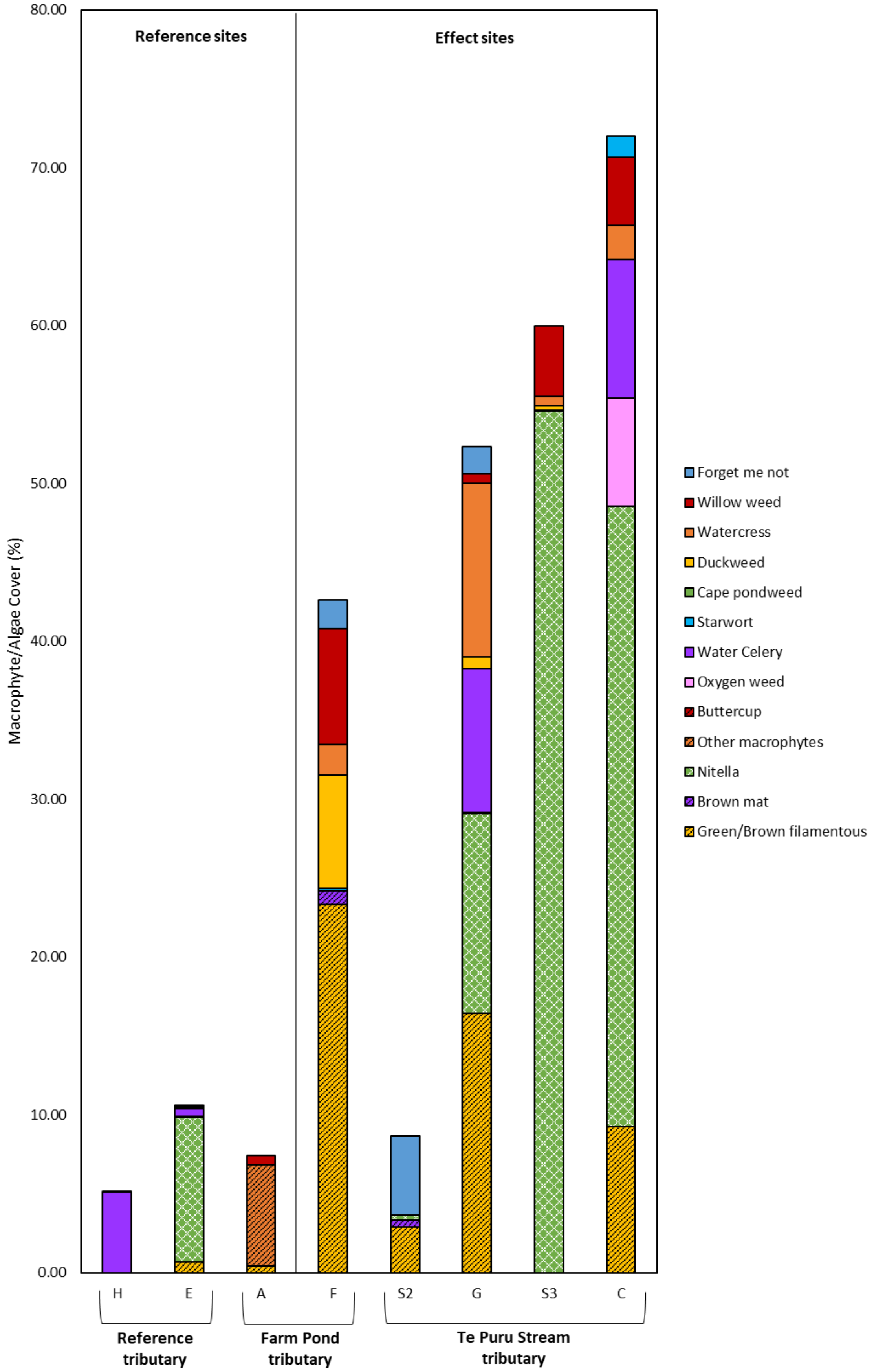

Figure 12. Macrophyte and algae % cover by species for the Te Puru Stream Tributaries

3.5 Comparison with 2022 Survey

The results of the 2024 study at Te Puru were compared to the same study carried out in 2022 (Bioresearches 2022). Results that appeared to deviate substantially from the 2022 survey or results that changed in regard to the current guideline value are summarised below. All 2022 data are visually compared to the 2024 data in Appendix 6.

3.5.1 Water Quality:

- Conductivity at all sites decreased from 2022 to 2024, with a minimum reduction of 17%. Notably, three effect sites (Site 15, G, and C) experienced a significant decrease of almost 50%.
- The TSS measurements in 2024 differed substantially from those in 2022. TSS reduced at both reference sites in 2024 (by 75 % at Site E and 33 % at Site A). Conversely, TSS doubled at effect Site F, increased by more than 60 % at effect Site 15, while decreasing by 13 % at effect Site B and by 40 % at the lowest effect Site C.
- Ammoniacal nitrogen concentrations decreased at all sites between 2022 and 2024, with the most notable reduction of 81 % at effect Site 15.
- Total phosphorus slightly decreased at the reference sites (Site E and A) from 2022 to 2024. However, total phosphorus increased at all effect sites, with a minimum increase of 14% at Site G and a maximum increase of 41 % at Site B.
- Dissolved reactive phosphorus substantially decreased at Site A between 2022 and 2024 (reduced by 62 %), while it reduced by 25 % at Site E. Conversely, dissolved reactive phosphorus increased at all effect sites in 2024 compared to 2022.
- Faecal coliform counts in 2024 were substantially lower compared to 2022 (with a minimum of 54 % reduction), except for Site A, which increased by 14 % in 2024.
- Enterococci counts increased substantially in 2024 (by a minimum of 75 % at Site A) compared to 2022. However, counts reduced at most effect sites in 2024, except for Site G, which experienced a 56 % increase.

3.5.2 Sediment Quality:

- Total carbon at the effect sites decreased, most substantially at the most downstream Site C, being more than two times lower in 2024 compared to 2022. However, total carbon increased at reference Site E in 2024 compared to 2022.
- Total nitrogen at all sites increased in 2024 compared to 2022, although with no substantial concentrations noted.
- The C:N ratio in 2024 differed from that noted in 2022. In 2024, the ratio was higher at the reference Site E but lower at the most upstream effect Site F. The C:N ratio was marginally lower at Site G in 2024 compared to 2022, but the most substantial change was noted at the most downstream effect Site C, where the ratio in 2024 was more than two times lower than that of 2022.
- An overall decrease in ammonium-N was noted in 2024 relative to 2022, except for Site C, which had higher ammonium-N in 2024.
- Total recoverable phosphorus varied at the sites between 2024 and 2022. Reference site E and the most upstream effect Site F had lower total recoverable phosphorus in 2024, but increases

were observed at the downstream effect Sites G and C (Site C had one and a half times more total recoverable phosphorus in 2024 than 2022).

3.5.3 Biological Surveys:

- Changes in macrophyte diversity varied between 2022 and 2024. Diversity at reference Site A decreased from 8 species in 2022 to 3 species in 2024, while it increased at Site H and E in 2024. Diversity also increased at two effect sites (Site G and C) and decreased at Site S2 in 2024 compared to 2022. However, diversity remained the same at Site F and S3 between 2024 and 2022.
- Macrophyte coverage only slightly increased at reference Sites H and E in 2024 but decreased substantially at Site A (by 82 %). Changes in % macrophyte cover at the effect sites were variable, with decreases noted at Sites S2 (70 %) and G (15 %), and increases at Sites F (81 %), S3 (22 %), and C (15 %) in 2024 compared to 2022.
- Fish diversity at reference sites in 2024 did not differ significantly from that noted in 2022 – With the exception of Site A, all other sites had the same diversity in 2024 to that of 2022. In 2024, Site A had 1 one more species in 2024, than that of 2022.
- There is an overall increase in the MCI and SQMCI measured in 2024 relative to that measured in 2022. Sites E and G were promoted to higher MCI quality classes. Sites A and C also moved up into higher SQMCI quality classes in 2024. Site A was reduced to a lower MCI quality class in 2024 but maintained the same SQMCI quality class as in 2022.

4. DISCUSSION

4.1 Summary

A survey of the upper Te Puru Stream catchment was undertaken on behalf of Watercare, as a comparative study of water quality and biological condition upstream and downstream of the Beachlands wastewater treatment plant discharge. This report presents the results of the water quality and biological surveys undertaken at ten sites over the period from the 31st of January to 2nd of February 2024, to determine the effects of the highly treated effluent discharged from the treatment facility on the water quality and biology of the receiving waters, a tributary of the Te Puru Stream.

The overall water quality and biological results indicated poor freshwater condition, partly due to the pastoral land use within the catchment. Appendix 6 provides a summary of historical water quality, sediment quality and macroinvertebrate data for comparison and trend analysis.

There were consistent trends where water quality and biological parameters were typically poorest at sites directly downstream of the discharge pond. However, variability was observed at sites further downstream, with a general trend of improving freshwater quality with distance downstream from the discharge pond across multiple parameters.

4.1.1 Physical characteristics

The diversity of substrate types was highest at reference Site H, with bedrock dominant and cobbles and gravels also common, with some silt loading present. Silt was recorded at effect sites downstream of the discharge pond, with an increase in gravel abundance evident as sites were further from the discharge. Observed at all sites were sediment plumes in the water whenever the stream bed was disturbed. The silt dominance at both reference and effect sites reflects the pastoral catchment. The increase in soft substrate downstream of the discharge is likely the result of fine material, algae, and sediment being retained in the farm pond and released during high flow to settle at nearby sites.

The width and depth of the stream varied between each site, with the stream generally flowing in incised, vertical banks with good access to the floodplain. Notably, no significant changes to the embankment structure/condition at the various sites were observed following the flood events of early 2023, and the incision that was noted is considered normal in comparison to previous monitoring occasions. The exception was Site A, where the site characteristics reflected a predominantly wetland habitat, with the stream transitioning into small and shallow braided channels over the floodplain at the sampling site.

Instream flow rates varied at the reference sites, with Site E having a very low flow rate and the highest flow rates recorded at effect Sites S2, G, and C, which are the most downstream sites. The volume of water being discharged from the discharge pond formed a significant proportion of the stream flow. Riparian vegetation extent and shading also varied between sites. The reference sites had riparian vegetation dominated by native trees and shrubs, resulting in high shading on the upper stream. Downstream, vegetation and shading decreased as the Te Puru Stream Tributary flowed through pasture.

4.1.2 Water quality

All reference sites had temperatures indicative of 'good' stream health (15°C to 19.9°C) (Biggs *et al.* 2002), with the effects sites all having temperatures indicative of 'fair' stream health (20 to 24.9°C). Although no marked temperature trend was noted between all the sites, a marginal increase in temperature was noted at the sites directly downstream of the discharge. It is probable that the low shading and summer heating of the water in the farm pond resulted in this temperature increase. The temperature of the most downstream site was similar to that of the reference tributary site (Site E). There is a lack of shading in the lower catchment, and the water temperature readings were undertaken during the peak of summer (within a week of very high ambient day temperatures- ranging from 25 to 29 °C), while previous monitoring has been undertaken in cooler autumn months. Water temperatures cool as the water flows through the Te Puru Stream tributary and is likely to eventually lower in temperature further downstream (beyond the monitoring sites) to transition into the 'good' temperature range (Biggs *et al.* 2002) again.

The conductivity at all effect sites was very high. Conductivity was elevated above ANZECC (ANZG, 2018) guideline values at all sites; however, conductivity at sites downstream of the discharge pond was up to 13 times higher than reference sites, indicative of very high concentrations of dissolved ions in the tributaries downstream of the WTP.

Although these findings show a similar trend to those from the previous surveys (Bioresearches, 2002, 2010, 2016, 2019, and 2022), which had elevated conductivity below the discharge, the conductivity levels in 2016, 2019, 2022, and 2024 at sites below the discharge were at least 1000 µS/cm higher than the highest conductivity recorded in 2002 or 2010. It should be noted that the conductivity recorded at the effect sites in 2024 was substantially lower (by at least 40 %) than that recorded at the effect sites in 2016, 2019, and 2022. Also, the conductivity at the reference sites is almost similar to the conductivity levels measured in 2002 (i.e., the lowest measured conductivity at the reference sites in 20 years). After the 2016 survey, it was recommended that these very high conductivity levels in the water downstream of the farm pond required investigation to determine the source and whether they are the result of a change in treatment or an input source to the treatment plant. Watercare subsequently carried out extensive investigations of the network, and the network was repaired close to the coastal management area, resulting in a decrease in conductivity (pers. com. Iris Tscharntke, Wastewater Operations Controller Southern Regional Wastewater Treatment Plants, 2019). The increases in conductivity in the stream recorded in 2019 and beyond indicate that there is likely infiltration through the network again. Following this, additional repairs to the wastewater network which removed saltwater intrusion, also resulted in a decrease of conductivity (pers. com. Emma Baker, Environmental Scientist at Watercare, 2024).

The slightly enriched waters above the farm pond are likely the result of increased nutrient runoff from the surrounding pastoral landscape and are similar to conductivity levels found in pastoral catchments (Biggs *et al*. 2002).

Dissolved oxygen concentration and saturation varied slightly between all sites. All sites, including reference Site E, failed to meet the stringent ANZECC 2018 oxygen saturation (%) guidelines. In comparison, the dissolved oxygen concentrations at Site B were just above the upper DGV set by the

NPS-FM (2020). All other sites met the NPS-FM (2020) lower guideline for oxygen concentration (mg/L) for maintaining stream health.

Chlorophyll α was measured below the lower detection limit (< 0.003 g/m^3) at most sites, except for the site directly downstream of the discharge pond (Site B). The concentration of chlorophyll α of all sites was below the lower guideline value (MfE, 2020). The higher levels of chlorophyll-α at Site B, in comparison to all other sites, were attributed to the influence of photosynthetic activity in the pond itself, with large amounts of algae observed. These findings were similar to those from the previous surveys (Bioresearches, 2002, 2010, 2016, 2019, and 2022).

Total suspended solids (TSS) were highest at the effect sites (B, F, and S15) and reference Site A. Despite this, visual clarity was relatively high at Sites B, F, and S15. An immediate reduction in TSS was noted at Site F, located below the discharge, but an increase in TSS was measured at Site 15. The farm pond appeared very turbid, and the high TSS at Site B can be attributed to this high level of suspended material.

Visual clarity at all sites had worsened since 2016, but almost all met the ANZECC DGV, the exception being reference Site A. As TSS effects visual clarity, the relatively high TSS at some sites relates to poor visual clarity. TSS in 2024 differed the most from that measured in 2022 at Site E (decreased by 75 %), F (increased by 100 %), and S15 (increased by almost 70 %). It's unclear why the TSS varied; however, it may potentially be prescribed to the ongoing land use changes (specifically noting the change at the upstream reference site), potentially due to erosion (increased stock rates) within the larger catchment.

Levels of pH fell within the ANZECC (ANZG, 2018) values at all sites and fell within the 'excellent' to 'fair' range for New Zealand stream health monitoring (Biggs *et al*. 2002) that would maintain stream life.

Carbonaceous biochemical oxygen demand ($cBOD_5$), a measure of the amount of oxygen needed by aerobic biological organisms to breakdown organic (carbonaceous) material, was below the default detection limit at all sites. $cBOD_5$ has remained consistently low since 2016.

High bacterial indicators were found both above and below the discharge pond, and all sites failed to meet ANZECC (2000) guidelines. These bacteria are found in the gut of warm-blooded animals and are indicators of faecal contamination. High bacteria levels both above and below the discharge pond likely reflect the pastoral catchment, where stock come in close proximity to water bodies, and the large population of water birds present in the discharge pond. The treatment plant discharge was not considered to be having any major effect on bacterial contamination of the Te Puru Stream (considering similarly high amounts upstream and downstream of the discharge).

Faecal coliforms measured in 2024 were substantially lower than that measured in 2022. In 2024, enterococci either increased or decreased at the individual sites compared to that of 2022, with the significant elevations noted at the reference sites (90 % increase in 2024). This may be attributed to farming practices, the number of livestock within the catchment. The bacterial contamination could be bovine (from the stock) and/or avian (from the significant number of birds on the pond).

All nitrogen components (total ammoniacal nitrogen, total nitrogen, nitrate, nitrite, total Kjeldahl nitrogen, and dissolved inorganic nitrogen) followed the same general pattern, where nitrogen levels were elevated at sites directly downstream of the farm pond, then decreased with distance downstream. Nitrogen levels recorded at the furthest downstream site (Site C) still tended to be higher than levels at reference sites.

Although total ammoniacal nitrogen and nitrate levels in the three sections of Te Puru Stream tributaries were above the ANZECC (ANZG, 2018) guideline values, they were within the site-specific acute specific ammonia toxicity guidelines for the Te Puru Stream Tributary developed by NIWA (Hickey, 2001), and below the upper DGV limit of the national MfE (2020) guidelines for 95 % species protection. As concluded in the previous monitoring surveys, the elevated nitrate levels were likely to have influenced the similarly elevated total nitrogen levels downstream of the discharge, as well as the high dissolved inorganic nitrogen, which is readily bioavailable. Elevated nitrogen values at both reference and effect sites indicate some influence from land use practices; however, the very high levels seen downstream of the farm pond indicate amplified nutrient enrichment caused by the wastewater discharge, albeit below the site-specific guideline values.

Total nitrogen, specifically at effect sites, was similar or less than that measured in 2022. The total nitrogen measured in 2022 and 2024 far exceeds the concentrations measured in 2016 and 2019 but is comparable to 2010 levels (Bioresearches, 2010). Ammoniacal nitrogen, a toxic pollutant often found in waste products such as sewage and dairy effluent, decreased in 2024 compared to that measured in 2022. Notably, the total ammoniacal nitrogen measured at Site E, F, and S15 is the lowest since 2002. The variability in ammonia levels, specifically at the reference sites, indicates the variable effect from the pastoral land use surrounding the catchment on the entire tributary, as opposed to effects of discharge from the wastewater treatment plant. Nonetheless, all levels were lower than the site-specific banded kōkopu protection guideline values (Hickey, 2001).

Dissolved inorganic nitrogen (DIN), considered to be one of the key nutrients promoting periphyton growth, was substantially higher at effect sites than at reference sites. By comparison with previous Bioresearches (2002, 2010, 2016, and 2019) results, the levels of DIN at effect sites (below the farm pond) were elevated, but marginally lower in the current survey compared with 2022.

Phosphorus (both total and dissolved reactive) showed a similar pattern of elevation below the discharge and reduced concentrations with distance downstream; however, phosphorus levels did not return to concentrations comparable to reference sites.

Approximately 73 % to 78 % of the total phosphorus recorded at effects sites comprised the bioavailable form – dissolved reactive phosphorus (DRP), compared to between 17 % and 35 % DRP at reference sites. Phosphorus results were slightly elevated in comparison to the 2019 and 2022 survey, but the 2024 levels are substantially less than that measured in 2002 and 2010. All previous surveys showed a similar pattern, with elevated levels of both total and dissolved reactive phosphorus immediately below the discharge. While phosphorus concentrations decreased with distance downstream, total phosphorus and DRP were still elevated above the reference levels in all surveys and exceeded ANZECC (ANZG, 2018) guidelines.

4.1.3 Sediment quality

Sediment quality results showed the concentration of carbon, nitrogen (total nitrogen and ammonium), and phosphorus were elevated below the farm pond when compared to reference sites, then decreased at downstream sites, a general trend throughout all surveys (2002 - 2024). Total carbon, total nitrogen, the C:N ratio of Site G decreased to similar or slightly higher concentrations to the reference site, and were comparable for the phosphorous parameters. These parameters are similar or slightly higher/lower at Site C (the most downstream site), indicating further nutrient input from the surrounding pasture near the most downstream site.

Carbon to nitrogen ratios (C : N) can give an indication of whether the source of organic matter input is from vascular land plants or non-vascular (e.g., algae) plant material. Algae typically have atomic C : N ratios between 4 and 10, whereas vascular land plants have C : N ratios of 20 or more (Premuzic *et al*. 1982; Jasper and Gagosian 1990). The C : N ratios were highest at Site E in 2024 and decrease with distance downstream, indicating more organic material came from algal sources than land sources downstream of the reference site. Apart from the markedly high C:N ratio at Site C in 2022, and the lowest ratio recorded in 2010 (at Site E – 7.7), all other ratios are within the measured range between 2002 and 2024.

4.1.4 Biological aspects

Macrophyte and algae cover differed between reference and effect sites, where macrophyte/algal percent cover increased downstream of the farm pond, along with aquatic plant diversity, a general trend observed from 2002. The increased macrophyte abundance and diversity are reflective of both the lower level of riparian vegetation and shading and of the increased bioavailable nutrient levels (dissolved inorganic nitrogen and dissolved reactive phosphorus) observed at effect sites. Macrophyte and algae composition differed between reference and effect sites, with Nitella algae present at most effect sites and comprising the largest percent cover. Also noted in 2024 is the presence of filamentous algae at effects sites, more so than what was recorded in 2022.

Compared to 2019, the reference sites had a higher diversity of macrophytes in 2024, with the effects sites having relatively the same diversity. Changes in diversity were more evident between 2024 and 2022, with less diversity at reference site A and but the same proportion of diversity higher at reference Site E, but overall, the macrophyte diversity and cover decreased approximately only by 4 % in 2024.

Macroinvertebrate results all showed similar trends, where biotic indices (number of taxa, %EPT, MCI, and SQMCI) were lower at effect sites compared to reference sites. Specifically, Site F, located closest to the discharge, had the lowest scores across all four indices in 2024, ranking as ‘poor’ in both MCI and SQMCI. Site G further downstream of the discharge increased in number of taxa, MCI, and SQMCI, but still lower than that of reference sites. Nonetheless, Site G had comparatively similar EPT taxa as that up reference site A.

Dominant taxa, which tended to be species characteristic of slow-flowing habitats or poor water quality, included the freshwater snail *Potamopyrgus antipodarum* (a trend which has been ongoing since 2022). However, in 2024, the reference sites were also dominated by similar species (snails or amphipods), with Site A having a high dominance (63%) of freshwater amphipod, Site H dominated by freshwater snail, followed by amphipods and shrimp, and Site E dominated by freshwater snail, caddisflies, and black flies.

Sites A and H had the highest MCI scores, falling in the 'Good' quality habitat category. Site E has an improved MCI category; similarly, Site E also promoted into the 'fair' SQMCI category. Site A also improved in SQMCI category. There appeared to be an overall increase in the habitat quality indicators in the 2024 survey macroinvertebrate results compared to 2022. The SQMCI scores of Site E and G is the highest that it has been recorded. This can be attributed to the slight increase in taxa at most sites (a decrease was only noted at Site F), and specifically an overall increase of EPT taxa. The poor macroinvertebrate scores downstream of the discharge are likely due to a combination of stressors, such as the decreased riparian vegetation and hard substrate at downstream sites (thus, a lack of good macroinvertebrate habitat), along with effects caused by the discharge itself such as increased temperature, nutrient input (including potentially toxic nutrients such as ammonium), and suspended sediment.

Native fish biodiversity tended to decrease with distance downstream, with only two native species recorded at Site G, C and F. Native biodiversity at reference sites was generally higher, with three to four species recorded at each site, including more sensitive taxa such as banded kōkopu and longfin eels. Native fish abundance was also higher at reference sites compared to effect sites. Fish IBI scores ranged between 'fair' and 'poor' at reference sites, with 'poor' to 'very poor' scores at the effect sites. Electric fishing of the Te Puru Tributary and lower Farm Pond Tributary could not be carried out as the conductivity of the water was too high to carry the charge from the electric fishing machine. As such, only trapping was carried out at these sites and the species diversity of these sites may have therefore been under-represented.

The presence of juvenile eels and juvenile banded kōkopu at the reference sites indicates that they have been able to migrate upstream past the discharge point over the past few years. This is similar to findings of the previous surveys (Bioresearches 2002, 2010, 2016, 2019 and 2022) in which both adult and juvenile banded kōkopu and eels were found at the upstream reference sites.

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6. APPENDICES

Appendix 1. Laboratory Water and Sediment Quality Results

Hill Labs
R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand
0508 HILL LAB (44 555 22)
+64 7 858 2000
mail@hill-labs.co.nz
www.hill-labs.co.nz

Certificate of Analysis Page 1 of 3

Client:	Bioresearches	**Lab No:**	3456213 SPv1
Contact:	Treff Barnett	**Date Received:**	31-Jan-2024
	C/- Bioresearches	**Date Reported:**	09-Feb-2024
	PO Box 2828	**Quote No:**	74278
	Auckland 1140	**Order No:**	
		Client Reference:	1608
		Submitted By:	Treff Barnett

Sample Type: Sediment

Sample Name:		Site F (Sediment) 31-Jan-2024 12:20 pm	Site E (Sediment) 31-Jan-2024 3:20 pm	Site G (Sediment) 31-Jan-2024 4:00 pm	Site C (Sediment) 31-Jan-2024 9:12 am
Lab Number:		3456213.8	3456213.9	3456213.10	3456213.11
Individual Tests					
Dry Matter	g/100g as rcvd	37	46	43	54
Total Recoverable Phosphorus	mg/kg dry wt	2,000	380	1,210	800
Total Nitrogen*	g/100g dry wt	0.26	0.12	0.20	0.12
Ammonium-N*	mg/kg dry wt	148	24	11	18
Total Carbon*	g/100g dry wt	3.9	2.2	2.9	1.62

Sample Type: Aqueous

Sample Name:		Site A 31-Jan-2024 11:10 am	Site B 31-Jan-2024 11:40 am	Site 15 31-Jan-2024 1:00 pm	Site F 31-Jan-2024 12:30 pm	Site E 31-Jan-2024 3:20 pm
Lab Number:		3456213.1	3456213.2	3456213.3	3456213.4	3456213.5
Individual Tests						
pH	pH Units	7.1	7.7	7.5	7.8	7.4
Electrical Conductivity (EC)	mS/m	21.9	193.6	134.5	190.8	16.2
Total Suspended Solids	g/m^3	6	7	10	6	< 3
Dissolved Inorganic Nitrogen*	g/m^3	0.130	2.7	1.75	2.7	0.128
Total Nitrogen	g/m^3	0.25	3.5	2.4	3.5	0.23
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.15	0.95	0.63	0.87	0.11
Total Phosphorus	g/m^3	0.029	0.69	0.45	0.61	0.040
Carbonaceous Biochemical Oxygen Demand ($cBOD_5$)	$g\ O_2/m^3$	< 2 #1	< 2 #1	< 2 #1	< 2 #1	< 2 #1
Faecal Coliforms	cfu / 100mL	560	540	340	410	460
Enterococci	MPN / 100mL	461	166	517	549	1,986
Chlorophyll a	g/m^3	< 0.003	0.006	< 0.003	< 0.003	< 0.003
Nutrient Profile						
Total Ammoniacal-N	g/m^3	0.029	0.167	0.022	0.057	0.011
Nitrite-N	g/m^3	< 0.002	0.173	0.036	0.094	0.002
Nitrate-N	g/m^3	0.099	2.4	1.69	2.5	0.115
Nitrate-N + Nitrite-N	g/m^3	0.101	2.6	1.73	2.6	0.117
Dissolved Reactive Phosphorus	g/m^3	0.005	0.51	0.29	0.48	0.015

Sample Name:		Site G 31-Jan-2024 4:00 pm	Site C 31-Jan-2024 9:12 am
Lab Number:		3456213.6	3456213.7
Individual Tests			
pH	pH Units	7.7	7.5
Electrical Conductivity (EC)	mS/m	121.8	127.5
Total Suspended Solids	g/m^3	< 3	< 3
Dissolved Inorganic Nitrogen*	g/m^3	1.53	1.50
Total Nitrogen	g/m^3	2.0	2.1
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.52	0.57

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked * or any comments and interpretations, which are not accredited.

Sample Type: Aqueous			
	Sample Name:	Site G 31-Jan-2024 4:00 pm	Site C 31-Jan-2024 9:12 am
	Lab Number:	3456213.6	3456213.7
Individual Tests			
Total Phosphorus	g/m^3	0.32	0.28
Carbonaceous Biochemical Oxygen Demand ($cBOD_5$)	$g\ O_2/m^3$	< 2 #1	< 2 #1
Faecal Coliforms	cfu / 100mL	1,800 #2	1,300 #2
Enterococci	MPN / 100mL	1,203	461
Chlorophyll a	g/m^3	< 0.003	< 0.003
Nutrient Profile			
Total Ammoniacal-N	g/m^3	0.011	0.010
Nitrite-N	g/m^3	0.017	0.013
Nitrate-N	g/m^3	1.51	1.47
Nitrate-N + Nitrite-N	g/m^3	1.52	1.49
Dissolved Reactive Phosphorus	g/m^3	0.24	0.20

Analyst's Comments

#1 Due to unexpected sample numbers and limited resources, we were unable to commence the carbonaceous Biochemical Oxygen Demand(cBOD5) analyses on the day that they arrived at the laboratory. The analysis was performed, as soon as possible on the unpreserved sample which had been kept in refrigerated storage at approximately 4°C.

#2 Statistically estimated count based on the theoretical countable range for the stated method.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Labs, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	8-11
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	8-11
Soil Prep Dry & Sieve for Agriculture	Air dried at 35°C and sieved, <2mm fraction.	-	8-11
Dry Matter	Dried at 103°C for 4-22hr (removes 3-5% more water than air dry) , gravimetry. (Free water removed before analysis, non-soil objects such as sticks, leaves, grass and stones also removed). US EPA 3550.	0.10 g/100g as rcvd	8-11
2M KCl Extraction*	2M potassium chloride extraction of as received fraction for analysis of NH4N, NO2N and NO3N. Analyst, 109, 549, (1984).	-	8-11
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	8-11
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	8-11
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	8-11
Ammonium-N*	2M potassium chloride extraction on as received fraction. Phenol/hypochlorite colorimetry. Flow Injection Analyser. APHA 4500-NH_3 H (modified) : Online Edition.	5 mg/kg dry wt	8-11
Total Carbon*	Catalytic Combustion (900°C, O_2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	8-11

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Nutrient Profile		0.0010 - 0.010 g/m^3	1-7
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1-7
pH	pH meter. APHA 4500-H^+ B (modified) : Online Edition. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-7

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B : Online Edition.	0.1 mS/m	1-7
Total Suspended Solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination. APHA 2540 D (modified) : Online Edition.	3 g/m^3	1-7
Dissolved Inorganic Nitrogen*	Calculation: NH_4-N + NO_3-N + NO_2-N. In-house calculation.	0.005 g/m^3	1-7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-7
Total Ammoniacal-N	Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) : Online Edition.	0.010 g/m^3	1-7
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) : Online Edition.	0.002 g/m^3	1-7
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N. In-House.	0.0010 g/m^3	1-7
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) : Online Edition.	0.002 g/m^3	1-7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) : Online Edition.	0.10 g/m^3	1-7
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) : Online Edition.	0.004 g/m^3	1-7
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H (modified) : Online Edition.	0.002 g/m^3	1-7
Carbonaceous Biochemical Oxygen Demand ($cBOD_5$)	Incubation 5 days, DO meter, nitrification inhibitor added, seeded. APHA 5210 B (modified) : Online Edition.	2 g O_2/m^3	1-7
Faecal Coliforms	Membrane Filtration, Count on CCA agar, Incubated at 44.5°C for 21-24 hours. APHA 9222 D (modified) : Online Edition.	1 cfu / 100mL	1-7
Enterococci	MPN count using Enterolert, Incubated at 41°C for 24 hours. MIMM 12.4, APHA 9230 D : Online Edition.	1 MPN / 100mL	1-7
Chlorophyll a	Acetone extraction. Spectroscopy. APHA 10200 H (modified) : Online Edition.	0.003 g/m^3	1-7

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 01-Feb-2024 and 09-Feb-2024. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Appendix 2. Raw Macroinvertebrate Data

PHYLUM	CLASS: Order	Family	Taxa	Taxa MCI hb	Taxa MCI sb	Site A	Site H	Site E	Site F	Site G	Site C
						SB	HB	HB	SB	HB	SB
ANNELIDA	**OLIGOCHAETA**		Oligochaeta	1	3.8	1		2			2
	HIRUDINEA		*Glossiphonia* sp.	3	1.2	1				1	
MOLLUSCA	**GASTROPODA**	Hydrobiidae	*Potamopyrgus antipodarum*	4	2.1	1	41	83	179	1121	263
		Lymneaidae	*Lymnaea columella*	3	1.2		1				
		Latiidae	*Latia neritoides*	3	6.1			1			
	BIVALVIA	Sphaeriidae	*Pisidium hodgkini*	3	2.9	1					
ARTHROPODA	**Ostracoda**		Ostracoda	3	1.9	4			3		1
	Amphipoda		*Paracalliope fluviatilis*	5	5.5	331	34	25	1	766	1222
	Decapoda		*Paranephrops planifrons*	5	8.4	1	2	1			1
			Paratya curvirostris	5	3.6		28	2		4	18
	INSECTA:										
	Megaloptera	Corydalidae	*Archichauliodes diversus*	7	7.3		1	1			
	Odonata	Zygoptera	*Xanthocnemis zealandica*	5	1.2	4				6	12
		Anisoptera	*Hemicordulia australiae*	5	0.4						1
	Ephemeroptera	Leptophlebiidae	*Deleatidium 'lilli'* group	8	5.6		1	7			
			Arachnocolus phillipsi	8	8.1	2					
			Zephlebia spp	7	8.8	16	7	3			
			Neozephlebia scita	7	7.6	10		4			
	Trichoptera	Hydropsychidae	*Orthopsyche fimbriata*	9	7.5					1	
		Hydroptilidae	*Oxyethira albiceps*	2	1.2	4		1		1	4
		Hydrobiosidae	*Hydrobiosis parumbripennis*	**7**	**7.4**		2				
			Psilochorema sp.	8	7.8			2			
			Neurochorema confusum	6	6			1			
			Costachorema sp.	7	7.2			2			
		Polycentropodidae	*Polyplectropus puerilis*	8	8.1	86					
		Leptoceridae	*Triplectides obsoleta*	5	5.7	1	20	7		1	4
		Conoesucidae	*Pycnocentrodes* sp.	5	3.8			42			
	Coleoptera	Ptilodactylidae	Ptilodactylidae	8	7.1		1	1			
		Scirtidae	Scirtidae	8	6.4	1					
		Hydrophilidae	Hydrophilidae	5	8	2					
			Enochrus tritus	5	2.6		1				
	Lepidoptera		*Hygraula nitens*	4	1.3						3
	Diptera	Hexatomini	*Paralimnophila skusei*	6	7.4	1					
		Simuliidae	*Austrosimulium australense* gp	3	3.9			26		2	
		Chironomidae	*Chironomus*	1	3.4	1	1	1		2	
			Orthcladiinae	2	3.2	4	7	11		5	
			Tanypodinae	5	6.5	51		1		1	
		Tanyderidae	*Mischoderus* sp.	4	5.9			1			
		Dixidae	*Paradixa* sp.	4	8.5	2	2				
	Collembola	Collembola .	Collembola	6	5.3						3
		TOTALS:	**NO. TAXA**			21	15	22	3	12	12
			NO. EPT TAXA			6	4	9	0	3	2
			NO. INDIVIDUALS			525	149	225	183	1911	1534
CHORDATA	**VERTEBRATA**	Poeciliidae	*Gambusia affinis*				3		19	1	1
		Gobiidae	*Gobiomorphus* sp.					1			1
		Galaxiidae	*Galaxias* sp.								

Appendix 3. New Zealand Freshwater Fish Database Forms

FRESHWATER FISH DATABASE FORM							1
Date **01/02/2024**		River/Lake system **Tributary to Te Puru Stream**				Catchment number **084.00**	
Time		Sampling locality **C: Lower**					
Observer **ld**		Access				Altitude (m) **15**	
Organisation **bior**		NZMS 260 Map no.		Coord.		Distance inland (km) **3.6**	
Fishing method **gmt**		Area fished (m2) or no. nets used		Number of electric fishing passes		Tidal water **n**	
HABITAT DATA							
Water	Colour			Clarity		Temp.	pH
	Average width (m)		Average depth (m)	Maximum depth (m)		Conductivity	
Habitat type (%)	Still	Back-water	Pool	Run	Riffle	Rapid	Casc.
Substrate type (%)	Mud	Sand	Fine gravel	Coarse gravel	Cobble	Boulder	Bed-rock
Fish cover (y/n)	Macrophyte	Instream debris	Undercut bank	Bank veg.			
Catchment vegetation(%)	Native forest	Exotic forest	Farm	Urban zone	Scrub	Swamp land	Other
Riparian vegetation(%)	Native forest	Exotic forest	Grass tussock	Exposed bed	Scrub willow	Raupo flax	Other
Type of river/stream/lake							
Water level			Downstream barrier			Pollution	
Large invertebrate fauna		Koura		Paratya		Freshwater mussel	
Bottom fauna abundance			Predominant species group			Permanent water	
FISH DATA							

Species		Abundance	Length	Habitat/Comments
Anguilla	**Unidentified eel**	**1**		
Gobiomorphus cotidianus	**Common bully**	**10**		
Gambusia affinis	**Gambusia**	**2**		
Anguilla dieffenbachii	**Longfin eel**	**1**		

Comments

FRESHWATER FISH DATABASE FORM								2
Date	01/02/2024	River/Lake system	Tributary to Te Puru Stream				Catchment number	084.00
Time		Sampling locality	H: Farmstop					
Observer	ld	Access					Altitude (m)	31
Organisation	bior	NZMS 260 Map no.	s11	Coord.			Distance inland (km)	5.5
Fishing method	gmt	Area fished (m2) or no. nets used		Number of electric fishing passes			Tidal water	n

HABITAT DATA

Water	Colour			Clarity		Temp.	pH
	Average width (m)		Average depth (m)	Maximum depth (m)		Conductivity	
Habitat type (%)	Still	Back-water	Pool	Run	Riffle	Rapid	Casc.
Substrate type (%)	Mud	Sand	Fine gravel	Coarse gravel	Cobble	Boulder	Bed-rock
Fish cover (y/n)	Macrophyte	Instream debris	Undercut bank	Bank veg.			
Catchment vegetation(%)	Native forest	Exotic forest	Farm	Urban zone	Scrub	Swamp land	Other
Riparian vegetation(%)	Native forest	Exotic forest	Grass tussock	Exposed bed	Scrub willow	Raupo flax	Other
Type of river/stream/lake							
Water level			Downstream barrier			Pollution	
Large invertebrate fauna		Koura		Paratya		Freshwater mussel	
Bottom fauna abundance			Predominant species group			Permanent water	

FISH DATA

Species		Abundance	Length	Habitat/Comments
Paranephrops	**Koura**	**4**		
Gobiomorphus basalis	**Crans bully**	**5**		
Gobiomorphus cotidianus	**Common bully**	**24**		
Galaxias fasciatus	**Banded kokopu**	**3**		

Comments

FRESHWATER FISH DATABASE FORM							3
Date	**01/02/2024**	River/Lake system	**Tributary to Te Puru Stream**			Catchment number	**084.00**
Time		Sampling locality	**E: farm access**				
Observer	**ld**	Access				Altitude (m)	**24**
Organisation	**bior**	NZMS 260 Map no.	**s11**	Coord.		Distance inland (km)	**5.1**
Fishing method	**gmt**	Area fished (m2) or no. nets used		Number of electric fishing passes		Tidal water	**n**

HABITAT DATA

Water	Colour			Clarity		Temp.	pH
	Average width (m)		Average depth (m)	Maximum depth (m)		Conductivity	
Habitat type (%)	Still	Back-water	Pool	Run	Riffle	Rapid	Casc.
Substrate type (%)	Mud	Sand	Fine gravel	Coarse gravel	Cobble	Boulder	Bed-rock
Fish cover (y/n)	Macrophyte	Instream debris	Undercut bank	Bank veg.			
Catchment vegetation(%)	Native forest	Exotic forest	Farm	Urban zone	Scrub	Swamp land	Other
Riparian vegetation(%)	Native forest	Exotic forest	Grass tussock	Exposed bed	Scrub willow	Raupo flax	Other
Type of river/stream/lake							
Water level			Downstream barrier			Pollution	
Large invertebrate fauna		Koura		Paratya		Freshwater mussel	
Bottom fauna abundance			Predominant species group			Permanent water	

FISH DATA

Species		Abundance	Length	Habitat/Comments
Gobiomorphus cotidianus	**Common bully**	**14**		
Anguilla	**Unidentified eel**	**4**		
Paranephrops	**Koura**	**1**		

Comments

FRESHWATER FISH DATABASE FORM

4

Date	01/02/2024	River/Lake system	Tributary to Te Puru Stream	Catchment number	084.00
Time		Sampling locality	A: Upper pond trib		
Observer	ld	Access		Altitude (m)	40
Organisation	bior	NZMS 260 Map no.	s11	Coord.	Distance inland (km) 5.8
Fishing method	gmt	Area fished (m2) or no. nets used		Number of electric fishing passes	Tidal water n

HABITAT DATA

Water	Colour			Clarity		Temp.	pH
	Average width (m)		Average depth (m)	Maximum depth (m)		Conductivity	
Habitat type (%)	Still	Back-water	Pool	Run	Riffle	Rapid	Casc.
Substrate type (%)	Mud	Sand	Fine gravel	Coarse gravel	Cobble	Boulder	Bed-rock
Fish cover (y/n)	Macrophyte	Instream debris	Undercut bank	Bank veg.			
Catchment vegetation(%)	Native forest	Exotic forest	Farm	Urban zone	Scrub	Swamp land	Other
Riparian vegetation(%)	Native forest	Exotic forest	Grass tussock	Exposed bed	Scrub willow	Raupo flax	Other
Type of river/stream/lake							
Water level			Downstream barrier			Pollution	
Large invertebrate fauna			Koura		Paratya		Freshwater mussel
Bottom fauna abundance			Predominant species group			Permanent water	

FISH DATA

Species		Abundance	Length	Habitat/Comments
Anguilla	**Unidentified eel**	**1**		
Galaxias fasciatus	**Banded kokopu**	**9**		
Paranephrops	**Koura**			
Gobiomorphus cotidianus	**Common bully**			

Comments

FRESHWATER FISH DATABASE FORM				5
Date **01/02/2024**	River/Lake system **Tributary to Te Puru Stream**			Catchment number **084.00**
Time	Sampling locality **G: Mid down trib**			
Observer **ld**	Access			Altitude (m) **18**
Organisation **bior**	NZMS 260 Map no. **s11**	Coord.		Distance inland (km) **4.4**
Fishing method **gmt**	Area fished (m2) or no. nets used	Number of electric fishing passes		Tidal water **n**

HABITAT DATA

Water	Colour			Clarity		Temp.	pH
	Average width (m)		Average depth (m)	Maximum depth (m)		Conductivity	
Habitat type (%)	Still	Back-water	Pool	Run	Riffle	Rapid	Casc.
Substrate type (%)	Mud	Sand	Fine gravel	Coarse gravel	Cobble	Boulder	Bed-rock
Fish cover (y/n)	Macrophyte	Instream debris	Undercut bank	Bank veg.			
Catchment vegetation(%)	Native forest	Exotic forest	Farm	Urban zone	Scrub	Swamp land	Other
Riparian vegetation(%)	Native forest	Exotic forest	Grass tussock	Exposed bed	Scrub willow	Raupo flax	Other

Type of river/stream/lake			
Water level	Downstream barrier		Pollution
Large invertebrate fauna	Koura	Paratya	Freshwater mussel
Bottom fauna abundance	Predominant species group		Permanent water

FISH DATA

Species		Abundance	Length	Habitat/Comments
Gambusia affinis	**Gambusia**	**3**		**gen**
Gobiomorphus cotidianus	**Common bully**	**21**		
Anguilla dieffenbachii	**Longfin eel**	**1**		

Comments

FRESHWATER FISH DATABASE FORM					6
Date	01/02/2024	River/Lake system **Tributary to Te Puru Stream**		Catchment number	084.00
Time		Sampling locality **F: Below pond**			
Observer	ld	Access		Altitude (m)	25
Organisation	bior	NZMS 260 Map no. **s11**	Coord.	Distance inland (km)	5
Fishing method	gmt	Area fished (m2) or no. nets used	Number of electric fishing passes	Tidal water	n

HABITAT DATA

Water	Colour			Clarity		Temp.	pH
	Average width (m)		Average depth (m)	Maximum depth (m)		Conductivity	
Habitat type (%)	Still	Back-water	Pool	Run	Riffle	Rapid	Casc.
Substrate type (%)	Mud	Sand	Fine gravel	Coarse gravel	Cobble	Boulder	Bed-rock
Fish cover (y/n)	Macrophyte	Instream debris	Undercut bank	Bank veg.			
Catchment vegetation(%)	Native forest	Exotic forest	Farm	Urban zone	Scrub	Swamp land	Other
Riparian vegetation(%)	Native forest	Exotic forest	Grass tussock	Exposed bed	Scrub willow	Raupo flax	Other
Type of river/stream/lake							
Water level			Downstream barrier			Pollution	
Large invertebrate fauna		Koura		Paratya		Freshwater mussel	
Bottom fauna abundance			Predominant species group			Permanent water	

FISH DATA

Species		Abundance	Length	Habitat/Comments
Anguilla	**Unidentified eel**	1		

Comments

Appendix 4. Auckland Fish Index of Biotic Integrity (IBI)

Index of Biological Integrity - Auckland Region : Fish

Centre for Freshwater Ecosystem Modelling and Management, Massey University

Site	IBI score	Rating
H	34	Fair
E	26	Poor
A	34	Fair
F	14	Very Poor
G	26	Poor
C	26	Poor

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Appendix 5. Macrophyte Survey Results

Site A															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		1.43	1.76	3.22	2.15	1.48	1.56	1.25	0.99	1.58	1.5	1.56	0.86		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0.05	3	0	0	2	0	1	0	0	0	0	1	0.5875	0.28684
Watercress	*Nasturtium officinale*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duckweed	*Lemna minor*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Celery	*Apium nodiflorum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	0	0	0	0	0	0	0	0	0	0	0	0	
Buttercup	*Ranunculus repens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other macrophytes	*Forget-me-knot*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Red ludwigia	0	1	5	10	3	15	40	3	0	0	0	0	6.41667	3.3427
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green filamentous		0	0	0	5	0	0	0	0	0	0	0	0	0.41667	0.41667
Brown mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Macrophytes (%)		0.05	4	5	10	5	15	41	3	0	0	0	1	7.00	3.36
Total Algae (%)		0	0	0	5	0	0	0	0	0	0	0	0	0.42	0.42
Bare Substrate (%)		99.95	96	95	85	95	85	59	97	100	100	100	99	92.58	3.42

Site H															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		1.05	1.11	1.23	1.42	1.07	2.31	2.76	2.52	2.38	1.64	2.27	1.08		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Watercress	*Nasturtium officinale*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duckweed	*Lemna minor*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0.01	0	0	0	0	0	0	0.00	0.00
Water Celery	*Apium nodiflorum*	0	60	0	0	0	0.05	0.1	0	0	0	0.01	1	5.10	4.99
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buttercup	*Ranunculus repens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other macrophytes	*Forget-me-knot*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Macrophytes (%)		0	60	0	0	0	0.06	0.1	0	0	0	0.01	1	5.10	4.99
Total Algae (%)		0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00
Bare Substrate (%)		100	40	100	100	100	99.94	99.9	100	100	100	99.99	99	94.90	4.99

Site E															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		1.77	1.73	2.86	2.77	2.56	2.41	2.12	1.71	2.12	1.94	2.07	1.89		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0	0	0	0	0	0	0	0	1	0	0	0	0.083333	0.083333
Watercress	*Nasturtium officinale*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duckweed	*Lemna minor*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Celery	*Apium nodiflorum*	0	0	0	0	0	0	0	1	3	0	1	1	0.5	0.261116
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	0	1	0	0	0	0	0	0	0	0	0	0.083333	
Buttercup	*Ranunculus repens*	0	0	0	0	0	0	0	0	1	0	0	0	0.083333	0.083333
Other macrophytes	*Forget-me-knot*	0	0	0	0	0	0	0	0.5	1	0	0	0	0.125	0.089718
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	5	10	15	5	25	30	0	0	0	0	20	0	9.166667	3.128155
Green mat		0	3	0	0	0	0	0	0	0	0	0	5	0.666667	0.466017
Green filamentous		0	0	5	1	0	2	0	0	0	0	0	0	0.666667	0.432283
Brown mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Macrophytes (%)		0	0	1	0	0	0	0	1.5	6	0	1	1	0.88	0.49
Total Algae (%)		5	13	20	6	25	32	0	0	0	0	20	5	10.50	3.23
Bare Substrate (%)		95	87	79	94	75	68	100	98.5	94	100	79	94	88.63	3.12

Site F															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		2.2	2.28	2.27	1.8	1.88	2.7	1.84	1.34	1.45	1.37	1.36	1.65		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	1	10	50	10	10	2	0	0	0	0	5	0	7.333333	4.068231
Watercress	*Nasturtium officinale*	1	5	10	5	2	0.1	0	0	0	0	0	0	1.925	0.915119
Duckweed	*Lemna minor*	10	20	5	40	1	0.1	0.01	0	0	0.1	5	5	7.184167	3.434091
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0.1	0	2	0	0	0	0	0	0	0	0	0.175	0.166117
Water Celery	*Apium nodiflorum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	0	0	0	0	0	0	0	0	0	0	0	0	
Buttercup	*Ranunculus repens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other macrophytes	*Forget-me-knot*	0	2	0	0	0	0	0	0	0	0	20	0	1.833333	1.659834
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown mat		10	0	0	0	0	0	0	0	0	0	0	0	0.833333	0.833333
Brown filamentous		20	20	30	40	10	30	10	0	0	10	30	80	23.33333	6.316565
Total Macrophytes (%)		12	37.1	65	57	13	2.2	0.01	0	0	0.1	30	5	18.45	6.75
Total Algae (%)		30	20	30	40	10	30	10	0	0	10	30	80	24.17	6.33
Bare Substrate (%)		58	42.9	5	3	77	67.8	89.99	100	100	89.9	40	15	57.38	10.39

Site S2															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		1.98	1.52	2.24	2.69	2.4	2.18	1.91	1.77	1.74	1.51	1.78	1.77		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Watercress	*Nasturtium officinale*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duckweed	*Lemna minor*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Celery	*Apium nodiflorum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	0	0	0	0	0	0	0	0	0	0	0	0	
Buttercup	*Ranunculus repens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other macrophytes	*Forget-me-knot*	25	0	15	0	0	10	10	0	0	0	0	0	5	2.383656
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	2	0	0	0	0	0	2	0	0	0	0	0	0.333333	0.224733
Green mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green filamentous		0	0	0	1	0	0	0	0	0	0	0	0	0.083333	0.083333
Brown mat		0	0	0	0	5	0	0	0	0	0	0	0	0.416667	0.416667
Brown filamentous		0	10	0	20	2	2	0	0	0	0	0	0	2.833333	1.76598
Total Macrophytes (%)		25	0	15	0	0	10	10	0	0	0	0	0	5.00	2.38
Total Algae (%)		2	10	0	21	7	2	2	0	0	0	0	0	3.67	1.83
Bare Substrate (%)		73	90	85	79	93	88	88	100	100	100	100	100	91.33	2.66

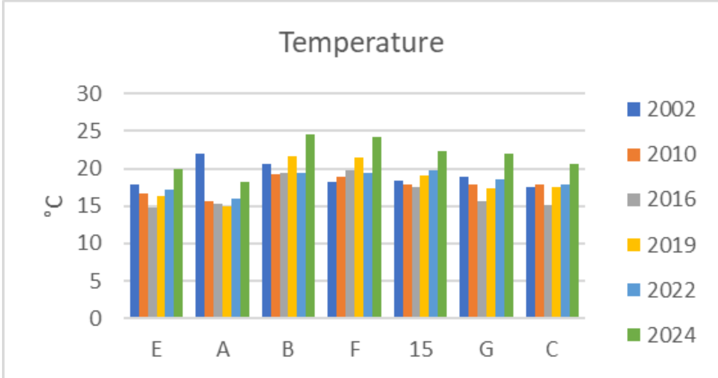
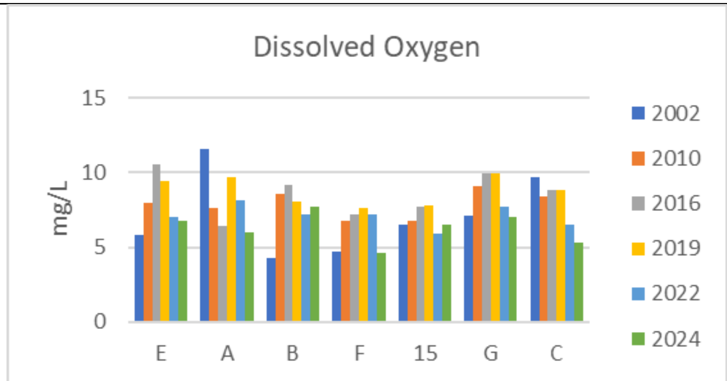
Site G															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		3.1	2.39	2.1	2.35	3.25	1.46	1.5	1.47	1.35	1.8	2.9	2.4		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0	0	0	0	0	0	0	2	0	0	5	0	0.583333	0.434468
Watercress	*Nasturtium officinale*	0	25	40	30	0	0	1	10	10	1	10	5	11	3.892495
Duckweed	*Lemna minor*	0	0	0	2	1	1	1	0	0	1	1	2	0.75	0.217597
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Celery	*Apium nodiflorum*	15	25	40	1	1	0	1	10	10	0	1	5	9.083333	3.576985
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	5	0	0	0	0	0	0	0	0	0	0	0.416667	
Buttercup	*Ranunculus repens*	0	0	0	0.1	0	0	0	0	0	0	0	1	0.091667	0.082992
Other macrophytes	*Forget-me-knot*	0	0	1	0	0	5	10	5	0	0	0	0	1.75	0.930339
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	2	20	10	5	0	0	5	10	10	20	40	30	12.66667	3.618834
Green mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green filamentous		1	0	1	35	5	5	0	35	30	35	30	20	16.41667	4.516734
Brown mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Macrophytes (%)		15	55	81	33.1	2	6	13	27	20	2	17	13	23.68	6.73
Total Algae (%)		3	20	11	40	5	5	5	45	40	55	70	50	29.08	6.80
Bare Substrate (%)		82	25	8	26.9	93	89	82	28	40	43	13	37	47.24	8.88

Site S3															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		1.6	1.87	3.02	2.81	3.71	2.9	3.9	2.28	2.73	2.55	2.46	2.42		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0	15	0	0	0	0	0	3	10	20	2	4	4.5	1.96754
Watercress	*Nasturtium officinale*	0	0	0.01	0.01	0.05	0.5	1	1	4	0.5	0	0	0.589167	0.329569
Duckweed	*Lemna minor*	0	0.01	1	0.01	0	0.1	0	0	1	0.1	1	0	0.268333	0.127807
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Celery	*Apium nodiflorum*	0	0	1	0	0	0	0	0.5		0.5	0.5	1	0.318182	0.121967
Oxygen weed	*Elodea canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curly pondweed	*Potamogeton crispus*	0	0	0	0	0	0	0	0	0	0	0.5	0	0.041667	0.041667
Buttercup	*Ranunculus repens*	0.1	0	0	0.5	0	0	0	0	0	0	0	0	0.05	0.041742
Other macrophytes	*Forget-me-knot*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	10	40	45	60	70	0	50	80	85	100	55	60	54.58333	8.358862
Green mat		0	0	0	0	0	0	0	2	0	0	2	0	0.333333	0.224733
Green filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Macrophytes (%)		0.1	15.01	2.01	0.52	0.05	0.6	1	4.5	15	21.1	4	5	5.74	2.07
Total Algae (%)		10	40	45	60	70	0	50	82	85	100	57	60	54.92	8.41
Bare Substrate (%)		89.9	44.99	52.99	39.48	29.95	99.4	49	13.5	0	-21.1	39	35	39.34	9.71

Site C															
Transect		1	2	3	4	5	6	7	8	9	10	11	12	**Mean**	**S.E**
Width (m)		0.43	1.15	2.1	2.1	2.25	2.17	1.5	1.7	1.73	2	2.25	2.5		
Macrophytes (%)															
Willow weed	*Persicaria sp.*	0	0	5	0	20	20	0	0	5	0	2	0	4.333333	2.182344
Watercress	*Nasturtium officinale*	10	5	0	0	0	0	1	0	5	5	0	0	2.166667	0.952137
Duckweed	*Lemna minor*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cape pondweed	*Aponogeton distachyus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Starwort	*Callitriche stagnalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Celery	*Apium nodiflorum*	30	10	10	4	5	5	5	1	10	15	10	0.1	8.758333	2.297082
Oxygen weed	*Elodea canadensis*	2	30	50	0	0	0	0	0	0	0	0	0	6.833333	4.641436
Curly pondweed	*Potamogeton crispus*	0	0	0	0	0	0	0	0	0	0	0	0	0	
Buttercup	*Ranunculus repens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other macrophytes	*Forget-me-knot*	0	0	0	0	0	0	0	5	10	1	0	0	1.333333	0.890466
Iron flocc		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitella	*Nitella hookeri*	2	10	10	60	60	40	30	70	60	50	30	50	39.33333	6.593538
Green mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green filamentous		0	0	1	5	10	10	10	10	10	10	30	15	9.25	2.34238
Brown mat		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown filamentous		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Macrophytes (%)		42	45	65	4	25	25	6	6	30	21	12	0.1	23.43	5.68
Total Algae (%)		2	10	11	65	70	50	40	80	70	60	60	65	48.58	7.71
Bare Substrate (%)		56	45	24	31	5	25	54	14	0	19	28	34.9	27.99	5.09

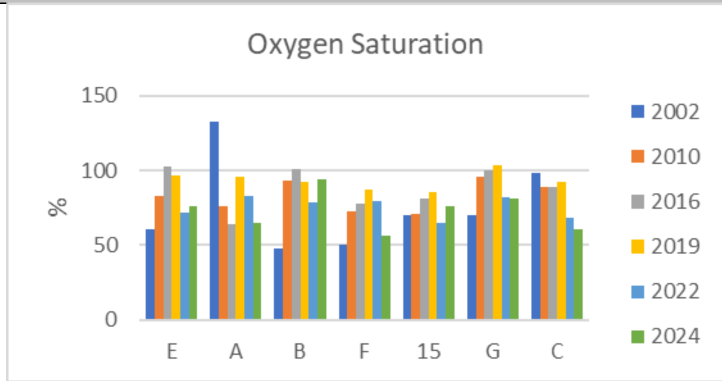
Appendix 6. Historical water quality, sediment quality and biological data (2002 – 2024)

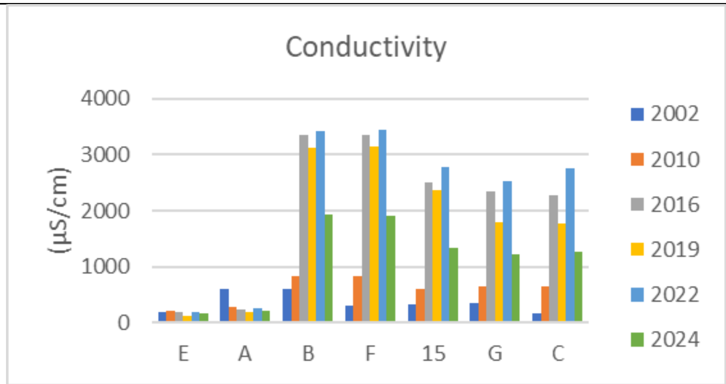
6.1 Water Quality

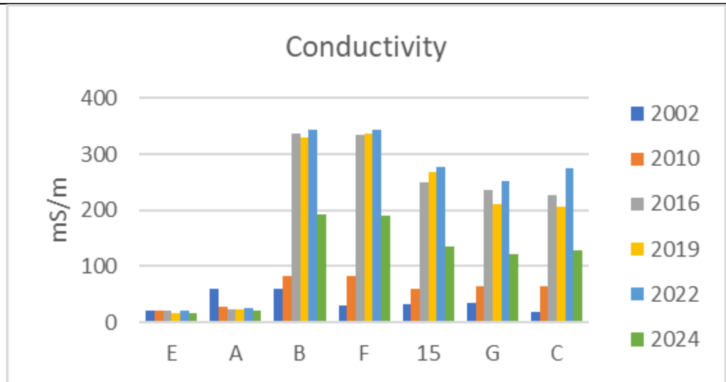
		E	A	B	F	15	G	C	Corresponding graph
Temperature (°C)	2002	17.9	22	20.7	18.3	18.4	18.9	17.6	
	2010	16.6	15.6	19.2	18.9	17.9	17.8	17.8	
	2016	14.8	15.3	19.5	19.7	17.5	15.6	15.2	
	2019	16.3	15	21.7	21.4	19.1	17.4	17.6	
	2022	17.2	16.0	19.5	19.5	19.7	18.6	17.9	
	2024	19.9	18.2	24.5	24.2	22.4	22	20.6	
Dissolved Oxygen (mg/L)	2002	5.79	11.55	4.25	4.73	6.51	7.07	9.67	
	2010	8	7.6	8.6	6.8	6.8	9.1	8.4	
	2016	10.5	6.4	9.2	7.2	7.7	9.9	8.8	
	2019	9.44	9.71	8.05	7.66	7.83	9.9	8.83	
	2022	7	8.12	7.18	7.22	5.88	7.70	6.47	
	2024	6.8	6	7.7	4.6	6.5	7.00	5.3	

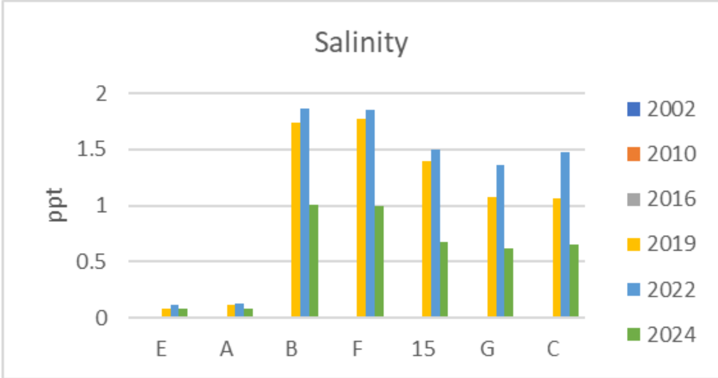
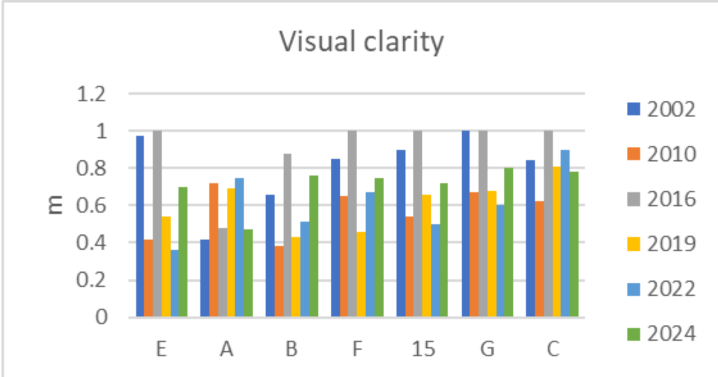
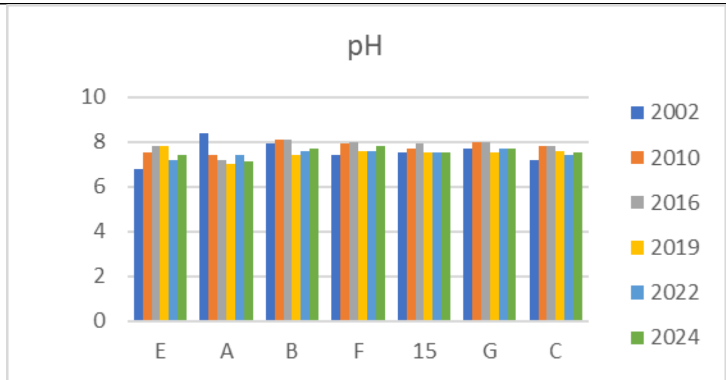
		E	A	B	F	15	G	C
Oxygen Saturation (%)	**2002**	61	132.4	47.5	50.4	70.2	70.2	98.5
	2010	83	76	93	73	71	96	89
	2016	103	64	101	78	81	100	89
	2019	96.5	96.1	92.6	87	85.5	103.4	92.6
	2022	71.9	82.8	78.4	79.5	64.5	82.3	68.5
	2024	76	65	94	56.0	76	81	61
Conductivity (µS/cm)	**2002**	202	610	598	307	334	358	176
	2010	218	279	828	828	597	649	639
	2016	199	228	3360	3340	2500	2350	2270
	2019	134.7	184.1	3126	3139	2377	1800	1782
	2022	203	256	3430	3440	2770	2530	2760
	2024	162	219	1936	1908	1345	1218	1275
Conductivity (mS/m)	**2002**	20.2	61	59.8	30.7	33.4	35.8	17.6
	2010	21.8	27.9	82.8	82.8	59.7	64.9	63.9
	2016	19.9	22.8	336	334	250	235	227
	2019	16.1	23.7	331	337	268	210	206
	2022	20.3	25.6	343	344	277	253	276
	2024	16.2	21.9	193.6	190.8	134.5	121.8	127.5

Corresponding graph



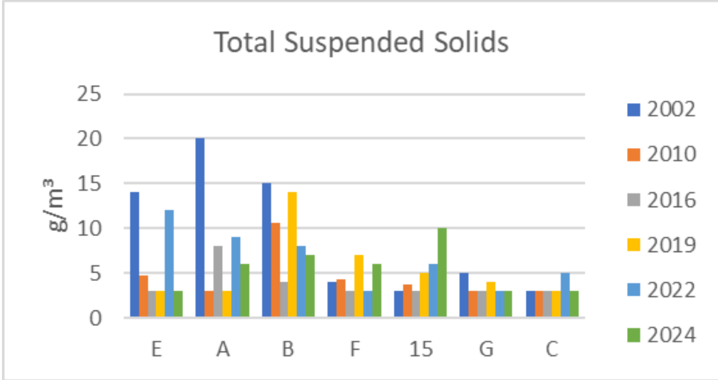


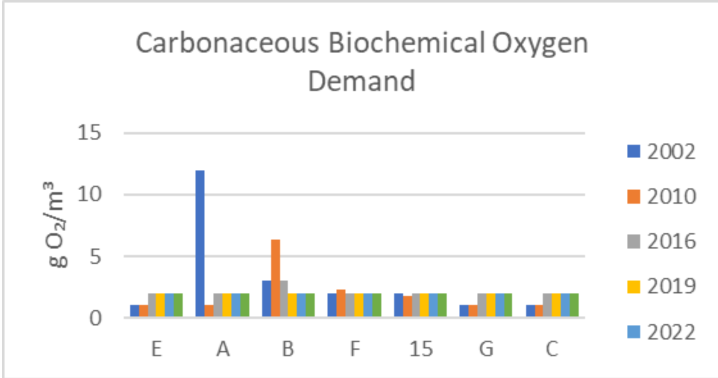


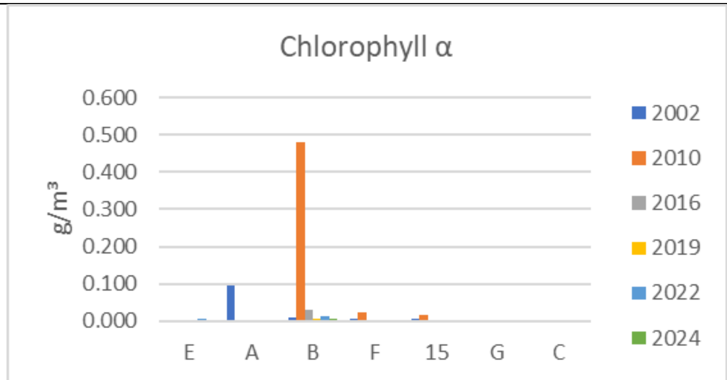
		E	A	B	F	15	G	C	Corresponding graph
Salinty (ppt)	**2002**								
	2010								
	2016								
	2019	0.08	0.11	1.74	1.77	1.39	1.08	1.06	
	2022	0.11	0.12	1.86	1.85	1.5	1.36	1.48	
	2024	0.08	0.08	1.01	1	0.68	0.62	0.65	
Visual Clarity (m)	**2002**	0.97	0.42	0.66	0.85	0.9	1	0.84	
	2010	0.42	0.72	0.38	0.65	0.54	0.67	0.62	
	2016	1	0.48	0.88	1	1	1	1	
	2019	0.54	0.69	0.43	0.46	0.66	0.68	0.81	
	2022	0.36	0.75	0.51	0.67	0.5	0.6	0.9	
	2024	0.7	0.47	0.76	0.75	0.72	0.8	0.78	
pH (pH unit)	**2002**	6.8	8.4	7.9	7.4	7.5	7.7	7.2	
	2010	7.5	7.4	8.1	7.9	7.7	8	7.8	
	2016	7.8	7.2	8.1	8	7.9	8	7.8	
	2019	7.8	7	7.4	7.6	7.5	7.5	7.6	
	2022	7.2	7.4	7.6	7.6	7.5	7.7	7.4	
	2024	7.4	7.1	7.7	7.8	7.5	7.7	7.5	

Parameter	Year	E	A	B	F	15	G	C
Total Suspended Solids (g/m³)	**2002**	14	20	15	4	3	5	3
	2010	4.7	3	10.6	4.3	3.7	3	3
	2016	3	8	4	3	3	3	3
	2019	3	3	14	7	5	4	3
	2022	12	9	8	3	6	3	5
	2024	3	6	7	6	10	3	3
Carbonaceous Biochemical Oxygen Demand (g O_2/m³)	**2002**	1	12	3	2	2	1	1
	2010	1	1	6.3	2.3	1.8	1	1
	2016	2	2	3	2	2	2	2
	2019	2	2	2	2	2	2	2
	2022	2	2	2	2	2	2	2
	2024	2	2	2	2	2	2	2
Chlorophyll α (g/m³)	**2002**	0.003	0.097	0.011	0.005	0.005	0.003	0.003
	2010	0.003	0.004	0.480	0.023	0.016	0.003	0.003
	2016	0.003	0.003	0.031	0.003	0.003	0.003	0.003
	2019	0.003	0.003	0.006	0.003	0.003	0.003	0.003
	2022	0.008	0.003	0.013	0.003	0.003	0.003	0.003
	2024	0.003	0.003	0.006	0.003	0.003	0.003	0.003

Corresponding graph

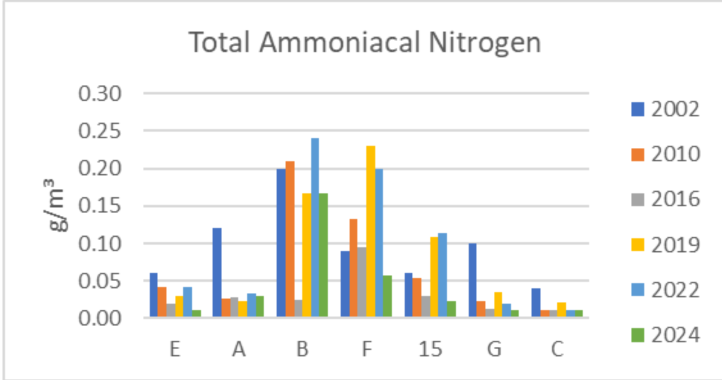


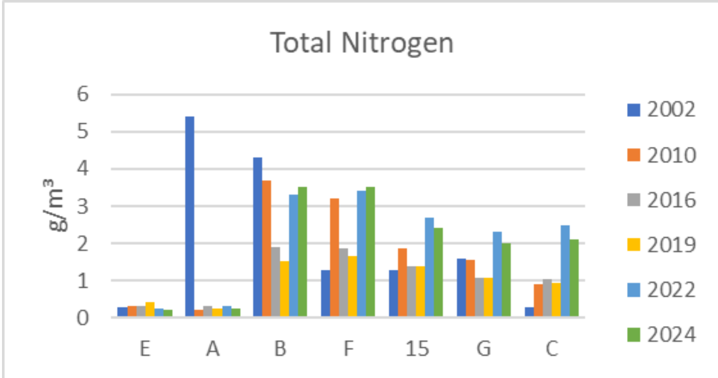


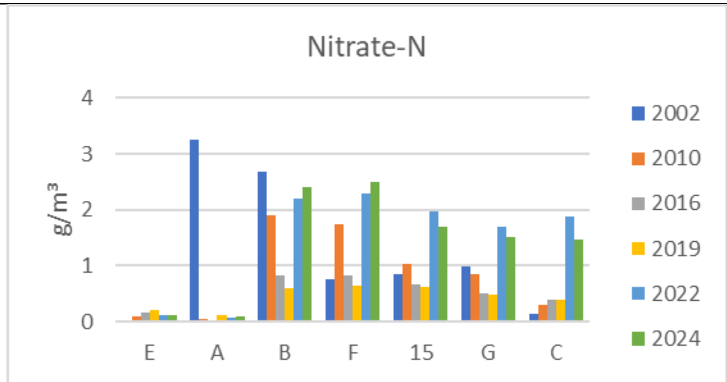


		E	A	B	F	15	G	C
Total Ammoniacal Nitrogen (g/m^3)	2002	0.1	0.1	0.2	0.1	0.1	0.1	0.0
	2010	0.0	0.0	0.2	0.1	0.1	0.0	0.0
	2016	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	2019	0.0	0.0	0.2	0.2	0.1	0.0	0.0
	2022	0.0	0.0	0.2	0.2	0.1	0.0	0.0
	2024	0.0	0.0	0.2	0.1	0.0	0.0	0.0
Total Nitrogen (g/m^3)	2002	0.3	5.4	4.3	1.3	1.3	1.6	0.3
	2010	0.32	0.22	3.7	3.2	1.86	1.57	0.91
	2016	0.33	0.32	1.89	1.86	1.4	1.08	1.03
	2019	0.44	0.25	1.53	1.65	1.4	1.08	0.94
	2022	0.25	0.33	3.3	3.4	2.7	2.3	2.5
	2024	0.23	0.25	3.5	3.5	2.4	2	2.1
Nitrate-N (g/m^3)	2002	0.032	3.26	2.68	0.761	0.844	0.992	0.152
	2010	0.103	0.058	1.9	1.74	1.04	0.85	0.31
	2016	0.157	0.015	0.82	0.82	0.67	0.51	0.4
	2019	0.2	0.11	0.61	0.64	0.62	0.49	0.4
	2022	0.116	0.082	2.2	2.3	1.97	1.7	1.89
	2024	0.115	0.099	2.4	2.5	1.69	1.51	1.47

Corresponding graph

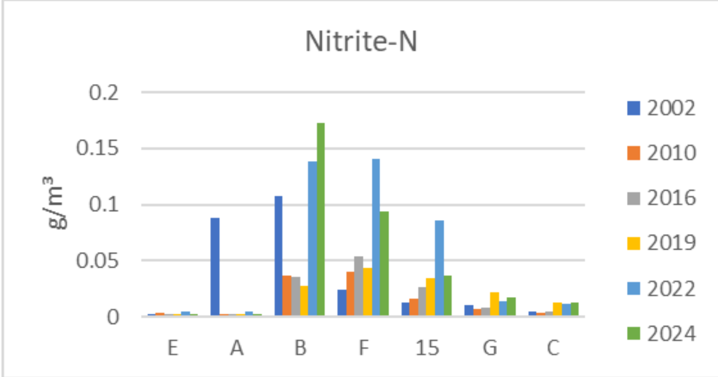


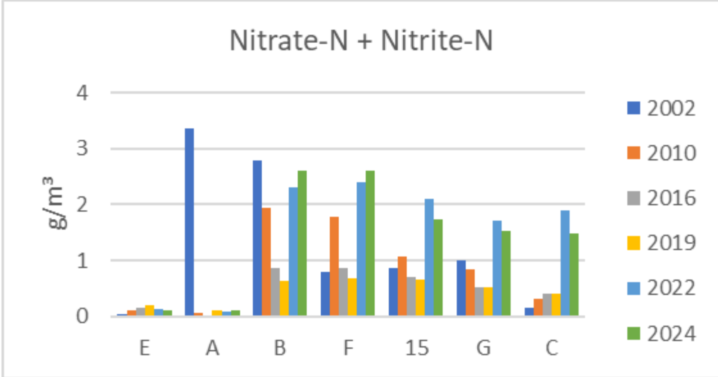


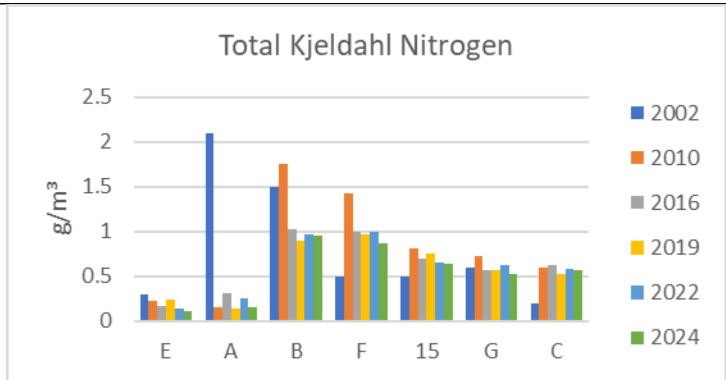


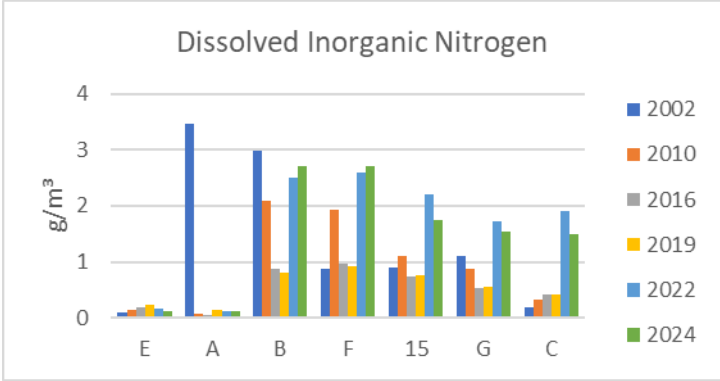
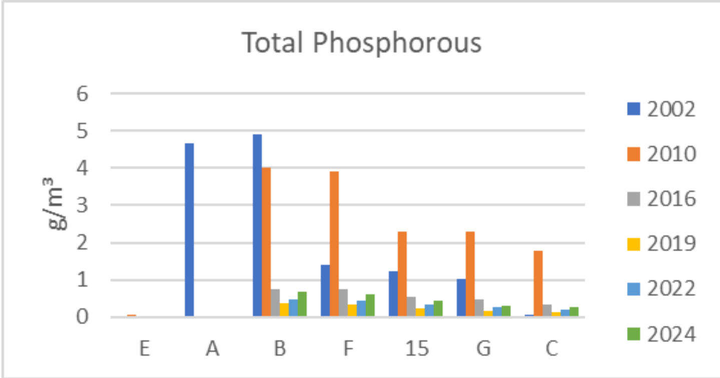
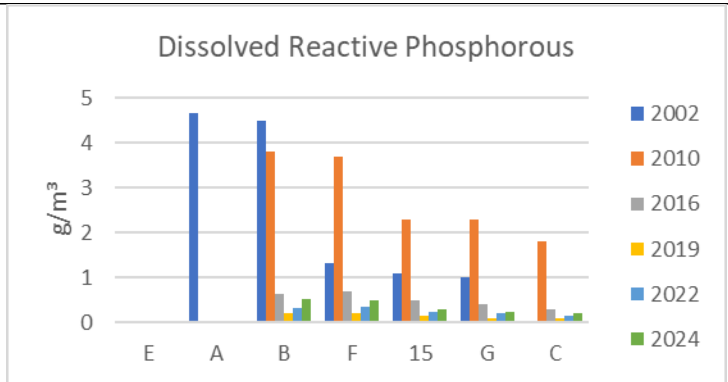
Parameter	Year	E	A	B	F	15	G	C
Nitrite-N (g/m³)	2002	0.002	0.088	0.107	0.024	0.012	0.01	0.004
	2010	0.0032	0.002	0.036	0.04	0.0158	0.007	0.0034
	2016	0.002	0.002	0.035	0.054	0.026	0.008	0.005
	2019	0.002	0.002	0.027	0.044	0.034	0.022	0.013
	2022	0.004	0.004	0.138	0.141	0.086	0.014	0.011
	2024	0.002	0.002	0.173	0.094	0.036	0.017	0.013
Nitrate-N + Nitrite-N (g/m³)	2002	0.034	3.348	2.787	0.785	0.856	1.002	0.156
	2010	0.106	0.06	1.94	1.78	1.06	0.85	0.32
	2016	0.159	0.017	0.86	0.87	0.7	0.52	0.41
	2019	0.21	0.11	0.64	0.68	0.65	0.52	0.41
	2022	0.12	0.086	2.3	2.4	2.1	1.71	1.9
	2024	0.117	0.101	2.6	2.6	1.73	1.52	1.49
Total Kjeldahl Nitrogen (g/m³)	2002	0.3	2.1	1.5	0.5	0.5	0.6	0.2
	2010	0.22	0.155	1.75	1.43	0.81	0.72	0.6
	2016	0.17	0.31	1.03	0.99	0.7	0.56	0.62
	2019	0.23	0.14	0.89	0.96	0.75	0.56	0.52
	2022	0.13	0.25	0.96	0.99	0.65	0.62	0.58
	2024	0.11	0.15	0.95	0.87	0.63	0.52	0.57

Corresponding graph



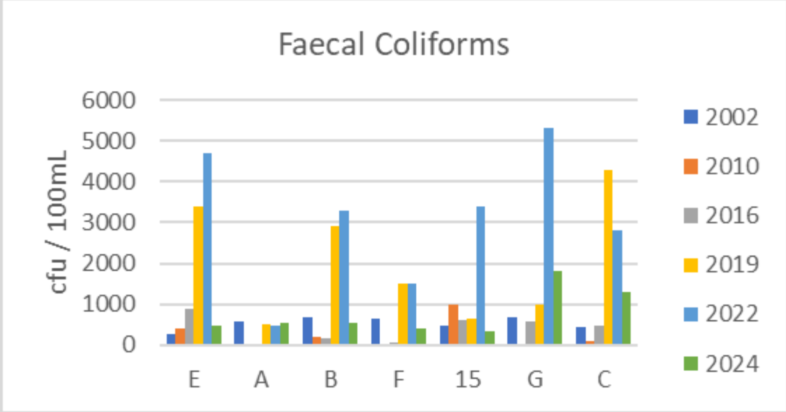


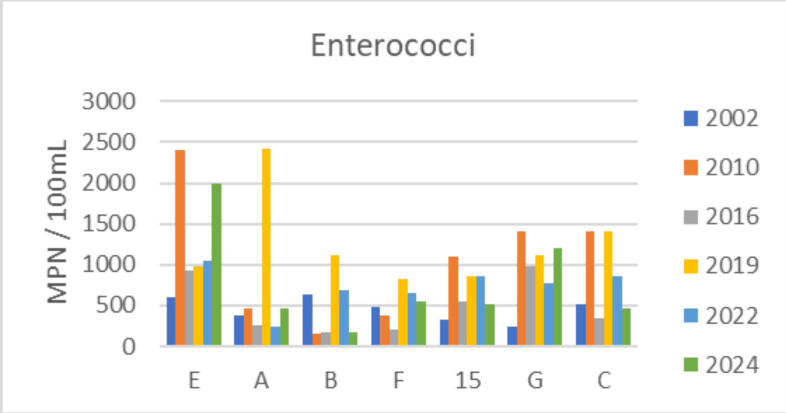


Parameter	Year	E	A	B	F	15	G	C	Corresponding graph
Dissolved Inorganic Nitrogen (g/m³)	**2002**	0.09	3.47	2.98	0.87	0.91	1.1	0.2	
	2010	0.148	0.086	2.1	1.92	1.11	0.87	0.32	
	2016	0.179	0.044	0.88	0.96	0.73	0.53	0.41	
	2019	0.24	0.133	0.8	0.92	0.76	0.55	0.43	
	2022	0.161	0.119	2.5	2.6	2.2	1.73	1.91	
	2024	0.128	0.13	2.7	2.7	1.75	1.53	1.5	
Total Phosphorous (g/m³)	**2002**	0.019	4.66	4.89	1.41	1.22	1.04	0.051	
	2010	0.058	0.025	4	3.9	2.3	2.3	1.77	
	2016	0.04	0.037	0.74	0.74	0.55	0.46	0.35	
	2019	0.036	0.026	0.38	0.34	0.24	0.164	0.144	
	2022	0.041	0.031	0.49	0.44	0.33	0.28	0.2	
	2024	0.04	0.029	0.69	0.61	0.45	0.32	0.28	
Dissolved Reactive Phosphorous (g/m³)	**2002**	0.017	4.67	4.48	1.32	1.1	0.992	0.039	
	2010	0.04	0.013	3.8	3.7	2.3	2.3	1.79	
	2016	0.029	0.008	0.64	0.68	0.48	0.4	0.28	
	2019	0.008	0.007	0.192	0.21	0.149	0.091	0.077	
	2022	0.02	0.013	0.33	0.34	0.23	0.21	0.146	
	2024	0.015	0.005	0.51	0.48	0.29	0.24	0.2	

		E	A	B	F	15	G	C
Faecal Coliforms (cfu / 100mL)	**2002**	280	570	670	650	480	680	430
	2010	410	12	210	24	1000	39	100
	2016	900	22	150	70	600	590	470
	2019	3,400	510	2,900	1,500	660	1,000	4,300
	2022	4,700	490	3,300	1,500	3,400	5,300	2,800
	2024	460	560	540	410	340	1,800	1,300
Enterococci (MPN / 100mL)	**2002**	600	380	630	480	320	240	520
	2010	2400	460	150	370	1100	1400	1400
	2016	921	260	172	214	548	980	345
	2019	985	2,420	1,120	816	866	1,120	1,414
	2022	1,046	236	687	649	866	770	866
	2024	1,986	461	166	549	517	1,203	461

Corresponding graph

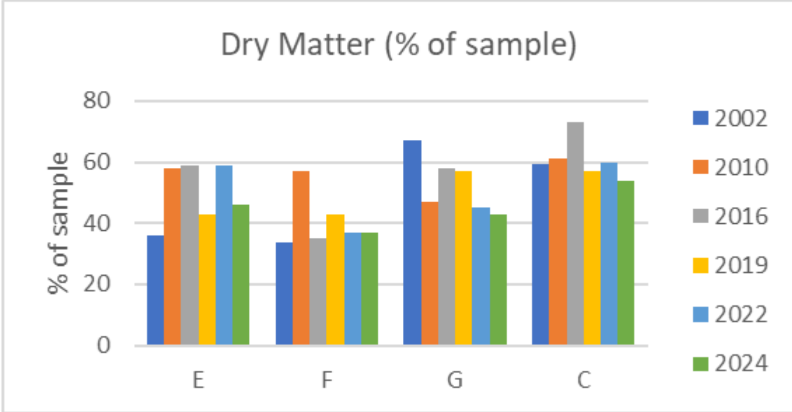


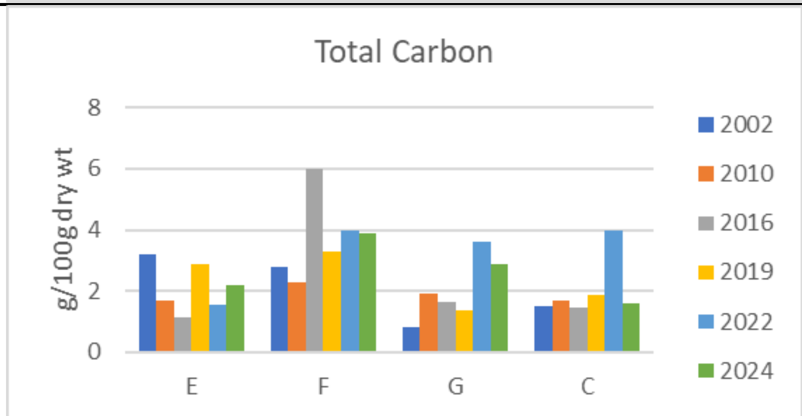


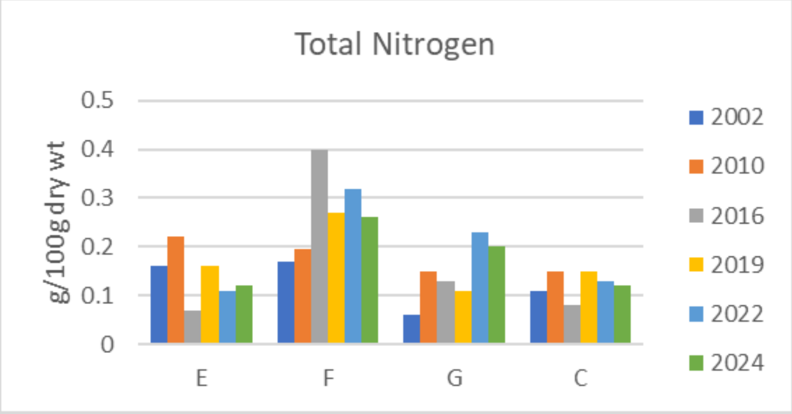
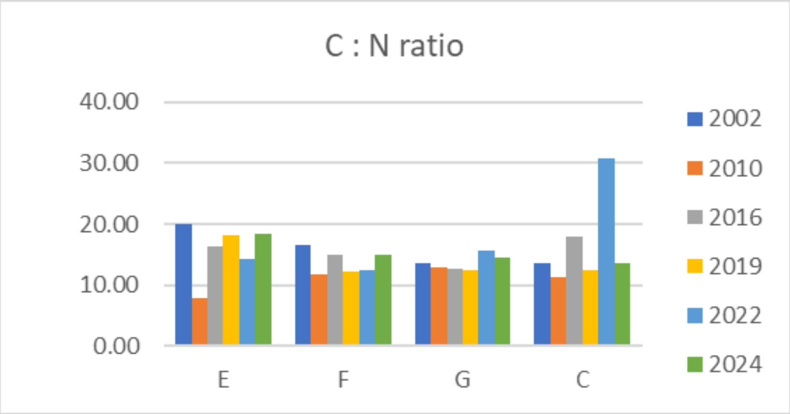
6.2 Sediment Quality

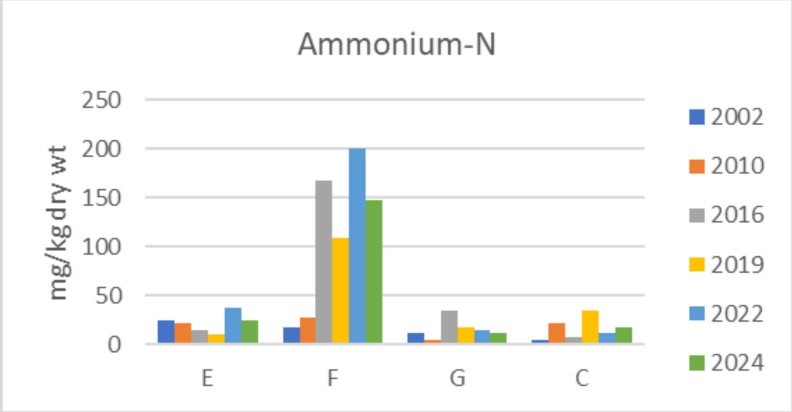
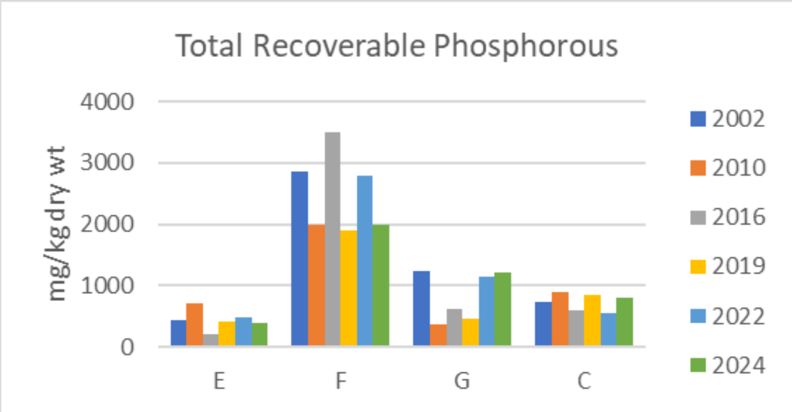
		E	F	G	C
Dry Matter (% of sample)	**2002**	35.9	33.9	66.9	59.1
	2010	58	57	47	61
	2016	59	35	58	73
	2019	43	43	57	57
	2022	59	37	45	60
	2024	46	37	43	54
Total Carbon (g/100g dry wt)	**2002**	3.184	2.805	0.822	1.496
	2010	1.71	2.3	1.93	1.71
	2016	1.14	6	1.65	1.44
	2019	2.9	3.3	1.36	1.86
	2022	1.56	4	3.6	4
	2024	2.2	3.9	2.9	1.62

Corresponding graph





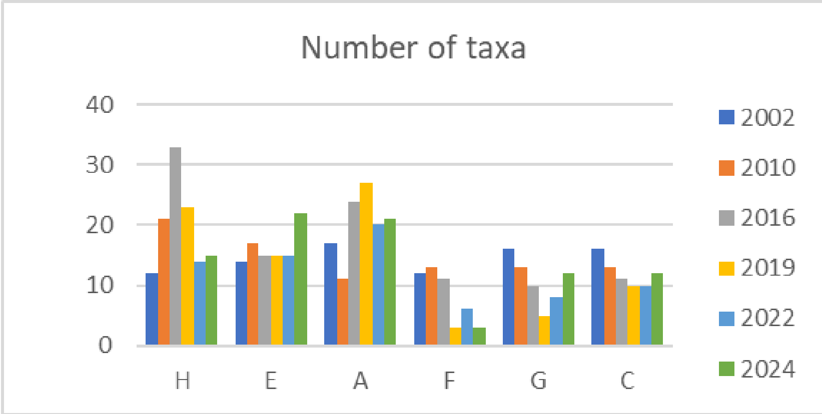
		E	F	G	C	Corresponding graph
Total Nitrogen (g/100g dry wt)	**2002**	0.16	0.17	0.06	0.11	
	2010	0.22	0.196	0.149	0.15	
	2016	0.07	0.4	0.13	0.08	
	2019	0.16	0.27	0.11	0.15	
	2022	0.11	0.32	0.23	0.13	
	2024	0.12	0.26	0.2	0.12	
C : N ratio	**2002**	19.90	16.50	13.70	13.60	
	2010	7.77	11.73	12.95	11.40	
	2016	16.29	15.00	12.69	18.00	
	2019	18.13	12.22	12.36	12.40	
	2022	14.18	12.50	15.65	30.77	
	2024	18.33	15.00	14.50	13.50	

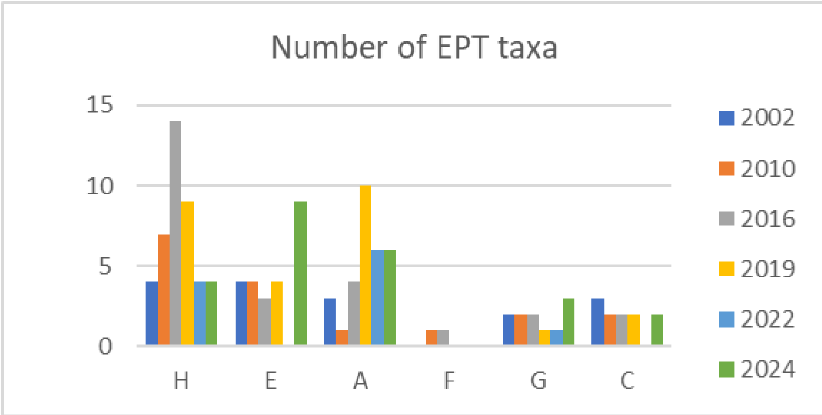
		E	F	G	C	Corresponding graph
Ammonium-N (mg/kg dry wt)	2002	25	17	11	5	
	2010	22	28	5	22	
	2016	15	168	35	7	
	2019	10	109	17	34	
	2022	38	200	15	12	
	2024	24	148	11	18	
Total Recoverable Phosphorous (mg/kg dry wt)	2002	440	2860	1230	730	
	2010	700	2000	370	880	
	2016	194	3500	620	590	
	2019	400	1890	450	850	
	2022	480	2800	1150	540	
	2024	380	2000	1210	800	

6.3 Macroinvertebrates

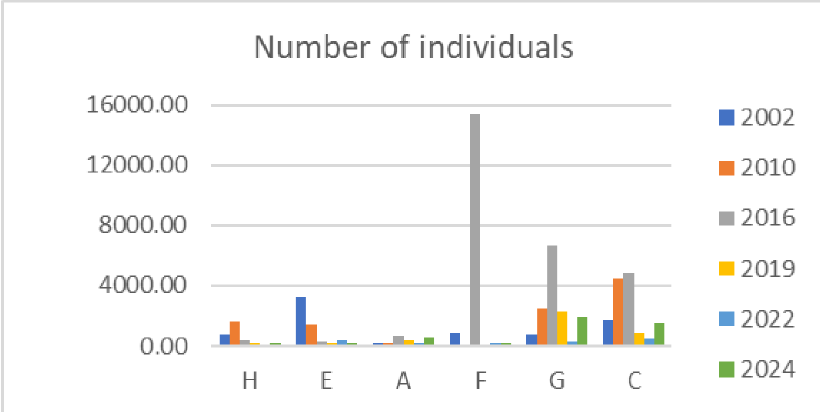
		H	E	A	F	G	C
NO. TAXA	2002	12	14	17	12	16	16
	2010	21	17	11	13	13	13
	2016	33	15	24	11	10	11
	2019	23	15	27	3	5	10
	2022	14	15	20	6	8	10
	2024	15	22	21	3	12	12
NO. EPT TAXA	2002	4	4	3	0	2	3
	2010	7	4	1	1	2	2
	2016	14	3	4	1	2	2
	2019	9	4	10	0	1	2
	2022	4	0	6	0	1	0
	2024	4	9	6	0	3	2

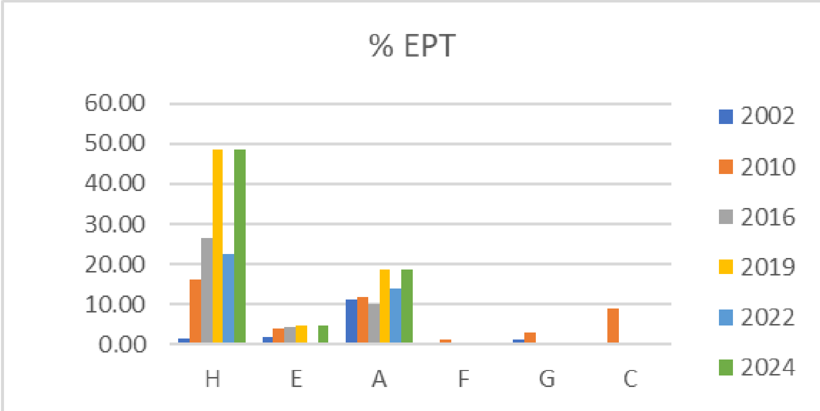
Corresponding Grah

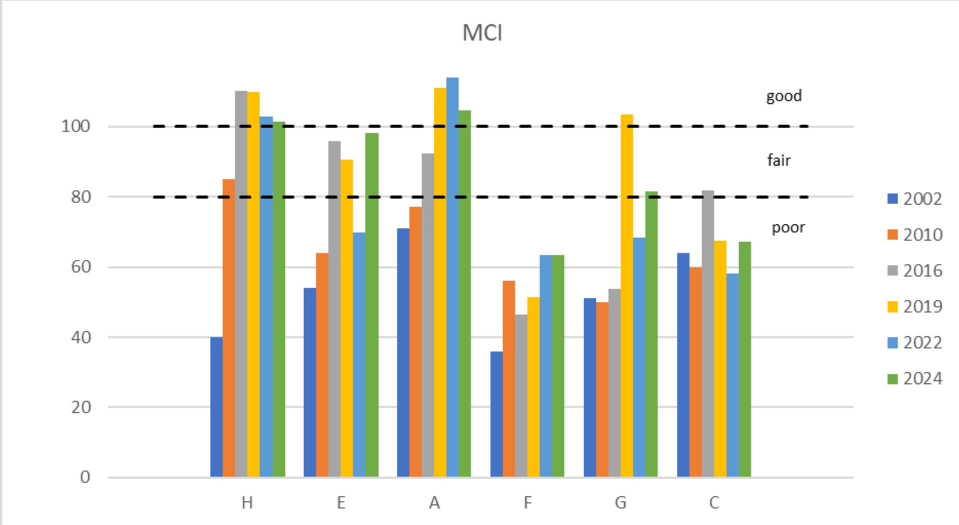
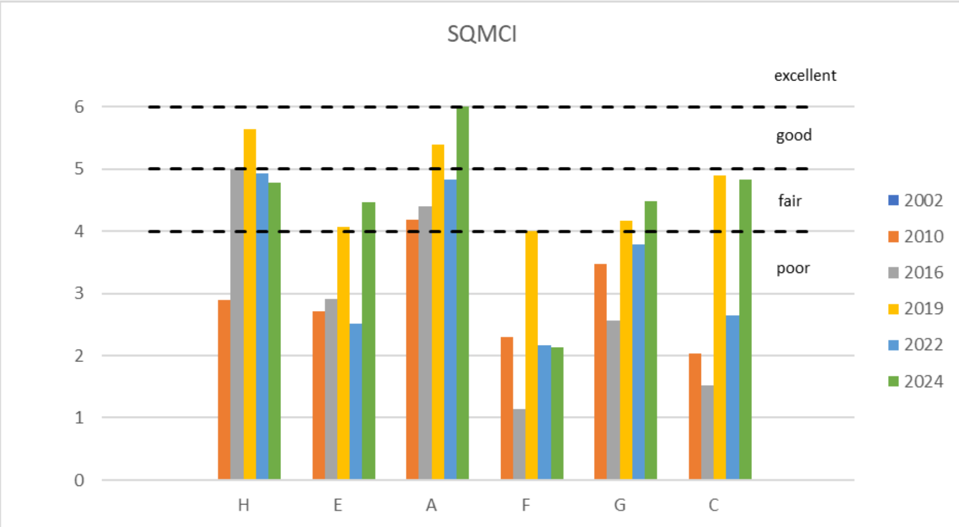




		H	E	A	F	G	C	Corresponding Grah
NO. INDIVIDUALS	2002	748	3256	217	876	745	1747	
	2010	1636	1460	180	129	2500	4508	
	2016	384	294	669	15418	6675	4869	
	2019	192	147	412	103	2265	832	
	2022	49	360	181	199	316	451	
	2024	149	225	525	183	1911	1534	
% EPT	2002	1.50	1.70	11.10	0.00	1.30	0.02	
	2010	16.00	4.00	12.00	1.00	3.00	9.00	
	2016	26.56	4.42	10.16	0.00	0.00	0.02	
	2019	48.44	4.76	18.45	0.00	0.04	0.36	
	2022	22.45	0.00	13.81	0.00	0.32	0.00	
	2024	48.44	4.76	18.45	0.00	0.04	0.36	





		H	E	A	F	G	C	Corresponding Grah
MCI	**2002**	40.00	54.00	71.00	36.00	51.00	64.00	
	2010	85.00	64.00	77.00	56.00	50.00	60.00	
	2016	110.30	95.73	92.42	46.36	53.80	81.82	
	2019	110.00	90.53	111.19	51.33	103.60	67.40	
	2022	102.86	69.73	113.90	63.33	68.25	58.20	
	2024	101.33	98.18	104.67	63.33	81.67	67.33	
SQMCI	**2002**	0	0	0	0	0	0	
	2010	2.89	2.71	4.18	2.29	3.48	2.04	
	2016	5.00	2.91	4.40	1.15	2.57	1.52	
	2019	5.64	4.06	5.39	4.00	4.17	4.89	
	2022	4.93	2.51	4.83	2.16	3.78	2.65	
	2024	4.78	4.46	6.01	2.13	4.49	4.83	