Water Quality and River Ecology Data Explorer User Guide and Methodology

Supplementary Report

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Auckland city from the air. Credit: Environmental Evaluation and Monitoring Unit.

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1. Overview

Auckland Council has a stewardship role to protect and restore our natural environment, preserving it for current and future generations. The Auckland Council Environmental Evaluation and Monitoring Unit (EEMU) monitors the state of the environment from the mountains to the sea to assess the health of the environment, to track changes over time and to identify potential issues.

In 2025, the Water Quality and River Ecology Data Explorer was created to provide an interactive summary of water quality and freshwater ecology data collected by EEMU across the rivers, lakes, groundwater, and coast of Tāmaki Makaurau. The Data Explorer replaces previous annually produced hard copy reports on coastal and river water quality and aims to make this information more accessible and provide different levels of detail for a range of users [1].

This tool provides data analyses and summary statistics for water quality data spanning hydrological years (July to June) from July 2009[2] to the most recent time period and river ecology data spanning hydrological years from summer 2002 to the most recent time period. The Data Explorer will be updated annually.

This methodology report includes further information on how to use the tool, methods used for the statistical and graphical analyses presented on the explorer, and additional background information on each programme including sampling methods and data management.

[1] This Data Explorer does not include all water quality or river ecology data collected by EEMU. Several programmes include new sites that do not yet meet the data requirements used for the explorer. We also manage other programmes, including those with continuous data that are not yet provided in this format. Please contact EEMU (Environmentaldata@aklc.govt.nz) for further information.

[2] Earlier data are available from Auckland Council for many sites and parameters. The oldest records available date back to 1987. Data can be requested from Environmentaldata@aklc.govt.nz.

Domains	Time periods	Data display
• Lake water quality • Groundwater quality • Coastal water quality • River water quality • River ecology	• Hydrological years (01 July to 30 June) • Water quality time periods customisable from 2009 to most recent hydrological year[1] • River ecology time periods customisable from 2002 to most recent hydrological year[1] • Minimum of five years data required for analysis (unless specified)	• Box plots: Summary statistics and variability • Map: Spatial patterns • Table: Summary statistics • Time series • Seasonal box plots (lake, coastal & river water quality only) • Depth profiles and stratification (lake water quality only)

[1] Data explorer is updated annually at end of calendar year.

2. How to use the Data Explorer

The Data Explorer includes brief text explaining how to use each data display and Figure 1 below provides a quick guide.

This section of this report provides a more detailed explanation of what you see and how to navigate each type of data display (2.1. Data types), more information on the parameters available (2.2.1. Select parameters), and more information on the site grouping options (2.2.2. Select site grouping).

Choose a tab	•Across the top of the page are tabs for each programme. •You can also change between programme tabs by Selecting Dataset within a data display.
Choose the type of data display	•For each programme tab there is a drop down list with different types of data display. •Start with the overall Box Plots or Map for an overview. •See Data Types for more information.
Follow the numbered steps to choose what is displayed	•Select the parameter(s) you are interested in. •If you choose 'all' parameters or sites it can take some time to load. •Change the default settings for the time period or filter different sites and display options.
View the data	•Charts are fully interactive. •Hover over points to see pop ups of the number values. •Zoom in on sections of graphs by clicking and dragging the mouse. •You can save images (.png files) of your selected graphics.
Find out more	•Notes tab in the Data Explorer: Key definitions. •Methodology Report: How to Use the Data Explorer. More information on the data analysis and monitoring methods. •Supplementary reports: Summary results from the most recent five years.

Figure 1: Quick guide to using the Data Explorer.

2.1. Data types

2.1.1. Box plots

The Box Plot display can be selected for lake, groundwater, coastal, and river water quality programme tabs. Box plots are not provided for river ecology information due to the lower frequency of observations (annual) compared to water quality data (monthly, or quarterly for groundwater).

Box plots compare each parameter across multiple sites. Double clicking on the box for a single site will take you to a new plot showing rolling boxplots for that single site, where each box represents a five-year period (or three-year with a black outline) for the year ending shown at the bottom of the plot.

You must select at least one parameter to start with. See the section 2.2.1. Select parameters for more information. Plots of other parameters selected from the drop down list can be stacked underneath in separate plots. Click on selected parameters or sites and press 'backspace' or 'delete' to remove them from the selection.

When box plots display multiple sites within the Data Explorer, the sites are ordered according to key aspects influencing water quality or site groupings, such as land cover or geographical area. See section 2.2.2. Select site grouping for more information. The sites you have selected will be coloured on the small map displayed top right of the page.

For lakes only, box plots can also display results from surface and bottom water samples separately. See section 3.2. Lake water quality for more information.

The default time period is set to the most recent five years. The time period can be changed to any time period spanning at least five years and can extend back to 2010. The length of record available is shorter for some programmes, sites, or parameters. For the most recent time period only, new sites or new parameters with a minimum of three years of data are displayed as 'interim' values with a bold outline and sites with 'insufficient data' are presented as a red cross. See section 4.1.2 Minimum data requirements and data status for more information.

Box plots are fully interactive. Vertical axes are automatically fitted to the range of data for each parameter and will vary for each stacked plot. If it is difficult to see the boxes, you can select and zoom in on a smaller portion of the graph, or you can select to log the y-axis[3]. Double clicking on the plot will revert it to the default scale. Hovering over part of a box plot will display a pop up showing the numeric summary statistics. Click the camera icon that appears above the legend to download a copy of the graphics displayed.

An example box plot appears in the boxplot explainer button on the Data Explorer (Figure 2). Box plots illustrate percentile statistics graphically. Percentiles are a way of ranking data over the observed data range, e.g. if a value is in the 20th percentile, this means 20% of all the data recorded is the same or lower. The boxes represent the inter-quartile range (25th and 75th percentiles), the centre line is the median (50th percentile), and the whiskers (vertical lines) show the 5th and 95th percentiles. Values beyond that range are plotted as outliers.

Viewing multiple sites side by side allows for easy comparison of the range of data across different sites or groups of sites. Viewing a single site over time allows for easy comparison of the variability in the range of

[3] A log scale is a method used to display values spanning a wide range. The scale is non-linear and increases exponentially. For example, instead of spacing being equal between values of 1,2,3,4, and 5, spacing is equal between values of 0.01,0.1,1,10, and 100.

data over time. However, detailed trend analysis is required to robustly assess changes at a site, which is not displayed on the Data Explorer.

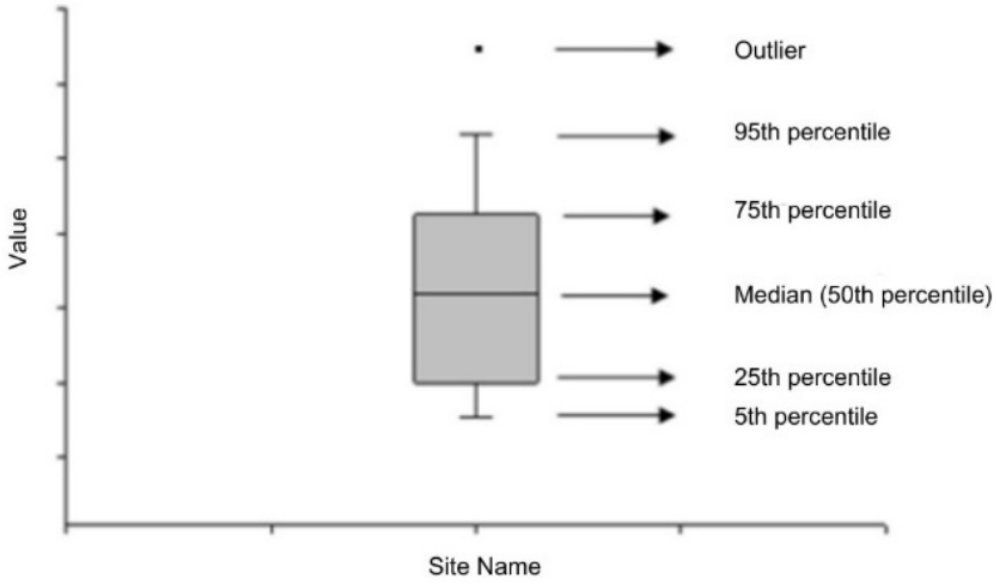

Figure 2: Example box plot.

2.1.2. Map

The Map display can be selected for all programme tabs to view spatial patterns in water quality and river ecology parameters. You must select a parameter (see section 2.2.1. Select parameters) to start with. You can only select one parameter to view at a time.

Click and drag to move around the map and double click or scroll to zoom in. Hover the mouse over a site for a pop up with the site name and the value displayed.

The default time period is set to the most recent five years. The time period can be changed to any time period spanning at least five years and can extend back to 2010. The length of record available is shorter for some programmes, sites, or parameters. For the most recent time period only, new sites or new parameters with a minimum of three years of data are displayed as 'interim' values with a bold outline and sites with 'insufficient data' are presented as a red cross. See section 4.1.2 Minimum data requirements and data status for more information.

The default statistic is set to the median value. The 5th and 95th percentile statistics can also be selected for water quality programmes or the minimum and maximum values for river ecology. Due to differences in frequency of observations, for Stream Ecological Values only, depending on the time period selected, this may reflect only a single sampling event and the minimum to maximum values will be the same (See section 4.1.2 Minimum data requirements and data status for more information).

The legend ranges from the smallest value to the largest value within the selected period for the selected parameter and will automatically change when viewing different statistics, time periods, or parameters. The colours assigned do not represent water quality state or condition relative to any water quality guidelines.

2.1.3. Table

The Table display can be selected for all programme tabs. The table enables you to view and download the summary statistics and site information that is displayed in the different graphics along with additional

information on data status. Summary statistics for the seasonal box plots, and raw observations visible in the Time Series tab are not included in the table.

You must select at least one parameter (see section 2.2.1. Select parameters) and at least one site to start with. You must select the parameter(s) before selecting the site(s). Hover over sites in the map in the top right corner to check site names. The sites you have selected will be coloured on the small map displayed top right of the page. Click on selected parameters or sites and press 'backspace' or 'delete' to remove them from the selection.

For the Lakes programme only, the Table tab also includes additional information on annual lake Trophic Index Scores that are not displayed elsewhere. See the Trophic Level Index (TLI) in section 3.3.3. Data collection for more information.

The default time period is set to the most recent five years. The time period can be changed to any time period spanning at least five years and can extend back to 2010. The length of record available is shorter for some programmes, sites, or parameters. For the most recent time period only, new sites or new parameters with a minimum of three years of data are recorded as 'interim' values, and sites that do not have enough information for display are recorded as 'insufficient data' in the status column. See section 4.1.2 Minimum data requirements and data status for more information

The information selected will appear in a Table below. You can then click the 'Download Table' button to start the download. By downloading data, you agree to our data disclaimer on the Notes tab.

2.1.4. Time series

The Time Series display can be selected for all programmes. The time series displays the underlying observations that are summarised in box plots and other graphics and can be used to investigate the timing of outliers, view seasonal patterns, identify censored values, or view the information available for sites that don't meet the minimum data requirements for summary statistics.

Individual observations can be viewed for each site and parameter for each sampling event (monthly or quarterly for water quality and annually or less frequently for river ecology). Sampling events are aligned on the X axis. Sites are monitored on different days within each month, see programme specific methodology for more information.

The display can be toggled to allow plots to be stacked for multiple sites for a single parameter or for multiple parameters for a single site.

- If the display is set to Multiple Sites (default) - You must select a parameter (see section 2.2.1. Select parameters) and then at least one site to start with. You must select the parameter before selecting the site(s). Hover over sites in the map in the top right corner to check site names. Click on selected sites and press 'backspace' or 'delete' to remove them from the selection.
- If the display is set to Multiple Parameters – You must select parameter(s) first and then select the site of interest. Click on selected parameters and press 'backspace' or 'delete' to remove them from the selection.

The plots are fully interactive. Vertical axes are automatically fitted to the range of data for each site/parameter and will vary for each stacked plot. You can select and zoom in on a smaller portion of the graph by clicking and dragging around the area of interest. Double clicking on the plot will revert it to the default scale after you zoom in. Hovering over a point will show the month and the value of the observation. Click the camera icon that appears above the legend when you however over the plot to download a copy of the graphics displayed.

2.1.5. Seasonal box plots

Seasonal box plots can be selected for lake, coastal and river water quality programme tabs. Seasonal box plots are not provided for groundwater quality and river ecology due to the lower frequency of observations compared to other water quality data. Seasonal box plots allow for easy comparison of the variability in the range of data between seasons and may provide insights into changes in seasonal patterns across different years. Some parameters display strong seasonal patterns that are common across most sites while some parameters may show differences in seasonal patterns between sites or limited seasonal variability. Seasonal box plots may provide a useful reference for comparison with other data sets collected over short time frames.

The display can be toggled to allow plots to be stacked for multiple sites for a single parameter or for multiple parameters for a single site.

- If the display is set to Multiple Sites (default) - You must select a parameter (see section 2.2.1. Select parameters) and then at least one site to start with. You must select the parameter before selecting the site(s). Hover over sites in the map in the top right corner to check site names. Click on selected sites and press 'backspace' or 'delete' to remove them from the selection.
- If the display is set to Multiple Parameters – You must select parameter(s) first and then select the site of interest. Click on selected parameters and press 'backspace' or 'delete' to remove them from the selection.

The default time period is set to the most recent five years. The time period can be changed to any time period spanning at least five years and can extend back to 2010. The length of record available is shorter for some programmes, sites, or parameters. For the most recent time period only, new sites or new parameters with a minimum of three years of data are displayed as 'interim' values with a black outline. See section 4.1.2 Minimum data requirements and data status for more information.

Box plots are fully interactive. Vertical axes are automatically fitted to the range of data for each site/parameter and will vary for each stacked plot. If it is difficult to see the boxes, you can select and zoom in on a smaller portion of the graph, or you can select to log the y-axis. Double clicking on the plot will revert it to the default scale. Hovering over part of a box plot will display a pop up showing the number values. Click the camera icon that appears above the legend to download a copy of the graphics displayed.

An explanation of the information shown in the boxes is provided above in the Boxplots section and in a boxplot explainer box on the explorer.

The seasons are defined in accordance with those used by National Institute of Water and Atmospheric Research (NIWA)[4].

- Winter: June, July, August
- Spring: September, October, November
- Summer: December, January, February
- Autumn: March, April, May

2.1.6. Depth profiles

Depth profiles can be selected for the lake water quality programme only as this is the only programme where we measure water quality parameters at multiple depths. These plots can be used to show the

[4] See https://niwa.co.nz/climate-and-weather/common-climate-and-weather-terms for definition of seasons.

difference in water quality between seasonally stratified and polymictic lake types (see Lake type in Section 2.2.2. Select site grouping). Assessing the depth profiles of these physio-chemical parameters can assist in understanding the stratification patterns within seasonally stratified lakes, and as more data are collected, can provide insights into changes in stratification processes across different years.

Depth profiles are available for three key physio-chemical parameters; dissolved oxygen, temperature, and pH (see Section 2.2.1. Select parameters). These profiles are displayed in heat map graphics where each tile represents a change in one metre depth. For some depths, the heat map tile is blank due to the equipment missing a record at that depth.

The legend ranges from the smallest value to the largest value for each parameter. The range of the legend will automatically change when viewing different sites or parameters. The colours assigned do not represent water quality state or condition of the site relative to any water quality guidelines.

The display can be toggled to allow plots to be stacked for multiple sites for a single parameter or for multiple parameters for a single site.

- If the display is set to Multiple Sites (default) - You must select a parameter (see Section 2.2.1. Select parameters) and then at least one site to start with. You must select the parameter before selecting the site(s). Click on selected sites and press ‘backspace’ or ‘delete’ to remove them from the selection. Hover over sites in the map in the top right corner to check site names.
- If the display is set to Multiple Parameters – You must select the parameter(s) first and then select the site of interest. Click on selected parameters and press ‘backspace’ or ‘delete’ to remove them from the selection.

The default time period is set to the most recent time period. Plots are fully interactive. Vertical axes are automatically fitted to the range of data for each site/parameter and will vary for each stacked plot. You can select and zoom in on a smaller portion of the graph. Double clicking on the plot will revert it to the default scale. Hovering over part of a box plot will display a pop up showing the date, depth and values. Click the camera icon that appears above the legend to download a copy of the graphics displayed.

2.1.7. Stratified conditions

The stratified conditions display can only be selected for the lake water quality programme, and only shows the seasonally stratified lakes. A lake is stratified when the difference between the surface temperature and the bottom water temperature is greater than 3°C (Burns et al., 2000). If the temperature difference is less than 3°C, the lake is classified as isothermal (well mixed). Assessing parameters under different mixing conditions can provide information on whether nutrients are being released from lakebed sediments through a process called internal nutrient loading.

This tab shows box plots providing a summary of the range of values observed over the selected time period for each parameter within each lake when stratified and when fully mixed (isothermal) (see Lake type in Section 2.2.2. Select site grouping).

The display can be toggled to allow plots to be stacked for multiple sites for a single parameter or for multiple parameters for a single site. Click on selected parameters or sites and press ‘backspace’ or ‘delete’ to remove them from the selection.

- If the display is set to Multiple Sites (default) - You must select a parameter (see section 2.2.1. Select parameters) and then at least one site to start with. You must select the parameter before selecting the site(s). Hover over sites in the map in the top right corner to check site names.

- If the display is set to Multiple Parameters – You must select parameter(s) first and then select the site of interest.

The default time period is set to the most recent time period. Box plots are fully interactive. Vertical axes are automatically fitted to the range of data for each site/parameter and will vary for each stacked plot. If it is difficult to see the boxes, you can select and zoom in on a smaller portion of the graph, or you can select to log the y-axis. Double clicking on the plot will revert it to the default scale. Hovering over part of a box plot will display a pop up showing the number values. Click the camera icon that appears above the legend to download a copy of the graphics displayed.

2.2. Options for display

2.2.1. Select parameters

A summary of parameters that can be viewed in the Data Explorer is provided in Table 1. Not all parameters are assessed for each programme. Some parameters are only assessed for a single programme.

Table 1: Summary of all parameters included within the Data Explorer.

	Parameter	Description
Physical Parameters	Salinity	Salinity is the concentration of dissolved salts in water. Estuarine waters range from 0.5 to 30 ppt and coastal or oceanic waters are usually 35 ppt. Salinity levels affect the toxicity of some contaminants.
	Conductivity	Electrical conductivity reflects the total ionic content of the water, which is affected by the presence of dissolved salts such as chloride, nitrate, nitrite, phosphate, sodium, magnesium, calcium etc. In freshwaters, conductivity is a crude indicator of how much matter is in the water while in saline waters, conductivity is closely related to salinity. Deionised (nearly pure) water has a conductivity of approximately 0.05 mS/cm while seawater is approximately 50 mS/cm.
	Temperature	Surface water temperature is primarily driven by seasonal and diurnal changes in solar radiation and climatic conditions. Temperature affects biological processes and moderates the toxicity of contaminants. Sites are monitored in the same order for consistency within site but differences between sites can be related to the time of day typically sampled.
	pH Total alkalinity	pH is a measure of the concentration of hydrogen ions in water. Low pH (<7) indicates that the water is more acidic, while high pH (>7) indicates it is more alkaline. Freshwaters are typically between pH 6.5 to 8 while coastal waters are usually highly stable at pH between 7.8 and 8.3. At sites with strong tidal influences pH will fluctuate with increasing or decreasing salinity. pH also fluctuates with diurnal cycles of photosynthesis and respiration and affects biological processes and toxicity of some contaminants such as metals. Total alkalinity refers to the water's ability to resist changes in pH. Alkaline compounds such as bicarbonates, carbonates, and hydroxides act as a buffer, helping to stabilise pH levels. The alkalinity of water is influenced by rocks and soils, salts, cycles of photosynthesis and respiration, and pollutants and discharges.
	Dissolved Oxygen (DO) mg/L Dissolved Oxygen % Saturation	Dissolved Oxygen (mg/L) is the concentration of dissolved oxygen present in the water, while DO (% saturation) expresses the amount of oxygen as a percentage of the maximum capacity of oxygen the water can hold depending on the temperature, atmospheric pressure and salinity conditions at the time. Cold water can hold more DO so the same concentration (mg/L) will have a lower saturation in cold water compared to warm water. Dissolved oxygen levels vary diurnally and seasonally as a result of plant photosynthesis and respiration of living organisms. Reduced DO levels can affect the growth and reproduction of aquatic organisms and in extreme cases cause stress and/or death.

	Parameter	Description
Water clarity	Turbidity	Turbidity is a measure of light scattered in water by particles including inorganic substances such as sediment and organic material such as algae. With increasing turbidity water becomes denser and sinks in the water column of calm waters.
	Total Suspended Solids	Total suspended solids are a measure of the concentration of suspended material in the water column such as plankton, non-living organic material, silica, clay and silt. Turbidity and total suspended solids are usually closely correlated but can vary where tannins or other coloured compounds can increase turbidity but are not associated with solid particles.
	Volatile Suspended Solids	Volatile suspended solids represent the organic matter content of the suspended solids in a water sample.
	Secchi depth	Secchi depth is the measurement technique to assess water clarity in lakes. Water clarity refers to the ability of light to travel through water, which is needed for aquatic plants to grow. Water clarity may be reduced when there is an increase in suspended sediment or how much algae is in the water.
	Visual clarity	Visual clarity is measured using a black disc or clarity tube to assess water clarity in rivers. Water clarity refers to the ability of light to travel through water, which is needed for aquatic plants to grow. Water clarity may be reduced when there is an increase in suspended sediment or how much algae is in the water.
Algae/ Phytoplankton	Chlorophyll a	Chlorophyll a is a photosynthetic pigment in plants and algae and is used as a measure of algal (phytoplankton) biomass in the water column. The concentration of chlorophyll a is affected by nutrients (which encourage algal growth), daylight, shading and flow regimes.
	Cyanobacteria biovolume	Cyanobacteria are a group of naturally occurring bacteria that can photosynthesise like true algae. In lakes, planktonic cyanobacteria are suspended in the water column and multiply to form 'blooms' in high concentrations. Blooms can reduce light in the water column, impact visual clarity and reduce the dissolved oxygen in the water. Some species can produce toxins that are harmful to animals and humans.
Nutrients	<u>Nitrogen Species</u> Ammoniacal Nitrogen (NH_3, NH_4^+-N) pH adjusted ammonia Nitrite-Nitrogen Nitrate-Nitrogen Total Oxidised Nitrogen (TOxN, NO_2 ,NO_3-N) Dissolved inorganic nitrogen (DIN) Total Nitrogen (TN)	Nitrogen (N) in the environment can be grouped into two main forms: organic nitrogen and inorganic nitrogen. Inorganic forms are bioavailable and can be taken up by plants. Organic N is not bioavailable and can only be converted to inorganic N via microbial processes (or production of inorganic fertilisers). High concentrations of bioavailable N can cause algal blooms, nuisance plant growth and eutrophication, and some forms can be toxic to aquatic organisms. <u>Inorganic (bioavailable) forms of N</u> Ammoniacal-N is a combination of un-ionised ammonia (NH3) and the ammonium ion ($NH4^+$). Un-ionised ammonia is the more toxic form to aquatic life and is highly dependent on water temperature, salinity and pH. For toxicity assessments, ammoniacal nitrogen results are adjusted for pH (see Adjustment for toxicity modifying factors). Nitrite-N is an intermediary product formed during the oxidation of ammonium via a microbial process called nitrification. The nitrification process rapidly converts nitrite to nitrate, so it is short lived in the environment. The presence of nitrite typically indicates an active discharge of inorganic (ammonium-containing) N in the immediate vicinity of the sampling site. Nitrate-N is the end product of the nitrification process. Nitrate is very stable and highly water soluble. It can be toxic to aquatic life in high concentrations. <u>Calculated descriptions of N</u> Total Oxidised N (TOxN) is the sum of nitrite and nitrate. Dissolved inorganic nitrogen is the total inorganic N fraction and is the sum of ammoniacal nitrogen, nitrite and nitrate nitrogen. Total Kjedahl Nitrogen is the sum of ammoniacal nitrogen and organic nitrogen (amino acids and proteins). <u>Total Nitrogen</u>

	Parameter	Description
		Total Nitrogen includes all forms of organic, inorganic, dissolved and particulate nitrogen.
	Dissolved Reactive Phosphorus (DRP) Total Phosphorus (TP)	Phosphorus is found in water as dissolved and particulate forms. Dissolved Reactive Phosphorus is immediately bioavailable and can be taken up by plants, adding to nuisance plant growth, eutrophication and algal blooms. Total Phosphorus is a measure of both dissolved and particulate forms in a water sample. Particulate phosphorus consists of organic material, as well as phosphorus in minerals and adsorbed onto mineral surfaces. The adsorption and desorption of phosphate from mineral surfaces creates a buffer that regulates dissolved phosphate concentrations in rivers and estuaries.
Bacteria	*E. coli*	*Escherichia coli* bacteria are found in the gut of warm-blooded animals (including humans, cows, ducks etc.). When found in rivers and lakes[5], *E. coli* indicate possible faecal pollution. While most *E. coli* themselves are harmless they serve as an easily detectable indicator for other harmful bacteria, protozoa or viruses which may also be in the water, causing increased risk to human health.
Metals and toxicity modifiers	Soluble copper Total copper	Soluble copper is the fraction of copper dissolved in the water, while total copper includes all forms of dissolved and particulate copper. Copper can be toxic to aquatic fauna in high concentrations. The dissolved fraction more closely represents the bioavailable portion in rivers, but several other water chemistry factors can influence this. The toxicity of copper to freshwater organisms is most strongly influenced by interactions with dissolved organic matter where lower toxicity is observed in the presence of dissolved organic carbon content.
	Dissolved organic carbon (DOC)	Dissolved organic carbon is a measure of dissolved organic matter from the decay of leaf litter and macrophytes and algae and from leaching through organic rich soils (such as wetlands), or from the discharge of wastewater. It is a source of energy in stream food webs and consequently has an influence on stream ecosystem metabolism. Dissolved organic carbon includes humic substances that can be yellow or brown in colour which can attenuate light and reduce water clarity.
	Soluble zinc Total zinc	Soluble zinc is the fraction of zinc dissolved in the water, while total zinc includes all forms of dissolved and particulate zinc. Zinc can be toxic to aquatic fauna in high concentrations. The dissolved fraction more closely represents the bioavailable portion in rivers, but several other water chemistry factors can influence this. The toxicity of zinc to freshwater organisms is most influenced by pH, dissolved organic matter, and water hardness.
	Total hardness	Total water hardness is the sum of calcium and magnesium concentrations as calcium carbonate in the water. These compounds generally originate from the weathering of rocks and soil. Water containing calcium carbonate at less than 60 mg/L is generally considered 'soft', 60-120 mg/L 'moderately hard', and 120-180 mg/L 'hard' (WHO, 2011). Most New Zealand waters are considered to be soft (MoH, 2018).
Other lake	Lake level	The relative height of the lake water in metres, read from a fixed staff gauge at the lake edge. Fluctuations in lake level are expected throughout the seasons in relation to rainfall and groundwater levels.
Other groundwater	Soluble iron Soluble manganese	Soluble iron and manganese are dissolved fractions of these two metals, usually occurring naturally where groundwater comes into contact with the soils, rocks and minerals containing solid iron and manganese. The solubility of iron and manganese is affected by the oxygen content of the water (dissolves more readily in deoxygenated conditions) and pH (dissolves more readily in acidic conditions). Changes in these compounds can indicate changes or contamination in the wider environment and they are important from a human health perspective.
	Soluble potassium Soluble sodium	Soluble sodium and potassium are salts dissolved in groundwater, occurring where groundwater passes through soils, rocks and minerals. Sodium and potassium are abundant in soils and rocks and highly soluble. Changes in these compounds can indicate changes or contamination in the wider environment and they are important from a human health perspective.

[5] Microbial parameters are currently not included in the coastal water quality SOE monitoring programme. Information about recreational water quality for coastal waters can be found on the Safeswim website (www.safeswim.org.nz).

	Parameter	Description
	Sulphate	Sulphate is a stable form of sulphur and its presence in groundwater can come from mineral dissolution from the surrounding soil, rocks and minerals, but also atmospheric deposition of marine aerosols. Changes in sulphate can indicate changes or contamination in the wider environment and is important from a human health perspective.
	Chloride	Chloride is a naturally occurring ion most commonly derived from dissolved salts such as sodium chloride and magnesium chloride as groundwater passes through soils, rocks and minerals. Chloride concentrations are very high in seawater so it can also be used to indicate seawater intrusion to aquifers.
	Total dissolved solids	Total dissolved solids are a measure of the dissolved combined content of inorganic and organic substances present in water. In groundwater, total dissolved solids are a product of the aquifer media the water passes through before it enters a well.
Ecology	Macroinvertebrate Community Index (MCI)	MCI scores range from 0 to 200, although in practice it is uncommon to find scores greater than 150 or less than 50. Higher MCI scores indicate better stream conditions. A tolerance value ranging from 1 to 10 is assigned to macroinvertebrate taxa recorded in freshwater samples. The tolerance values of each taxa present within a sample are then used to calculate an overall score, which is indicative of stream condition. See **Index Scores** for more information.
	Quantitative Macroinvertebrate Community Index (QMCI)	QMCI scores range from 0 to 10. The QMCI is calculated in a similar way to the MCI, except instead of using presence/absence it is calculated by counting the number of specimens for each macroinvertebrate taxon within the sample. See Index scores for more information. The QMCI metric has been used since 2014 for macroinvertebrate SOE monitoring data.
	Semi-Quantitative Macroinvertebrate Community Index (SQMCI)	SQMCI scores range from 0 to 10. The SQMCI is calculated in a similar way to the QMCI, except instead of using actual counts of the number of specimens for each macroinvertebrate taxon it instead uses a coded-abundance format (Rare to Very Very Abundant). See Index scores for more information. The SQMCI was used prior to 2014 by Auckland Council but has since been replaced by the QMCI parameter for macroinvertebrate SOE monitoring data.
	%EPT-$_{HA}$ taxa abundance	EPT stands for Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly). These are macroinvertebrate taxa that are sensitive to water pollution. This metric is calculated by dividing the number of EPT specimens in a sample by the total number of all specimens. A high percentage of EPT taxa abundance indicates good stream health. *Note: -$_{HA}$ indicates that this metric excludes Oxyethira and Paroxyethira. These two caddisfly taxa would skew the results if included, as unlike other EPT taxa they are highly pollution-tolerant.*
	EPT-$_{HA}$ taxa richness	EPT taxa richness is a measure of the total number of EPT taxa found within a sample. A higher score indicates better water quality. *Note: -$_{HA}$ indicates that this metric excludes Oxyethira and Paroxyethira. These two caddisfly taxa would skew the results if included, as unlike other EPT taxa they are highly pollution-tolerant.*
	ASPM	Macroinvertebrate Average Score Per Metric (ASPM). A higher ASPM score indicates good stream health. This is a multi-metric index that is calculated by taking the mean of three metrics: • MCI score • EPT-$_{HA}$ taxa richness • % EPT-$_{HA}$ abundance
	Stream Ecological Valuation (SEV)	SEV scores range from 0 to 1. The Stream Ecological Valuation (SEV) provides an integrated and quantitative measure of a stream's ecological value, based on river habitat and function data, which includes measures of instream habitat abundance, channel morphology and riparian characteristics. See Index Scores for more information.

2.2.2. Select site grouping

There are many ways that waterbody and landscape groups or other physical classes can be defined. The primary spatial groups that are used in the Data Explorer differ between domains. There are two ways the sites can be grouped for each of lakes and coastal water quality and for river water quality and ecology, and only one grouping for groundwater sites.

Lake area

Lake water quality monitoring sites are spread throughout five geographically distinct areas in the region.

Lake Area	Description
South Head - South Kaipara Peninsula	Nine of the monitored lakes are dune lakes located in three areas. These lakes are located in predominantly rural areas of the region.
Āwhitu - Āwhitu Peninsula	
Te Arai - north-east coast inland of Pākiri Beach	
West Coast – in or near the Waitākere Ranges	Three dune lakes located on the west coast of the region, surrounded by rural or native forest catchments.
Central – Urban isthmus	Lake Pupuke is the only lake in the central Auckland area. It is a volcanic lake formed from a historic crater. With no input from streams, it is fed by precipitation, groundwater and surface run-off only. The lake is surrounded by a well-established urban catchment and is valued for its open-space, recreational and amenity values.

Lake type

The lakes on the Data Explorer can be displayed by the two lake types in Auckland, related to water mixing patterns:

- Polymictic: water mixes fully from the surface to the bottom of the lake all year. These lakes are shallow.
- Seasonally Stratified: water separates into two layers during the warmer months where warmer water sits on top of colder water. These two layers mix in winter.

Groundwater aquifer

The groundwater aquifers are all within Auckland Council's Aquifer Management Area (AMA[6]) network. The aquifers were defined based on known geological boundaries, measured or modelled groundwater levels and flow paths, and/or surface water catchment boundaries (surface water catchment boundaries were used where aquifers are widespread, e.g., Waitematā group aquifers).

Table 2 describes the aquifers monitored in the groundwater quality monitoring programme.

[6] Not every AMA is represented by a groundwater quality monitoring site - see Auckland Council Geomaps "groundwater" layer for the full profile of AMAs.

Table 2: Geology of the aquifers monitored in the groundwater quality monitoring programme.

Aquifer	Description of geology
Franklin Sand	Semi-confined sands of the Pleistocene age Tauranga Group, which includes Puketoka Formation alluvium.
Franklin Volcanic	Basalts from lava flows in three main eruptive centres near Bombay, Pukekohe, and Glenbrook. Shallow, largely unconfined aquifers with some deeper basalts.
Franklin Kaawa	Sedimentary rock underlying the basalts of the Franklin Volcanic Field.
Waiau Pā Waitematā	Early Miocene aged basement rocks for the area. Consolidated sequence of marine interbedded mudstones and graded sandstones.
Three Kings Basalt	Basalts from several eruption phases overlying the erosional surface of the Waitematā and Tauranga Group sedimentary rocks.
Onehunga Volcanic	Basalts from several eruption phases overlying the erosional surface of the Waitematā and Tauranga Group sedimentary rocks.
Kumeu Waitematā	A sub-group of the Waitematā aquifers situated within the Waitematā Group sedimentary rocks. Comprised of alternating sandstones and mudstones, with some sand, silt, shells and minor clay and gravels.
Ōmaha Waitematā	Interbedded sandstones and mudstones of the Waitematā Group overlying the basement Greywacke rock.
Ōmaha Sand	Unconsolidated dune and alluvial sands overlying the Waitematā formations over most of the Ōmaha Flats and Ōmaha Spit.

Coastal area

Water quality monitoring sites are spread throughout six geographically distinct areas including the three main harbours and two of the three largest estuaries in the region.

- Kaipara Harbour
- Waitematā Harbour
- Manukau Harbour
- East Coast Bays
- Tāmaki Estuary
- Wairoa River Estuary

Coastal exposure

Monitoring sites that are in, or near the entrance of, narrow inlets or tidal rivers in upper harbour and estuary locations are the most sensitive to, and most affected by freshwater inputs (and generally point sources). Tidal creek sites experience the broadest range of physical and chemical conditions (such as salinity, pH, water temperature) due to these freshwater inputs. High flushing and dilution diminish the influence of freshwater runoff on exposed coastal sites and the difference in physical and chemical conditions over the tidal cycle are smaller. Most water quality parameters follow a gradient in quality from the tidal creeks to more exposed coastal sites.

- Creek: monitoring sites are in narrow channels upstream of the confluence with the main estuary or harbour body and where median salinity over 2007-2016 was <30 ppt (polyhaline or brackish).
- Estuary: monitoring sites are in the main body or the mouth of harbours or large estuaries.
- Coast: sites are on the east coast within the Hauraki Gulf. These sites are less subject to direct influences from adjacent land-use due to greater exposure and oceanic influences.

Rivers - Land cover

Contaminant concentrations are frequently higher in rivers and streams with catchments dominated by urban and pastoral land cover types while ecological health indicators are lower (of poorer quality) (Snelder et al., 2017; Whitehead et al., 2018; Larned et al., 2019; Gadd et al., 2020).

Land cover in the upstream catchment of a river site explains more variation in stream contaminant concentrations than land cover in the adjacent riparian zone of the sampling site (Larned et al., 2019). The land cover groups that are used in this Data Explorer are based on the rules originally established by Snelder and Biggs (2002) that are used in the national River Environment Classifications (REC) but with a more conservative approach. The rural land cover class is divided into two categories, and a lower threshold for 'urban' land cover is used than for the REC (Chaffe, 2021) as described below.

The upstream catchment area for each monitoring site was defined using natural drainage topography, the existing Auckland Council permanent streams network layer, and the stormwater underground services layer. A geospatial assessment of land cover was undertaken for each catchment upstream of the monitoring location using the provisional land cover update for the Auckland region. This process was aligned with the previous national Land Cover Database processes but updated for imagery obtained in summer 2023/2024[7].

The dominant land cover categories for each catchment in this report were determined according to the following decision criteria:

- Native forest – more than 95 per cent native forest or scrub.
- Exotic forest – more than 80 per cent within exotic forestry.
- Urban – more than 7 per cent urban land cover.
- Urban – Project: Urban site with further investigations underway.

Sites not meeting the above criteria were classified as having predominantly rural land cover under the following categories:

- Rural low – rural catchment with more than 50 percent forest cover (native and exotic).
- Rural high – rural catchment with less than 50 percent forest cover.

Further breakdown of the proportions of land cover within the upstream catchment for each site are outlined below for river water quality and river ecology programmes.

[7] *While developed with the intention of aligning with the upcoming LCDBv6, this Auckland-specific dataset may not be fully incorporated into the national LCDBv6.*

Rivers– Biophysical unit

The New Zealand River Environment Classification (REC2.4, transferred to DN2.4) classifies segments of a river based on their upstream catchment characteristics.

The third tier of the river environment classification is based on combined climate, source of flow, and geology information. REC classifications are expected to explain a degree of natural variation at a national scale in both nutrient and trophic responses, and sediment dynamics among streams (Stoffels et al., 2021; Canning, 2020).

There are two climate classes across Auckland, Warm Wet (WW) and Warm Dry (WD). All Auckland waterways are defined as low elevation (L) in terms of source of flow. Dominant geology types include soft sedimentary (SS), hard sedimentary (HS), and volcanic acidic (VA) (Snelder et al., 2004). When these classes are combined, streams in the region are within seven different biophysical units.\

3. Monitoring and programme specific methods

Auckland Council's water quality and river ecology monitoring programmes support the following wider objectives:

Regulatory alignment

- Contributes to Auckland Council's obligations under section 35 of the Resource Management Act 1991 with respect to the state of the environment monitoring and reporting.
- Contributes towards state of the environment reporting under the Hauraki Gulf Marine Park Act (2000).
- Contributes to our ability to maintain and enhance the quality of the region's environment (Local Government Act 2002).
- Provides evidence for the "Environment and Cultural Heritage" component of the Auckland Plan 2050.

Decision making

- Provides regionally specific baseline data to underpin sustainable management through resource consenting and associated compliance monitoring.
- Provides supporting information for assessing the effectiveness of policy initiatives and strategies, and their operational delivery.
- Identifies progressive, cumulative effects with long-term impacts on water quality.

Public resource

- Provides supporting information that mana whenua can utilise in their role as kaitiaki.
- Increases the knowledge base for Aucklanders and promotes awareness of water quality issues.

3.1. Water quality general methods

3.1.1. Data collection

Water quality samples collected under the programmes that are displayed on the Data Explorer are assessed for a wide variety of physical and chemical properties, as outlined in Table 1.

All water quality programmes involve obtaining measurements of physical parameters on-site using a portable water quality meter. Bottles of water are also collected from each site, chilled, and sent to a laboratory for analysis of a range of physical, chemical and biological parameters. Further details on analytical methods and detection limits for all programmes are outlined in Appendix B.

Several methodological aspects are common across lake, groundwater, coastal, and river water quality programmes in relation to monitoring methodology, and data management, as described below.

Programme specific sections that follow these paragraphs cover methodology for specific programme design, sampling methods, domain specific aspects such as tidal cycles and water depth and analyses.

3.1.2. Quality assurance

National Environmental Monitoring Standards (NEMS) are established for the collection, transport and storage of water quality samples to ensure consistency and accuracy across monitoring programmes. The NEMS quality coding (QC) framework was adopted by Auckland Council from January 2020.

Data collected before the adoption of NEMS were coded using the original Auckland Council Hydrological 10-151 Quality Coding system (IANZ certified). As there were no NEMS or the NEMS were not yet implemented at the time of data collection, the methods used are deemed to be according to best practice at the time.

Data identified as poor quality by either QC standard were excluded from all analyses and are not displayed on the explorer.

All water quality data are stored in Auckland Council's water quality archiving database (KiWQM).

Full details on quality codes associated with each data point can be requested from Environmentaldata@aklc.govt.nz

3.2. Lake water quality

3.2.1. Programme overview

The Lake water quality programme began consistently monitoring lakes in 1988 and was reviewed in late 2019. The major changes of the programme refresh included monitoring more lakes and a greater range of lake types, including those with differing, geophysical and surrounding catchment properties. Another key change was an increase in the frequency of sample collection from quarterly or every six weeks to monthly.

In January 2020, monthly water quality monitoring began on 16 lakes in the Auckland region. Eight of these lakes (Tomorata, Spectacle, Pupuke, Wainamu, Rototoa, Kuwakatai, Keretā and Whatihua) had been monitored historically for varying periods of time[8]. The other eight lakes had not been monitored before.

Since then, three lakes are no longer monitored and therefore a total of 13 lakes in the Auckland region are currently monitored and displayed in the explorer.

3.3.2. Lake descriptions

Table 3 presents the characteristics of the 13 lakes currently monitored across the Auckland region. These lakes have a variety of catchment land cover[9], riparian zone coverage, geology, depths, mixing regimes (lake type) and stream connectivity. Most of the lakes are not influenced by permanent stream inflow, and are instead primarily fed by precipitation, overland flow, ephemeral streams, drainage channels and groundwater.

[8] For consistency, data collected before 2020 is not displayed on the Data Explorer for these lakes but can be requested from Environmentaldata@aklc.govt.nz.

[9] Land cover assignment is as per river water quality and river ecology. See 2.2.2. Select site grouping section for more information.

Table 3: Lake characteristics.

Lake	Area	Max depth (m)	Lake type	Dominant land cover category	50 m riparian zone canopy cover > 0m height[10]	Rock group (geology)
Rototoa	South Head	25	Seasonally stratified	Rural low	75%	Sandstone
Kuwakatai	South Head	15	Seasonally stratified	Rural high	63%	Sandstone
Keretā	South Head	2	Polymictic	Rural low	56%	Sandstone
Te Kanae	South Head	18	Seasonally stratified	Rural low	92%	Sandstone
Ōkaihau	West Coast	12	Seasonally stratified	Rural low	21%	Sandstone
Kawaupaku	West Coast	20	Seasonally stratified	Native forest	97%	Conglomerate
Wainamu	West Coast	12	Seasonally stratified	Native forest	67%	Conglomerate, sandstone
Pokorua	Āwhitu	4	Polymictic	Rural high	46%	Mudstone
Whatihua	Āwhitu	11	Seasonally stratified	Rural high	23%	Sandstone
Pupuke	Central	56	Seasonally stratified	Urban	52%	Tuff, basalt
Slipper	Te Arai	5	Polymictic	Rural high	50%	Sandstone, greywacke
Spectacle	Te Arai	5	Polymictic	Rural high	40%	Sandstone, mudstone
Tomorata	Te Arai	5	Polymictic	Exotic forest	61%	Sandstone

3.3.3. Data collection

Monitoring methods are generally consistent with the New Zealand lake water quality monitoring protocols (Burns et al., 2000; NEMS 2019). In broad overview, at the deepest part of each lake, a depth profile is collected by measuring temperature, pH, dissolved oxygen, salinity, conductivity and turbidity at 1 m intervals, until the maximum depth of the lake is reached. For seasonally stratified lakes, this profiling allows the stratification status of the lake to be identified in real time, which subsequently determines at what depth the surface and bottom water samples should be collected on each sampling occasion.

All lakes have a sample taken from the top layer (referred to as the surface waters sample[11]). Deeper seasonally stratified lakes have a sample collected from the mid-hypolimnion (referred to as the bottom waters sample). All samples are taken using a Van Dorn sampler which enables collection of a sample from the appropriate depth.

[10] Lake canopy cover is typically represented by emergent vegetation and/or overhanging vegetation from riparian zone. Data based on Auckland Canopy Height Model (2016/2018).

[11] Some parameters are only collected from the surface sample, including chlorophyll. Other parameters are classed as surface waters for display purposes including E. coli, cyanobacteria, water level and Secchi depth.

Escherichia coli (E. coli) and cyanobacteria are sampled differently from other water quality parameters. *E. coli* samples are taken from the surface of the lake (e.g., 10 – 20 cm depth) using a sterile bottle. Phytoplankton samples are taken using a five-metre tube to collect a composite sample of the upper five metres of surface water. Phytoplankton samples, including cyanobacteria biovolume, are analysed by National Institute of Water and Atmospheric Research (NIWA) laboratory in Hamilton.

Water level at the time of sampling is read from a fixed manual staff gauge at each lake edge, except Lake Pupuke and Lake Rototoa, which have continuous water level meters and those readings are used.

Secchi depth is measured from a Secchi disc attached to a tape measure. The disc is lowered into the water until it disappears; this depth is noted using the tape measure. The disc is lowered a little further and then slowly raised until it reappears, this depth is noted. The average of the two readings is the final Secchi depth.

Trophic Level Index (TLI)

The ecological health of lakes is summarised using the Trophic Level Index (TLI). The index is based on surface water results for four water quality parameters (total nitrogen (TN), total phosphorus (TP), chlorophyll *a,* and water clarity[12] (from Secchi depth)) that assess the trophic state of lakes (Burns et al., 2005). TLI was calculated using the annual mean of each variable for each year (see Appendix C for index calculations). TLI scores range from 0 to 7, with a lower number indicating better water quality, as shown in Table 4.

Table 4: Descriptions of the trophic level state for each TLI score.

TLI	Trophic Level State	Description
< 2	Microtrophic / Very good	Very low nutrient levels and algae, with very high water clarity.
2-3	Oligotrophic / Good	Low levels of nutrients and algae, with high water clarity.
3-4	Mesotrophic / Fair	Moderate levels of nutrients and algae.
4-5	Eutrophic / Poor	Elevated levels of nutrients and algae, with low water clarity.
> 5	Supertrophic / Very poor	Saturated with nutrients, high algae growth with blooms possible in summer. Very low water clarity.

3.3. Groundwater quality

3.3.1. Programme overview

Auckland Council's groundwater quality monitoring programme was established in 1998 and was designed to detect long-term changes across the Auckland region. The programme originally comprised 27 sites across the region including National Groundwater Monitoring Programme (NGMP) sites managed by Geological and Nuclear Science (GNS).

[12] For two lakes (Keretā and Pokorua) TLI was calculated without water clarity data, due to the shallow nature of these lakes.

This programme was temporarily suspended for one year in 2013 and recommenced in 2014 with a reduced network but a more consistent sampling frequency and regime. The current groundwater quality programme focuses on monitoring aquifers exhibiting change or interpreted as being under pressure, generally relying on knowledge of land use activities at the time; namely aquifers in Franklin known to be impacted by horticultural activities (as summarised in Meijer et al., 2016), and urban sites susceptible to stormwater/wastewater infiltration with potentially high metal and microbial concentrations (Lewis et al., 2015). Sites required by GNS for the National Groundwater Monitoring Programme were also retained.

Auckland Council currently monitors groundwater quality in eight aquifers (Table 2) which are represented by 21 monitoring sites, three of which are surface springs. Of these 21 sites, 19 - including the 6 NGMP sites (Table 5) - are currently shown on the explorer. This excludes two new sites that were added to the programme in 2022, but there is not enough data to summarise these sites on the data explorer currently.

Table 5: Summary site details for the groundwater quality monitoring programme.

Aquifer	Site	Aquifer type	Spring/bore (bore depth)
Franklin Sand	Fielding Road Sand	Semi-confined	Bore (57-64 m)
Franklin Volcanic	BP Bombay	Unconfined	Bore (62-79 m)
	Fielding Road Volcanic	Unconfined	Bore (16-47 m)
	Rifle Range Rd Shallow	Confined	Bore (42 m)
	Rifle Range Rd Deep	Unconfined	Bore (90 m)
	Wilcox Gunclub Rd	Unconfined	Bore (27 m)
	Hickey Springs	-	Spring
	Hillview Springs	-	Spring
	Patumahoe Springs	-	Spring
Franklin Kaawa	Ostrich Farm Rd 1 Deep	Confined	Bore (84 m)
	Ostrich Farm Rd 2 Shallow	Confined	Bore (46-48 m)
Waiau Pā Waitematā	Seagrove Rd	Confined	Bore (201 m)
Three Kings Volcanic	Watson Ave	Unconfined	Bore (32-38 m)
Onehunga Volcanic	Alfred St	Unconfined	Bore (40 m)
Kumeu West Waitematā	Waitākere Rd 2 Deep	Confined	Bore (150 m)
	Waitākere Rd 1 Shallow	Semi-confined	Bore (15 m)
Ōmaha Waitematā	Quintals Rd	Confined	Bore (130 m)
	Ōmaha Flats	Confined	Bore (90 m)
Ōmaha Sand	Ōmaha Walkway	Unconfined	Bore (7 m)

3.3.2. Data collection

Each site is sampled quarterly according to the National Environmental Monitoring Standards (NEMS) for groundwater quality (NEMS, 2019). For parameters measured in the field, all sensors are

calibrated/validated in accordance with NEMS, and certain stabilisation criteria are met before samples are collected.

Water sample collection and field sensor measurements at bore sites require an electric portable pump and controller connected to a long hose. A flow cell is attached to the hose and the field sensor is inserted, ensuring the sensor readings and water samples are collected from groundwater that has not been exposed to air.

Groundwater collected from bores must be purged prior to sample collection to ensure the water is from the aquifer itself and not water that has been sitting in the well casing. There are two methods used each with specific NEMS requirements:

Three times purge method: this involves purging at least three times the calculated volume of the well. Field parameters must be monitored on at least four separate occasions with the last two meeting the stabilisation criteria (Table 6).

1. Low Flow purging: this involves pumping groundwater at low rates comparable to ambient groundwater flow, minimising drawdown and the mixing of stagnant water with newly drawn aquifer water. It requires purging the calculated total volume in the pump and tubing plus the volume of the drawdown in the well. To ensure adequate purging, three times the volume of the hose (81 L) is purged.

The low flow sampling method is preferred as it takes less time, however NEMS criteria are only able to be met at three sites with this method: Seagrove Rd, Quintals Rd, Ōmaha Flats and Ōmaha Walkway. Groundwater collected from all other bore sites uses the three times purge method.

Once purging is complete, and the stabilisation criteria are met (Table 6), water samples are collected via the flow cell.

Samples are collected from springs as follows:

- Patumahoe Springs: collection of water at the surface near a spring
- Hickey Spring: collection at the surface from a covered well at the Watercare treatment facility.
- Hillview Spring: collection via a tap from an existing pump station.

NGMP samples are collected, preserved, and sent to the GNS Wairakei Laboratory to be analysed. These results are provided to Auckland Council on request for inclusion into our database.

Table 6: Parameters collected in the field and stabilisation criteria for sample collection.

Field parameter	Unit	Stabilisation criteria (NEMS, 2019)
Dissolved oxygen (DO)	mg/L	± 0.3
pH	pH	± 0.1
Temperature	°C	± 0.2
Oxygen reducing potential (ORP)	mV	NA
Turbidity	FNU	± 10%
Electrical conductivity (EC)	mS/cm	± 3%

3.4. Coastal water quality

3.4.1. Programme overview

The coastal environment in the Auckland region sits within two oceanic systems (Pacific Ocean and Tasman Sea) and contains three major harbours and numerous estuaries.

The coastal water quality monitoring programme characterises the state of Auckland's ambient coastal and estuarine water quality and tracks long-term changes in it.

Auckland Council began monitoring coastal water quality in 1987. Since then, the council has expanded the number of sites monitored and progressively developed the sampling, analysis and reporting methods used.

Currently, 32 sites are included in the Data Explorer. The Meola Reef site at Point Chevalier in the Waitematā Harbour is the most recent addition to the programme. As monitoring commenced in January 2023, results for this site are presented as interim.

The location of the Tāmaki sampling site was changed in 2019 when expansion of the Half Moon Bay Marina changed access to the site. The original site was located at Half Moon Bay, but the construction of the new North Pier at the marina surrounded it with new breakwaters, making it unsuitable for future monitoring. Monitoring at an alternate site located at the end of the Half Moon Bay ferry terminal therefore commenced in July 2019, with dual analysis undertaken at both sites for a period of 18 months[13] (Kelly and Kamke, 2023). Data from both sites are included in the explorer under the "Tāmaki" site name. Data until 30/06/2019 is from the Tāmaki at Half Moon Bay Site, while data since 01/07/2019 is from the Tāmaki at Ferry Terminal location.

3.4.2. Data collection

Auckland Council collects coastal and estuarine water quality samples monthly by helicopter and boat[14], and prior to 2023, were collected from land for Tāmaki Estuary sites.

The collection of water samples by helicopter enables sites that are spread over the region to be sampled within the narrow time window created by tidal constraints, making comparison between sites more robust. Natural temporal variation in water quality is avoided as much as possible by maintaining a consistent sampling time relative to the tidal cycle and time of day. Samples are collected during the outgoing tide with the first sample on each run taken between 30 and 125 minutes after high tide. The run order of the Central and Upper Waitematā Harbour run was adjusted in March 2023 to better capture the influence of land-use effects and improve consistency in sampling on the outgoing tide[15]. While the programme is set up to be as consistent as possible, the addition and removal of sites had led to changes of run order and sampling times over the years.

Water samples are collected from the surface (approximately the top 0.3 m of water) by either lowering two 1 litre plastic bottles into the water directly or by lowering a Van Dorn sampler into the water and

[13] Data comparison showed minimal difference between sites.

[14] Sites in the inner Hauraki Gulf (East Coast and Wairoa River), Kaipara Harbour, and Manukau Harbour are sampled by helicopter, sites in the upper and central Waitematā Harbour and the Tāmaki Estuary are collected by boat.

[15] Originally central harbour sites were sampled first and upper harbour sites last. This resulted in early sampling of the central harbour sites not fully catching the water of the ebb tide. Changing the run order and starting at the upper harbour sites and moving into the central harbour with the outgoing tide ensured all samples are now collected at ebb tide.

subsequently filling the bottles. Field measurements are collected on site at the same depth as the water samples.

3.5. River water quality

3.5.1. Programme overview

The River Water Quality monitoring programme was initiated in 1986. The programme was designed to be regionally representative, monitor a variety of sizes and types of rivers, and represent the range of different catchment land cover classes and activities found across the region.

The programme included 17 sites originally and has incrementally expanded over time with more substantial reviews and expansion of the network undertaken in 2009 and 2022 (Auckland Regional Council, 1995; Neale, 2010). The current network includes 49 sites across the region.

The river water quality monitoring network aims to represent the region across two spatial classifications. The first is broad scale land cover categories, the second is third tier REC classifications for Climate/Source of Flow/ Geology (Snelder and Biggs 2004) (see the section 2.2.2. Select site grouping). A summary of the land cover classes within the upstream catchments of each monitoring site is outlined in Figure 3 below.

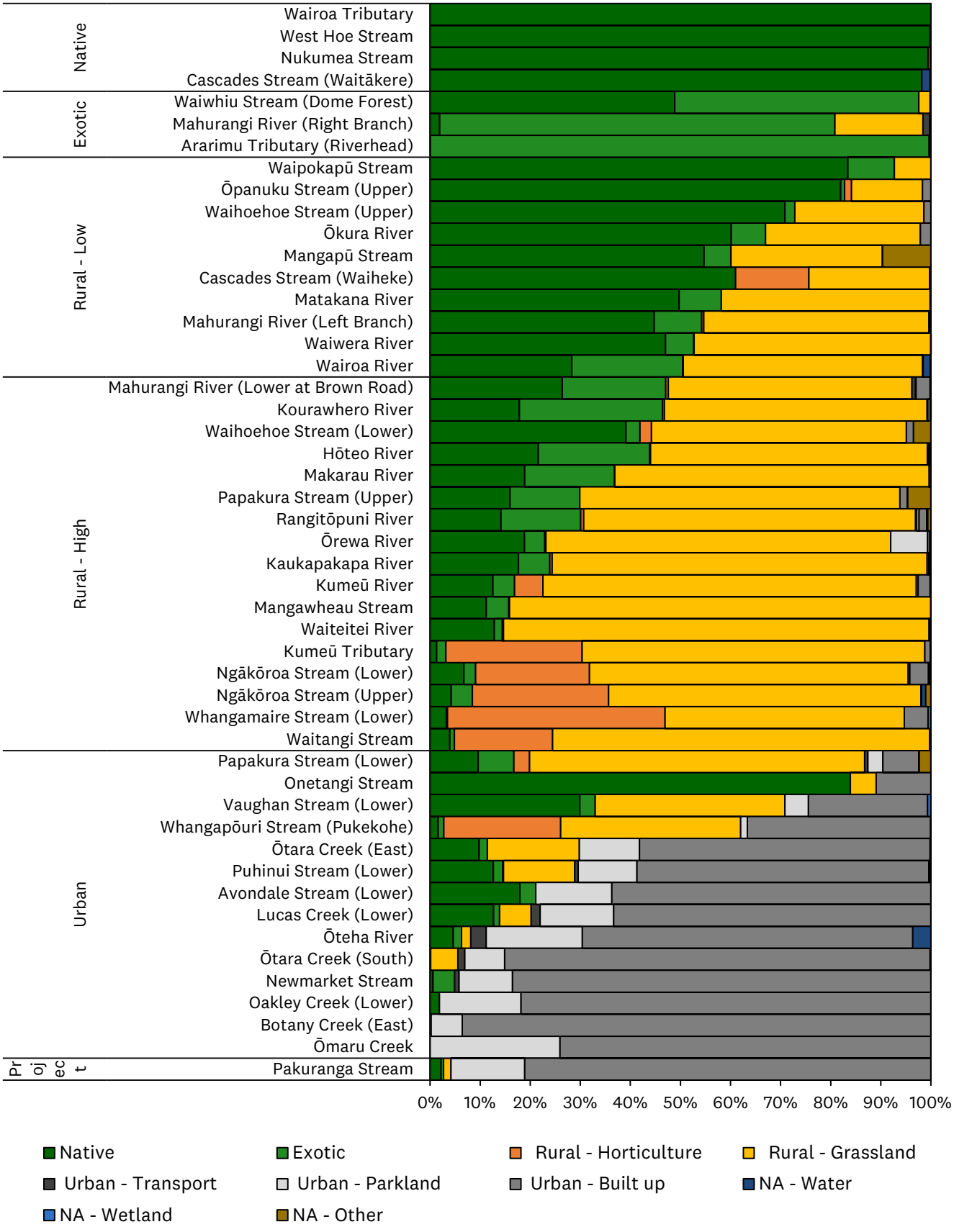

Figure 3 Proportion of each land cover class in the upstream catchment of river water quality monitoring sites and dominant land cover class assigned (LCDB regional update 23/24 - provisional (Auckland Council, 2025).

3.5.2. Data collection

It is not logistically feasible to sample all river water quality monitoring sites on the same day due to the large number of sites and the distances between them. Sites are grouped into sampling runs within a spatial area and all sites are sampled within a timespan of three weeks within each month. Sites are visited in the same order on each sampling occasion to ensure sampling occurs at approximately the same time of day each month for each site.

While the programme is set up to be as consistent as possible, the addition and removal of sites has led to changes of run order and sampling times over the years particularly in 2016 and 2022 coinciding with programme reviews.

For river water quality, data are excluded if influenced by salt water (>0.5 ppt) (e.g., where samples are collected from a stream mouth at high tide).

NIWA previously monitored the Hōteo River and Rangitōpuni River sites and provided the data to Auckland Council. That monitoring did not include salinity, total suspended solids, copper or zinc. Temperature and dissolved oxygen were determined in the field, and the remainder were determined by laboratory analysis at NIWA's water quality laboratory in Hamilton[16]. Auckland Council reinitiated monitoring at Rangitōpuni River in July 2016 and NIWA discontinued monitoring at this site in July 2021. Results are presented from both agencies over this period where minimum data requirements are met. Auckland Council reinitiated monitoring at Hōteo River in July 2023 and NIWA discontinued monitoring in December 2023. At this time only results from NIWA are available for this site on the Data Explorer.

Water samples are collected from the surface (approximately the top 0.3 m of water) by lowering bottles into the water directly either by hand or via a sampling pole. Field measurements are collected on site.

3.6. River ecology

3.6.1. Programme overview

Auckland Council's river ecology monitoring programme commenced in 1999 and involves the collection of macroinvertebrate and aquatic habitat data from permanent, wadeable rivers throughout the region.

The programme originally started with 7 sites and has now expanded to 68 sites, which have been selected as representative of the range of land cover types found within the Auckland Region. An outline of the land cover in the upstream catchments for each site is shown in Figure 4.

[16] Further information can be obtained from https://www.niwa.co.nz/freshwater/water-quality-monitoring-and-advice/national-river-water-quality-network-nrwqn.

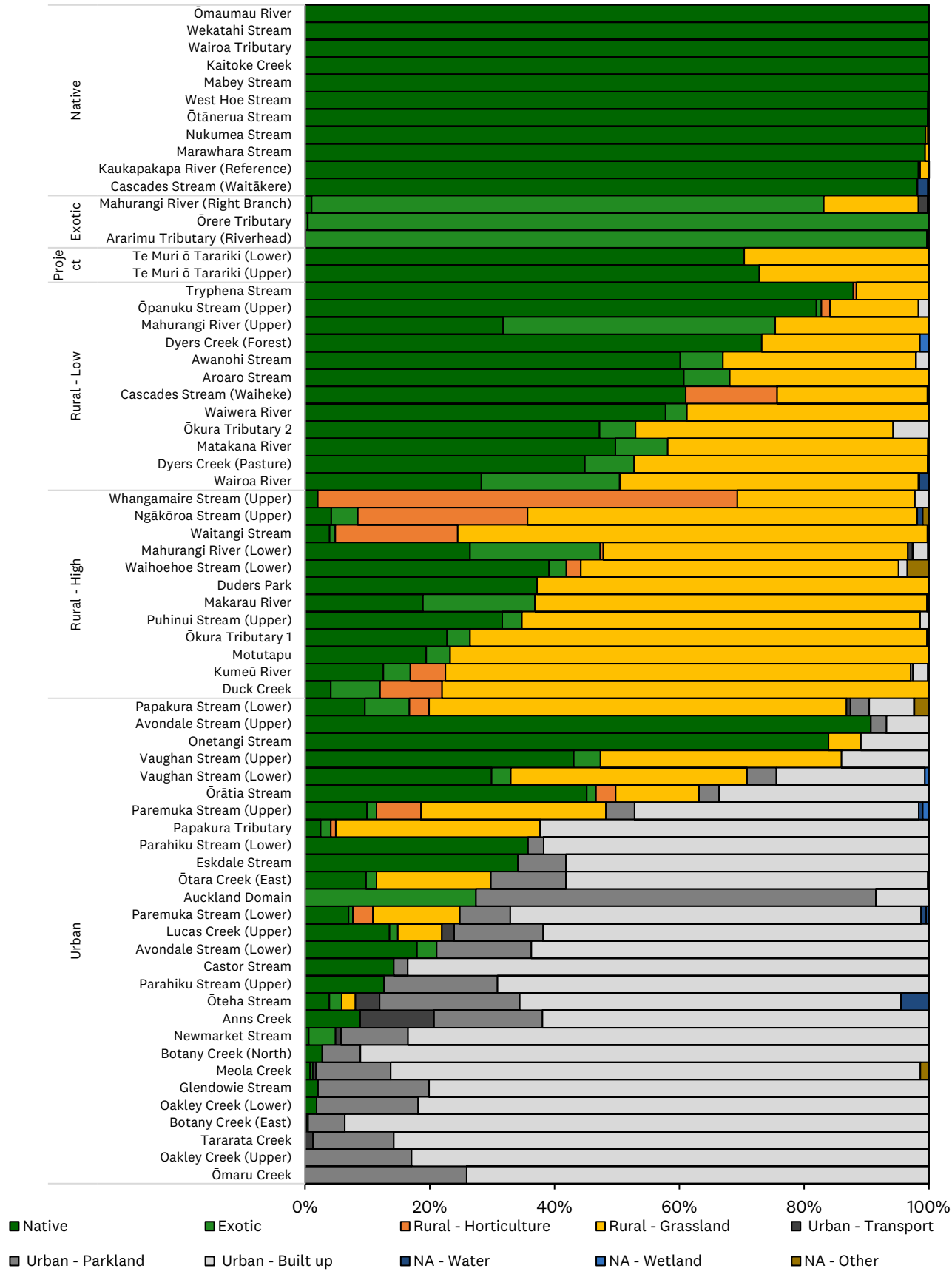

Figure 4 Proportion of each land cover class in the upstream catchment of River Ecology monitoring sites and dominant land cover class assigned (LCDB regional update 23/24 - provisional (Auckland Council, 2025).

3.6.2. Data collection

Macroinvertebrates

Annual macroinvertebrate samples are collected by Auckland Council staff during each summer sampling season (November-April) in accordance with standard semi-quantitative hard-bottomed and soft-bottomed sampling protocols for wadeable rivers and streams (Stark et al., 2001; Maxted et al. 2003). These protocols require a fixed area of river habitat (gravel, boulders or riffles in hard-bottomed rivers; and woody debris, macrophytes or bank margins in soft-bottomed rivers) to be manually disturbed and dislodged organisms swept into a handheld D-net (0.5 mm mesh).

Samples are preserved in 70 percent ethanol in the field and subsequently processed and identified by qualified macroinvertebrate taxonomists.

Until 2014 all macroinvertebrate samples were processed using coded abundance (Protocol P1 in Stark et al., 2001). From 2014 this was methodology was changed to the more intensive 'full count plus subsampling' process (Protocol P3 in Stark et al., 2001), which involves counting the total number of specimens in each macroinvertebrate taxa. This enables calculation of quantitative MCI (QMCI) rather than the semi-quantitative MCI (SQMCI) that was previously used in the monitoring programme.

Stream Ecological Valuation (SEV)

The Stream Ecological Valuation (SEV) methodology has been undertaken for all monitoring sites since 2009. This methodology provides an integrated and quantitative measure of a stream's ecological value, which allows for comparisons between sites and for the detection of trends within the same site over time.

River habitat and function data, which includes measures of instream habitat abundance, channel morphology and riparian intactness, are recorded at the same time as macroinvertebrate samples are collected, in accordance with standard SEV methodologies (Rowe et al., 2008; Neale et al., 2011; Storey et al., 2011). Observational cross section and reach scale measures are assessed at each site along a sample reach of approximately 100 metres.

3.6.3. Quality assurance

Macroinvertebrates

Macroinvertebrate samples undergo standard quality control (QC) checks by the laboratories contracted for this work to ensure that the results are consistent with Council's data standards. These QC protocols are nationally standardised (Stark et al., 2001; NEMS, 2022) for macroinvertebrate reporting. To ensure taxa are correctly identified, 10 percent of all samples collected are subjected to quality control procedures in accordance with standard protocols (Stark et al., 2001; NEMS, 2022).

In general, the level of identification and assigned tolerance values align with those described in Stark and Maxted (2007b). Where taxa or tolerance values are previously unprescribed, these are assigned using professional judgement and based on standard guidelines (Stark & Maxted, 2007b).

Stream Ecological Valuation (SEV)

Observational field SEV data are input into the respective calculators for each version of the SEV (Rowe et al., 2008; Storey et al., 2011). In accordance with the SEV assessment methodology, macroinvertebrate presence-absence data and a predictive Fish Index of Biotic Integrity (F-IBI) score, based on modelled data of native fish distributions, is also entered into the calculator along with results from desktop geospatial analyses.

The raw data and SEV calculations are internally reviewed, and quality checked to ensure that data quality remain consistent between years.

3.6.4. Index scores

The macroinvertebrate community index (MCI) and its quantitative variant (QMCI) were originally developed to measure the effects of nutrients on macroinvertebrate communities in hard-bottomed streams in New Zealand (Stark, 1985). The MCI/SQMCI/QMCI scores and standardised quality classes (Stark & Maxted, 2007a) are now considered a measure of general water quality and habitat quality combined.

The MCI and its variants follow the same principles, in which a tolerance value ranging from 1 to 10 is assigned to macroinvertebrate taxa recorded in freshwater samples. The tolerance value given to each taxon relates to stream condition or an environmental gradient and reflects a perceived sensitivity to environmental pressures, with a value of 1 indicative of highly tolerant taxa and a value of 10 highly sensitive taxa. The tolerance values of each taxa identified within a sample are then used to calculate an overall score, which is indicative of stream water quality (see Appendix C: Index calculations).

- The Macroinvertebrate Community Index is based on the presence/absence of taxa only. This metric has been assessed for the entire time period available.
- The Semi-Quantitative MCI is based on coded abundance of different taxa. This metric was used from 2002 to 2014, when macroinvertebrate samples were analysed using Protocol P1 – Coded Abundance (Stark et. al 2001).
- The Quantitative MCI is based on full counts of abundance of different taxa. This metric has been used from 2014 onwards, when the more intensive Protocol P3 – Full Count with Subsampling Option (as per Stark et. al 2001) was adopted for macroinvertebrate sample analysis.

The SQMCI and QMCI metrics are directly comparable with each other. Use of the SQMCI is no longer recommended for SOE monitoring, with the QMCI now the standard metric together with the MCI (NEMS, 2022).

The interpretation of the range of index scores for each indicator is provided in Table 7 and Table 8. There should be some flexibility when interpreting the thresholds or boundaries between described quality classes and that is best to view the boundaries as ‘fuzzy’. In order to account for observed error associated with MCI estimations (Stark, 1998), they suggest a ‘fuzzy boundary’ of ±5 MCI units either side of the thresholds to account for this variability.

Table 7: Interpretation of Macroinvertebrate Community Index (MCI) scores (Stark & Maxted, 2007b).

MCI score	Quality Class	Description
>119	Excellent	River in excellent ecological condition. Indicative of excellent water quality and habitat conditions.
100-119	Good	River in good ecological condition. Indicative of possible mild pollution and/or good habitat conditions.
80-99	Fair	River in fair ecological condition. Indicative of probable mild pollution and/or fair habitat conditions.
<80	Poor	River in poor ecological condition. Indicative of probable severe pollution and/or poor habitat conditions.

Table 8: Interpretation of QMCI and SQMCI scores (Stark & Maxted, 2007b).

QMCI/SQMCI score	Quality Class	Description
>5.99	Excellent	River in excellent ecological condition. Indicative of excellent water quality and habitat conditions.
5.00-5.99	Good	River in good ecological condition. Indicative of possible mild pollution and/or good habitat conditions.
4.00-4.99	Fair	River in fair ecological condition. Indicative of probable mild pollution and/or fair habitat conditions.
<4.00	Poor	River in poor ecological condition. Indicative of probable severe pollution and/or poor habitat conditions.

The percentage of EPT abundance - Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) - is calculated by dividing the number of EPT specimens[17] in a sample by the total number of all specimens present. A related metric, EPT taxa richness, is simply the total number of EPT taxa found within a sample.

Stream Ecological Valuation (SEV) assessments

The SEV scores derived from the calculations described in Storey et al. (2011) can be interpreted using the quality classes in Table 9 below.

Table 9: Interpretation of Stream Ecological Valuation (SEV) scores (Chaffe, 2021).

SEV score	Quality Class	Description
≥0.81	Excellent	River in excellent ecological condition. Indicative of ecological function and habitat conditions close to or at reference condition.
0.61-0.81	Good	River in good ecological condition. Indicative of good habitat conditions, few stream functions are impaired. Low deviation from reference state.
0.41-0.60	Fair	River in fair ecological condition. Indicative of fair habitat quality, some stream functions are impaired. Moderate deviation from reference state.
<0.40	Poor	River in poor ecological condition. Indicative of poor habitat condition, several stream functions are impaired. Substantial deviation from reference state.

[17] Excluding the hydroptilid caddisflies *Oxyethira* and *Paroxyethira* from the analysis, as, unlike other EPT taxa, they are highly pollution-tolerant.

4. Data analysis methods

4.1. Data analysis

Data analysis was undertaken in the same way across all domains using R (R Core Team, 2024) and R Studio (Posit team, 2024). Summary statistics were calculated using the Hazen percentile method as recommended by the New Zealand Ministry for the Environment for the evaluation of water quality data (McBride, 2016).

4.1.1. Data time periods

Data are reported in periods spanning hydrological years from 01 July to 30 June. The hydrological year is also commonly referred to as a 'water year'. This is considered a more meaningful time period to understand water quality and freshwater ecology dynamics as it avoids splitting the summer months (December to February). The summer period is typically when lake stratification is observed, is the peak season for algal growth and additional physical stressors on freshwater environments from higher temperatures and lower dissolved oxygen. This also spans the period that seasonal ecology field monitoring is undertaken within the river ecology programme (December to April).

4.1.2. Minimum data requirements and data status

Data analyses in the explorer are based on a minimum five-year assessment period spanning the abovementioned hydrological year e.g. 01 July 2020 to 30 June 2025. No data are displayed for water quality sites or parameters with less than three years of data available.

A minimum five-year period was selected to represent a statistically robust estimate of the state of water quality based on monthly monitoring (McBride, 2016). This duration is commonly applied to water quality statistical assessments including national state and trends (Whitehead et al., 2022; LAWA).

Auckland Council applies a minimum data requirement that 80 percent of samples at each site, from a minimum of 80 percent of years, are required for analysis of summary statistics and presentation of box plots. For example, in a five-year assessment period with monthly sampling, a minimum of 48 samples is needed (Table 10). This ensures the maintenance of a standard that provides robust summary statistics in accordance with the principles outlined in McBride (2016). It is not realistic to require 100% of samples as this would not allow missed sampling events due to special circumstances or risks to health and safety, or for the exclusion of data that do not meet quality standards.

For river ecology macroinvertebrate indices, the same minimum data requirements are applied however only basic summary statistics are calculated (minimum, median, maximum) due to the difference in frequency of observations (typical annual monitoring). The river ecology Stream Ecological Valuation (SEV) parameter is exempt from minimum data requirements due to the difference in frequency of observations; therefore, less than three years of data may be displayed for some sites and time periods.

Table 10: Standard minimum data requirements for water quality programmes.

Programme	Minimum percentage of years with data over selected time period (%)	Minimum percentage of total samples collected over the selected time period (%)	Sampling interval	Standard 5-year min period minimum no. samples
Lake Water Quality	80	80	Monthly	N=48
Coastal Water Quality	80	80	Monthly	N=48
Groundwater Quality	80	80	Quarterly	N=16
River Water Quality	80	80	Monthly	N=48
River Ecology (Macroinvertebrates)	80	80	Annually	N=4
River Ecology (SEV)	N/A	N/A	Two to Five Yearly	N/A

Auckland Council also introduces some water quality information with a minimum of three years of data available as 'interim' values - **for the most recent time period only**. This enables data from newly established sites or parameters to be shared sooner while also providing a reasonable estimate of summary statistics (McBride, 2016). For previous or longer time periods the minimum five-year period is maintained.

Status definitions are outlined below. The status of the selected summary statistics is provided in the Table tab. In the Box Plot, Map, Seasonal Box Plot and Stratification condition tabs, interim data are displayed with a bold or black outline and insufficient data are presented as a red cross.

- **Final:** the standard minimum time period for summary statistics is five years. Results for this and any longer time period are classed as final if minimum data requirements are met.
- **Insufficient**: data are classed as insufficient when minimum data requirements were not met for the chosen time period.
- **Interim:** for the most recent five-year reporting period only, summary statistics from data records at least three years but less than five years (and meeting the data requirements of 80% of years and 80% of samples over three years) are classed as interim.
- **No Status (blank):** applies to river ecology SEV data only.

For example, for a parameter where data collection started in July 2021 (hydrological year 2022) and a minimum of three years of data are available, this parameter would be displayed as 'interim' for the time period 2020-2024 selected. If the previous five year time period of 2019-2023 or a longer time period was selected this data would not be displayed as less than three years of data would be available.

A parameter where data collection started in July 2019 (hydrological year 2020) would have the minimum of five years of data available by June 2024 and would therefore be displayed as 'Final' for the time period 2020-2024 selected. If the five year time period of 2018-2022 was selected, then a cross for 'insufficient' data would be displayed as this would not meet the standard minimum data requirements (less than four years data available).

For seasonal box plots the same minimum data requirements are applied to the entire time period selected as outlined in the section above. No further filtering rules are applied in relation to representation of seasons. Seasonal box plots are based on a minimum of five years of data; however, the seasonal aspect consequently means that each box is based on a smaller data set of up to a minimum of 15 data points. It is recommended that a period of ten years of data are viewed for a more robust estimate of seasonal variation in water quality parameters (i.e. 30 data points) where available.

4.1.3. Censored values

For some parameters, censored values occur when true values are too low (below the detection limit), or too high (above the reporting limit) to be measured with precision by the analytical method being used by the laboratory.

To calculate summary statistics, censored values were replaced by imputed values generated using Regression on Order Statistics (ROS) for the entire time series for each site/parameter (Larned et al., 2015). The ROS procedure produces estimated values for the censored data that are consistent with the distribution of the uncensored values for each site and parameter. This method only works when a sufficient amount of non-censored data are available. If this is not the case, censored values are replaced by values half the detection limit. The precision of the summary statistics is limited for those with a high proportion of censored data. For example, where >50% of values are censored, calculated site medians (and lower percentiles) would be based on imputed values and should be read with caution. Where only 8% of values are censored, the 5^{th} percentile would be based on imputed values and should be read with caution, whereas the 10^{th} percentile and above would be based on non-censored data. The proportion of censored data for any selected site, parameter and time period can be viewed through the Table tab.

For the presentation of individual samples in the Time series tab, censored values were replaced by values half the lower detection limit and are indicated by the colour of the point (green). In the presentation of box plots, individual data points below the lower whisker (which extends to the 5^{th} percentile) may be censored values.

For right censored data (i.e. larger than the analytical method detection limit), summary statistics were calculated using values imputed by survival analysis (Helsel, 2012). A parametric distribution is fitted to the non-censored values using maximum likelihood methods. The values for the censored values are then estimated by randomly sampling larger values from this distribution. This method requires a minimum of 24 uncensored observations. If this requirement is not met, right censored values are replaced with the face value of the detection limit + 10 percent. For the time series tab, all right censored values are replaced with the face value of the detection limit + 10 percent and are indicated by the colour of the point (pink).

4.1.4. Adjustment for toxicity modifying factors

Some water quality parameters reported in the explorer including ammonia, copper and zinc can be toxic to aquatic life. The toxicity of these parameters is not attributed to the total concentrations in water but dependent on other parameters, so called toxicity modifying factors. Adjustments have been made to the relevant data as outlined below after censored value correction.

Ammoniacal Nitrogen is comprised of NH_3 (toxic) and NH_4^+ (harmless) and the equilibrium between NH_3 and NH_4^+ in water is dependent on pH, temperature, and ionic composition of the water. Higher pH drives the equilibrium towards producing more NH_3, thereby increasing toxicity. Default toxicity trigger values for ammonia are defined by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) fixed to a pH of 8.0. We applied a pH correction to freshwater ammoniacal nitrogen data and adjusted the data to a pH of 8.0 according to Hickey (2014). For this process field pH data was used and substituted with lab pH data in the case of data gaps. For pH <6 and pH > 9, which are outside the correction relationship of this method, the minimum (pH 6) and maximum (pH 9) correction ratios were applied. The guideline values for ammonia are currently under review by the Australian and New Zealand Governments and Australian state and territory governments (ANZG). We expect to update our procedures to these guidelines once they are finalised.

Copper and zinc are currently reported in freshwater as total and dissolved forms. The bioavailable fractions of these metals, which are relevant in terms of toxicity, will be updated and available when the technical briefs by ANZG are finalised.

4.2. Limitations

4.2.1. Programme changes

The number of sites within each programme has varied over time, primarily to improve the regional coverage. Some sites have also been discontinued due to budget and resource constraints or logistical issues.

The number and type of water quality parameters measured has varied since programme inception as new technology has become more affordable, instrument sensitivity has improved, and the programme objectives modified.

4.2.2. Data continuity

Due to logistical requirements, changing priorities, and improvements to methodologies, some discontinuities exist within the dataset.

- In September 2015, matrix adjustment for calibration standards was introduced for coastal water samples for Total Nitrogen analysis, while the reference method as shown in Appendix B remained the same.
- The service provider used for laboratory analysis changed in July 2017 from Watercare Services Ltd to Hill Laboratories Ltd (Hills). This coincided with some changes to analytical methodologies and detection limits for select parameters.

Some discrepancies have been observed in longer-term data coinciding with the above methodology changes and caution is advised when considering summary statistics spanning these periods or when viewing rolling periods over time. Other step changes may also occur coinciding with methodology changes at other points in time and further information on analytical methodology is outlined in Appendix B: Analytical methods for water quality parameters. This Data Explorer is not intended to provide technical analysis of trends or to further evaluate potential causes of trends, including step changes.

The groundwater quality monitoring programme was suspended in June 2013 due to budget constraints. In mid-2014, it recommenced with a reduced network but a more consistent sampling frequency and regime. Caution is advised when considering viewing data or summary statistics spanning any time periods including 2013 and 2014 due to a year of missing data.

4.2.3. Missed samples

There have been numerous events that have impacted water quality monitoring operations including suspension of monitoring under Covid–19 lockdown conditions during 2020-2021, issues with delivery of samples for laboratory analysis associated with Covid-19 lockdowns, and large weather events.

Missed sampling events are allowed for in relation to minimum data requirements and this is acknowledged as a limitation for any further interpretation of results where the impacts of these events on water quality may be of interest.

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Appendix A: Land cover aggregation

LCDB5 Class Name	Aggregated Land Cover Classes	Broad Level Dominant Land Cover
Deciduous Hardwoods	Exotic forest	Exotic
Exotic Forest	Exotic forest	Exotic
Forest - Harvested	Exotic forest	Exotic
Gravel or Rock	Other	NA
Landslide	Other	NA
Not Land	Other	NA
Sand or Gravel	Other	NA
Surface Mine or Dump	Other	NA
Estuarine Open Water	Water	NA
Lake or Pond	Water	NA
River	Water	NA
Flaxland	Wetland	NA
Herbaceous Freshwater Vegetation	Wetland	NA
Herbaceous Saline Vegetation	Wetland	NA
Mangrove	Wetland	NA
Broadleaved Indigenous Hardwoods	Native forest	Native
Fernland	Native forest	Native
Indigenous Forest	Native forest	Native
Manuka and/or Kanuka	Native forest	Native
Matagouri or Grey Scrub	Native forest	Native
Orchard, Vineyard or Other Perennial Crop	Horticulture	Rural
Short-rotation Cropland	Horticulture	Rural
Gorse and/or Broom	Rural	Rural
High Producing Exotic Grassland	Rural	Rural
Low Producing Grassland	Rural	Rural
Mixed Exotic Shrubland	Rural	Rural
Built-up Area (settlement)	Urban	Urban
Urban Parkland/Open Space	Urban Parkland	Urban
Transport Infrastructure	Urban Transport	Urban

Aggregated land cover classes used for a breakdown of river landcover graphics in Sections 3.5.1 and 3.6.1.

Broad level dominant land cover used for land cover categories displayed on the data explorer for rivers (See Section 2.2.2. Rivers – Land cover).

Appendix B: Analytical methods for water quality parameters

Table B-11: Water quality analytical methods – field parameters for the Lakes, Rivers, Coast and Groundwater programmes

Group	Parameter	Units	Field Equipment/ 2010-2014	Detection Limit	Equipment 2014*-current	Detection Limit
Physical	Dissolved oxygen saturation	% sat	YSI 556	0	EXO sonde, optical method	0
Physical	Dissolved oxygen	mg/L	YSI 556	0	EXO sonde, optical method	0
Physical	Temperature	°C	YSI 556	-5	EXO sonde, thermistor	-5
Physical	Conductivity	mS/cm	YSI 556	0	EXO sonde, 4-electrode nickel cell	0
Physical	Salinity	ppt	YSI 556	0	EXO sonde, 4-electrode nickel cell	0
Physical	pH	pH units	YSI 556	0	EXO sonde, glass combination electrode	0
Clarity	Turbidity	FNU	NA	NA	EXO sonde, optical 90° scatter	0
Clarity	Secchi depth (Lakes programme only)	m	Secchi disc	NA	Secchi disc	NA
Physical	Lake level	m		NA	External staff gauge (from 2021)	NA

**Coast switched to EXO sonde in September 2014; no exact months available for other programs.*

Table B-2: Lakes and River Water quality analytical methods – laboratory parameters

Group	Parameter	Units	Watercare Lab 2009-June 2017* Methods	Detection Limit	Hill Lab July 2017-current* Methods	Detection Limit
Clarity	Total suspended solids	mg/L	APHA (2005/2012) 2540 D	0.2	APHA (2017) 2540 D 23rd ed (modified)	3 (2017-Oct 2020) 1 (October 2020-Current)
Clarity	Turbidity	NTU	APHA (2005/2012) 2130 B (modified)	0.1 (2010-August 2015) 0.05 (from August 2015)	APHA (2017) 2130 B 23rd ed (modified)	0.05
Clarity	Volatile suspended solids (Lakes programme only)	mg/L	NA	NA	APHA (2017) 2540 E (modified)	3 (June 2019-October 2020), 1 (October 2020-current)
Nutrients	Ammoniacal nitrogen	mg N/L	APHA (2005/2012) 4500-NH3 G (Modified) APHA (online edition) 4500-NH3 H (modified) (from July 2016)	0.005	APHA (2017) 4500-NH3 H 23rd ed	0.005

Group	Parameter	Units	Watercare Lab 2009-June 2017*		Hill Lab July 2017-current*	
			Methods	Detection Limit	Methods	Detection Limit
Nutrients	Nitrite nitrogen (Streams programme only)	mg N/L	NA	NA	APHA (2017) 4500-NO_3^- I 23rd ed (modified)	0.001
Nutrients	Nitrate nitrogen (Streams programme only)	mg N/L	NA	NA	Calculation ((NO3N+NO2N) – NO2N)	0.001
Nutrients	Dissolved inorganic nitrogen	mg N/L	AC Calculation (NH4-N + NO3-N + NO2-N)	0.007	Calculation (NH4-N + NO3-N + NO2-N)	0.005
Nutrients	Total oxidised nitrogen	mg N/L	APHA (2005/2012) 4500-NO3 F (modified) APHA (online edition) 4500-NO3 I (from July 2016)	0.002	APHA (2017) 4500-NO_3^- I. Flow injection	0.001
Nutrients	Total kjeldahl nitrogen	mg N/L	Calculation	0.02	Calculation (TN – (NO3N+NO2N))	0.01
Nutrients	Total nitrogen	mg N/L	APHA (2005/2012) 4500-P J & 4500-NO3 F (modified), APHA (online edition) 4500-P J & 4500-NO3 I (modified) (from July 2016)	0.02, 0.01 (from September 2014)	APHA (2017) 4500-N C & 4500-NO_3^- I 23rd ed (modified)	0.01
Nutrients	Dissolved reactive phosphorus	mg P/L	APHA (2005/2012) 4500-P B, F (modified), APHA (online edition) 4500-P F (from October 2015)	0.005, 0.002 (from September 2014)	APHA (2017) 4500-P G 23rd ed (modified) Flow injection	0.004, 0.001 (from May 2019)
Nutrients	Total phosphorus	mg P/L	APHA (2005/2012) 4500-P B, J (modified)	0.005, 0.004 (from August 2014)	APHA (2017) 4500-P B, E (modified), APHA (2017) 4500-P H (modified) (from December 2020)	0.004, 0.002 (from December 2020)
Algae	Chlorophyll a	mg/L	APHA (2005/2012) 10200 H (Modified)	0.0006	APHA (2017) 10200 H (modified) 23rd ed, APHA 10150 C (modified) 23rd ed (from May 2024)	0.003 (Aug 2017-May 2019), 0.0002 (from June 2019-June 2020), 0.00002 (from July 2020)
Metals	Soluble copper (Streams programme only)	µg/L	USEPA 200.8 (modified)	0.00001	APHA (2017) 3125 B 23rd ed	0.0005
Metals	Total copper (Streams programme only)	µg/L	USEPA 200.8 (modified)	0.00001	APHA (2017) 3125 B 23rd ed / USEPA 200.8	0.00053
Metals	Soluble zinc (Streams programme only)	µg/L	USEPA 200.8 (modified)	0.0003	APHA (2017) 3125 B 23rd ed	0.001
Metals	Total zinc (Streams programme only)	µg/L	USEPA 200.8 (modified)	0.0003	APHA (2017) 3125 B 23rd ed / USEPA 200.8	0.0011
Bacteria	E.coli	cfu/100mL	USEPA (2002) Method 1603	2	APHA (2017) 9222 G, APHA (2017) 9222 I 23rd ed (From March 2020)	1
Modifiers	Dissolved organic carbon	mg/L	NA	NA	APHA (2012/2017) 5310 C (modified) 23rd ed	0.3
Modifiers	Total hardness (Streams programme only)	mg/L	NA	NA	Calculation APHA (2017) 2340 B 23rd ed.	1.0

Group	Parameter	Units	Watercare Lab 2009-June 2017*		Hill Lab July 2017-current*	
			Methods	Detection Limit	Methods	Detection Limit
Modifiers	Soluble calcium (Streams programme only)	mg/L	NA	NA	APHA (2017) 3125 B 23rd ed	0.05
Modifiers	Soluble magnesium (Streams programme only)	mg/L	NA	NA	APHA (2017) 3125 B 23rd ed	0.02
Physical	Total alkalinity (Streams programme only)	mg/L	NA	NA	APHA (2017) 2320 B 23rd ed (modified)	1.0
Algae	Cyanobacteria biovolume (Lakes programme only)	mm^3L^{-1}	NA	NA	Microscopic analysis of settled sample following the Utermöhl/Nauwerck method	NA
Physical	pH		APHA 4500-H B	0.1	NA	NA

**unless otherwise specified*

Table B-3: Analytical methods for coastal water quality parameters assessed.

Group	Parameter	Units	Watercare Lab 2010-July 2017		Hills Lab August 2017-Current	
			Methods	Detection Limit	Method	Detection Limit
Clarity	Total suspended solids	mg/L	APHA (2005/2012) 2540 D	0.2	APHA (2017) 2540 D 22nd ed.	3
Clarity	Volatile suspended solids	mg/L	NA	NA	APHA 2540 E (modified) (from July 2024)	3
Clarity	Turbidity	NTU	APHA (2005/2012) 2130 B (modified)	0.05	APHA (2012/2017) 2130 B (modified) 22nd/ 23rd ed.	0.05
Nutrients	Ammoniacal nitrogen	mg N/L	APHA (2005/2012) 4500-NH3 G (modified), APHA (online edition) 4500-NH3 H (from July 2016)	0.005	APHA (2017) 4500-NH3 H (modified) 23rd ed.	0.005
Nutrients	Total oxidised nitrogen	mg N/L	APHA (2005/2012) 4500-NO3 F (modified), APHA (online edition) 4500-NO3 I (from July 2016)	0.002	APHA (2012/2017) 4500-NO3 I 22nd /23rd ed.	0.001

Group	Parameter	Units	Watercare Lab 2010-July 2017		Hills Lab August 2017-Current	
			Methods	Detection Limit	Method	Detection Limit
Nutrients	Total nitrogen	mg N/L	APHA (2005/2012) 4500-P J, 4500-NO3 F (modified), APHA (online edition) 4500-P J (modified),4500- NO3 I (from July 2016)	0.02, 0.01 (from Sept 2015)*	APHA (2017) 4500-N C & 4500-NO3 I (modified) 22nd/ 23rd ed	0.01
Nutrients	Nitrate nitrogen	mg N/L	(Nitrate-N + Nitrite-N) - Nitrite-N	0.002	(Nitrate-N + Nitrite-N) - NO2N	0.001
Nutrients	Nitrite nitrogen	mg N/L	APHA (2005/2012) 4500-NO2 B (modified)	0.002	APHA (2012/2017) 4500 NO3 I 22nd /23rd ed (modified)	0.001
Nutrients	Total Kjeldahl nitrogen	mg N/L	Calculation	0.02	Calculation: TN - (NO3N + NO2N)	0.01
Nutrients	Dissolved reactive phosphorus	mg P/L	APHA (2005/2012) 4500-P B, F (modified), APHA (2012) (online edition) 4500-P F (from October 2015)	0.005, 0.002 (from Sept 2014)	APHA (2017) 4500-P G (modified) 22nd/23rd ed	0.004, 0.001 (from May 2018)
Nutrients	Total phosphorus	mg P/L	APHA (2005/2012) 4500-P B, J (modified), APHA (2012) (online edition) 4500-P J (modified) (from October 2015)	0.005, 0.004 (from Sept 2014)	APHA (2012/2017) (online edition) 4500-P B & E (modified) 22nd/23rd ed, APHA (2017) 4500-P H (modified) 23rd ed (from December 2020)	0.004
Algae	Chlorophyll *a*	mg/L	APHA (2005/2012) 10200 H (modified) Spectroscopy	0.0006	APHA (2012/2017) 10200 H (modified) 22nd/23rd ed. Flurometry, APHA (2017) 10150 C (modified) (from June 2024)	0.003, 0.0002 (from May 2018)
Physical	pH	pH	NA	NA	APHA (2012) 10200 H (modified) 22nd ed. (from August 2018- May 2019), APHA (2017) 4500-H+ B (modified) 23rd ed. (From July 2020)	0.1

**Change in calibration procedure for saline matrix samples – September 2015.*

Table B-4: Analytical methods for Ground water quality parameters assessed

Group	Parameter	Units	Hills Lab April 2008 to October 2009		Watercare Lab October 2009 to July 2017		Hills Lab -July 2017 to current	
			Methods	Detection limit	Methods	Detection limit*	Methods	Detection limit
Bacteria	E.Coli	cfu/100ml	NA	NA	EPA (2002) 1603	2	APHA (2012/2017) 9222 G 22nd/23rd ed, APHA (2017) 9222 I 23rd ed (from June 2020)	1
Clarity	Total suspended solids	mg/L	APHA (2005) 2540 D 21st ed	0.5	APHA (2005/2012) 2540 D	0.2	APHA (2012/2017) 2540 D 22nd/23rd ed (sampled August 2017 -May 2020)	3
Clarity	Total dissolved solids	mg/L	APHA (2005) 2540 C (modified) 21st ed	10	APHA (2005/2012) 2540 C (modified)	15	APHA (2012/2017) 2540 C 22nd/23rd ed	10
Clarity	Turbidity	NTU	APHA (2005) 2130B 21st ed	0.05	APHA (2005/2012) 2130 B (modified), USEPA 180.1 (From April 2010)	0.1, 0.05 (From October 2014)	APHA (2012/2017) 2130 B 22nd/23rd ed.	0.05
Metals	Sulphate	mg/L	APHA (2005) 4110 B 21st ed	0.5	APHA (2005/2012) 4110 B (Sampled from April 2013), USEPA 300.0 (From November 2015)	0.02	APHA (2012/2017) 4110 B 22nd/23rd ed (modified)	0.5
Metals	Soluble iron	mg/L	APHA (2005) 3125 B 21st ed	0.005	USEPA 200.8 (modified)	0.002	APHA (2012/2017) 3125 B 22nd/23rd ed	0.02
Metals	Soluble manganese	mg/L	APHA (2005) 3125 B 21st ed	0.0005	USEPA 200.8 (modified) (Sampled from April 2015)	0.0005	APHA (2012/2017) 3125 B 22nd/23rd ed (from Oct 2017)***	0.0005
Metals	Soluble potassium	mg/L	APHA (2005) 3125 B 21st ed	0.05	USEPA 200.8 (modified), APHA (online) 3125 or in house ICP-MS (From October 2015)	0.1, 0.05 (from October 2014), 0.02 (from May 2016)	APHA (2012/2017) 3125 B 22nd/23rd ed	0.05
Metals	Soluble sodium	mg/L	APHA (2005) 3125 B 21st ed	0.02	USEPA 200.8 (modified), APHA (online) 3125 or in house ICP-MS (From October 2015)	0.1	APHA (2012/2017) 3125 B 22nd/23rd ed	0.02
Metals	Soluble copper	mg/L	NA	NA	USEPA 200.8 (modified) (Sampled from May 2014), APHA (online) 3125 or in house method by ICP-MS (All 2016 samples), In House based on EPA 200.8 by ICPMS (From January 2017)	0.0002	APHA (2012/2017) 3125 B 22nd/23rd ed	0.0005
Metals	Soluble zinc	mg/L	NA	NA	USEPA 200.8 (modified) (Sampled from May 2012), APHA (online) 3125 or in house method by ICP-MS (All 2016 samples), In House based on EPA 200.8 by ICPMS (From January 2017)	0.001	APHA (2012/2017) 3125 B 22nd/23rd ed	0.001
Modifiers	Total hardness	mg/L	Calculation	1	APHA (2005) 2340 B, USEPA 200.8 (modified) (From January 2012), APHA (online) 3125 or in house ICP-MS (From October 2015)	0.03	APHA (2012/2017) 2340 B 22nd/23rd ed	1
Ions	% difference	%	NA	NA	APHA (2005) 1030 E (Sampled from October 2011)	NA	APHA (2012/2017) 1030 E 22nd/23rd ed	0.1

Group	Parameter	Units	Hills Lab April 2008 to October 2009		Watercare Lab October 2009 to July 2017		Hills Lab -July 2017 to current	
			Methods	Detection limit	Methods	Detection limit*	Methods	Detection limit
	in ion balance							
Nutrients	Ammoniacal nitrogen	mg N/L	APHA (2005) 4500 NH3 F (modified) 21st ed	0.01	APHA (2005) 4500 NH3 G (modified)	0.005	APHA (2012/2017) 4500-NH3 H 22nd/23rd ed	0.005
Nutrients	Total oxidised nitrogen	mg N/L	APHA (2005) 4500-NO3- I (Proposed) 21st ed.	0.002	Calculation, APHA (2005/2012) 4110 B (modified) (from January 2012), USEPA 300.0 (from October 2015)	0.002	APHA (2012/2017) 4500-NO3 I 22nd/23rd ed (modified)	0.001
Nutrients	Nitrate nitrogen	mg N/L	Calculation (Nitrate-N + Nitrite-N) - NO2N.	0.002	APHA (2005/2012) 4110 B, APHA (2005/2012) 4110 B (modified) & USEPA 300.0 (From October 2015)	0.002	Calculation (Nitrate + Nitrite) - NO2N	0.001
Nutrients	Total Nitrogen	mg N/L	NA	NA	APHA (online) 4500 P J, 4500 NO3 F (modified) (Sampling started May 2014)	0.01	APHA (2012/2017) 4500-NC & 4500-NO3 I 22nd/23rd ed (modified)	0.01
Nutrients	Nitrite nitrogen	mg N/L	APHA (2005) 4500 NO3- I (proposed) 21st ed	0.002	APHA (2005/2012) 4110 B (modified), APHA (2005/2012) 4110 B (modified) & USEPA 300.0 (From October 2015)	0.002	APHA (2012/2017) 4500-NO3-I 22nd/23rd ed (modified)	0.001
Nutrients	Dissolved reactive phosphorus	Mg P/L	APHA (2005) 4500-P E (modified) 21st ed.	0.004	APHA (2005) 4500 P F, APHA (2002/2012) 4500 P B, F (modified) (From January 2012)	0.005, 0.002 (From October 2014)	APHA (2012/2017) 4500-P G 22nd/23rd ed	0.001(August 2017 to January 2018**, May 2019 to current) 0.004 (April 2018 to April 2019)
Nutrients	Total phosphorus	mg P/L	APHA (2005) 4500-P E (modified) 21st ed.	0.004	APHA (2005) 4500 P B, F, APHA (2005/2012) P B, J (modified) (From Feb 2012), APHA (online) 4500 P J (modified) (From October 2015)	0.005, 0.004 (From October 2014)	APHA (2012/2017) 4500-P B & E 22nd/23rd ed (modified), APHA (2017) 4500-P H 23rd ed (from January 2021)	0.004, 0.002 (from January 2021)
Nutrients	Chloride	mg/L	APHA (2005) 4110 Cl - E (modified) 21st ed	0.5	APHA (2005/2012) 4110 B, USEPA 300.0 (From November 2015)	0.02	APHA (2012) 4500 Cl-E 22nd ed (modified), APHA (2012/2017) 4110 B 22nd/23rd ed (modified) (From April 2018)	0.5
Nutrients	Fluoride	mg/L	NA	NA	APHA (2005/2012) 4110 B (modified) (Sampled from May 2012), USEPA 300.0 (From November 2015)	0.02	APHA (2012/2017) 4500-F-C 22nd/23rd ed	0.05
Physical	pH	pH	APHA (2005) 4500 H+ B 21st ed	0.1	APHA (2005/2012) 4500 H B (ended May 2015)	0.1	APHA (2012/2017) 4500-H+ B 22nd ed (from October 2017)	0.1
Physical	Total Alkalinity	mg/L	APHA (2005) 2320B (modified) 21st ed	1	APHA (2005/2012) 2320 B	1	APHA (2012/2017) 2320 B (modified) 22nd/23rd ed	1

**No detection limits listed prior to 2012 (2009-2011)*
*** No lab results available with detection limits and lab methods for November 2017 and January 2018 sampling, detection limit changed between Nov 2017 and January 2018 sampling rounds.*
**** Parameter not sampled from January 2019 to Nov 2020*

Appendix C: Index calculations

Trophic Lake Index (TLI)

The regression and overall equations used to calculate the TLI (Burns et al. 2005):

$$\mathrm{TL_N} = -3.61 + 3.01 \log(\mathrm{TN})$$

$$\mathrm{TL_P} = 0.218 + 2.92 \log(\mathrm{TP})$$

$$\mathrm{TL_S} = 5.10 + 2.27 \log\left(\frac{1}{\mathrm{SD}} - \frac{1}{40}\right)$$

$$\mathrm{TL_C} = 2.22 + 2.54 \log(\mathrm{Chl}\ a)$$

$$\mathrm{TLI} = \frac{(\mathrm{TL_N} + \mathrm{TL_P} + \mathrm{TL_S} + \mathrm{TL_C})}{4}$$

Where:
TN = total nitrogen (mg/m^3)
TP = total phosphorus (mg/m^3)
SD = Secchi depth (m)
Chl *a* = chlorophyll *a* (mg/m^3)

Note unit conversion from mg/L from raw data to mg/m^3 for calculations.

Macroinvertebrate Community Index (MCI)

Macroinvertebrate Community Index (MCI) scores are determined using presence-absence data and calculated using the formula provided below:

$$MCI = \frac{\sum_{i=1}^{i=S} a_i}{S} \times 20$$

Where:

S = the total number of scoring taxa in the sample
a_i = the tolerance value for the ith taxon

Quantitative Macroinvertebrate Community Index (QMCI)

Quantitative Macroinvertebrate Community Index (QMCI) scores are calculated using the formula below:

$$QMCI = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

Where:

S = the total number of taxa in the sample
n_i = the abundance (number of specimens) for the ith scoring taxon
a_i = the tolerance value for the ith taxon
N = the total abundance of the scoring taxa for the entire sample

Semi-Quantitative Macroinvertebrate Community Index (SQMCI)

Semi-Quantitative Macroinvertebrate Community Index (SQMCI) scores are determined using the formula below (note that this is identical to the formula used for the QMCI, with the difference being that coded abundance data is used rather than direct counts of abundance):

$$SQMCI = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

Where:

S = the total number of taxa in the sample
n_i = the coded abundance for the ith scoring taxon (i.e. R=1, C=5, A=20, VA=100, VVA=500)
a_i = the tolerance value for the ith taxon
N = the total of the coded abundances for the entire sample

Macroinvertebrate Average Score Per Metric (ASPM)

Calculated from three metrics – the MCI, EPT$_{\text{-HA}}$ taxa richness and % EPT$_{\text{-HA}}$ abundance – by taking the mean of the three metrics. Each metric is firstly scaled (normalised) by:

$$X' = [X - X_{min}] / [X_{max} - X_{min}]$$

Where:

X' = the scaled site score,
X = the raw site score
X_{min} and X_{max} = the minimum and maximum site scores of the entire dataset.

When normalising scores for the ASPM, use the following minima and maxima:

- %EPT$_{-HA}$ abundance: 0–100
- EPT$_{-HA}$ taxa richness: 0–29
- MCI: 0–200

Note: $_{-HA}$ denotes the exclusion of the hydroptilid caddisflies *Oxyethira* and *Paroxyethira* from the analysis, as, unlike other EPT taxa, they are highly pollution-tolerant.

Find out more:

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