Lake monitoring programmes

The ARC operates two lake monitoring programmes in the Auckland region (see in Figure 11). These monitoring programmes are:

The Water Quality Programme. This monitors some of the physical, chemical and microbiological properties of seven lakes around the Auckland region, six times each year. This provides information on the water temperature and the amount of nutrients, oxygen, sediment and other pollutants in the lakes. The results enable the ARC to assess the life supporting capacity of the lake (how suitable it is for supporting life) and the microbiological quality of the lake (how suitable it is for recreational use).

The **Ecological Quality Programme** monitors the biological community of up to 29 lakes. This programme operates two sub-programmes:

- **Rotifers**. These are part of the lake zooplankton community and are sampled at the seven lakes in the lake water quality monitoring programme (at the same time as the water quality samples are taken). The type and number of rotifers are used to provide an indication of the ecological health of the lake.
- **Macrophytes** (aquatic submerged plants). These are surveyed at 29 lakes within the Auckland region. The type and amount of macrophytes are used to provide an indication of the ecological health of the lake.

The ARC's lake water quality and ecological quality monitoring programmes aim to characterise the environmental and biological conditions of these lakes and to understand the effects of environmental stressors upon them.

Lake water quality programme

Four water quality parameters are used to assess the life supporting capacity of lake water at each of the seven lakes:

- chlorophyll a
- secchi depth
- total phosphorus
- total nitrogen.

The levels of these parameters at each monitoring site are evaluated for compliance with thresholds for life supporting capacity that are derived from national guidelines.

The results are used to produce a lake water quality index called the Trophic Level Index (TLI) that allows the ARC to assign a quality class to each of our lake monitoring sites (Box 5).

Box 5 The Trophic Level Index (TLI)

The TLI is an indicator of lake water quality and a combination of four parameters: nutrient levels (phosphorus and nitrogen), water clarity, and algae abundance (measured using chlorophyll a). The measurements of these parameters are combined in an equation to produce the TLI. It ranges from 0 to 7 and can be used to assign a quality class, also known as a trophic level, to each lake. The lower the TLI, the better the water quality of the lake.

TLI	Trophic level	Description	Water Quality
< 2	Microtrophic	Very low nutrients and algae, with very high water clarity. These lakes are usually high altitude lakes, fed by water inputs from snow melt or glaciers.	Excellent
2 – 3	Oligotrophic	Low levels of nutrients and algae, with high water clarity.	↓
3 – 4	Mesotrophic	Moderate levels of nutrients and algae.	↓
4 – 5	Eutrophic	Elevated levels of nutrients and algae, with low water clarity.	↓
5 – 6	Supertrophic	Saturated with nutrients, high algae growth with blooms possible during summer. Very low water clarity.	↓
> 6	Hypertrophic	Super-saturated with nutrients, very high algae growth with blooms common in summer. Very low water clarity.	Very poor

4.3

Freshwater

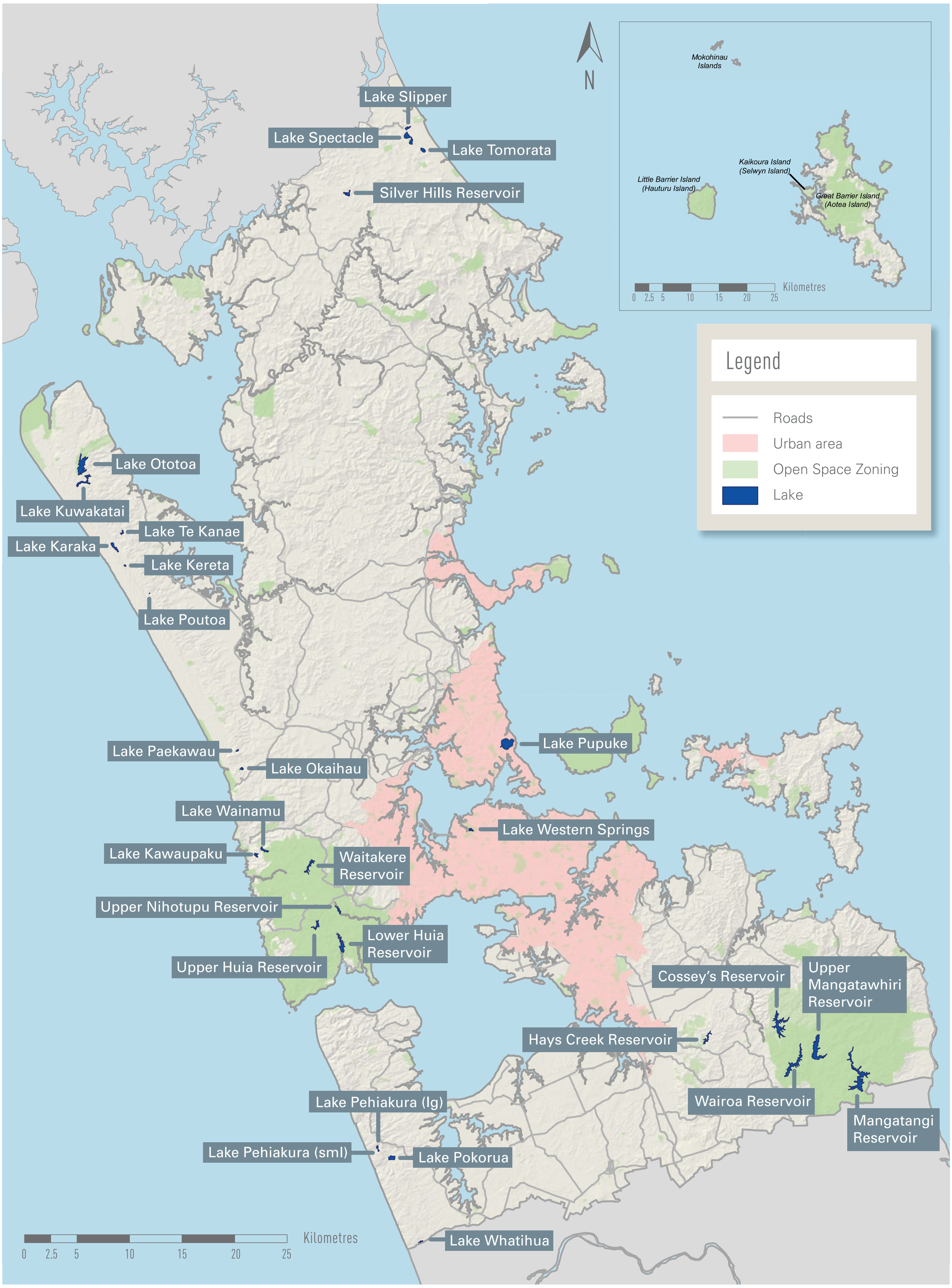


FIGURE 11 Locations of the lakes that the ARC monitors in the Auckland region. (Source: ARC).

Indicator 8: Lake water quality

Site based

Monitoring data for the four water quality parameters were used to produce the TLI lake water quality index for each of the seven lakes in the monitoring programme. The TLI was used to determine a quality class for each of the lakes. Table 18 shows the results for the 2007 lake sampling year (July 2007 to June 2008).

TABLE 18 Lake TLI index and biological productivity class (2007 sampling year). (Source: ARC).

Lake	Catchment	TLI	Quality class
Ototoa	Forested	3.9	Mesotrophic
Pupuke	Urban	4.0	Eutrophic
Tomorata	Rural	4.4	Eutrophic
Wainamu	Forested	4.4	Eutrophic
Kuwakatai	Rural	5.2	Supertrophic
Kereta	Rural	5.8	Supertrophic
Spectacle	Rural	6.2	Hypertrophic

All of the lakes had quality classes that indicated some degree of nutrient enrichment. None of the lakes were classified as microtrophic or oligotrophic.

Lake Ototoa had the lowest TLI and therefore considered to have the best water quality of the seven lakes monitored in the Auckland region. In contrast, Lake Spectacle had the highest TLI and is considered to have the worst water quality.

Although not enough lakes were sampled to identify reliable relationships between the type of land cover in the surrounding catchment and the water quality of the lake, the results shown in Table 18 suggest a far more complex relationship than the one that was clearly identified for rivers.

Trends

The 2005 Water Quality of Selected Lakes in the Auckland Region report examined trends in lake water quality between 1992 and 2005. This analysis was used to identify trends in the four water quality parameters that are used to assess the life supporting capacity of the water for each of the seven monitored lakes and the overall TLI.

The change in the overall TLI indicated that the water quality of Lakes Kereta and Tomorata improved between 1992 and 2005. Improving trends in chlorophyll a were seen at both lakes, with improving trends in total phosphorus at Lake Kereta and secchi depth at Lake Tomorata.

The change in the overall TLI indicated that the water quality of Lakes Ototoa and Spectacle declined between 1992 and 2005. All four parameters showed declining trends at Lake Ototoa, with three of the four parameters showing declines at Lake Spectacle.

TABLE 19 Trends* in individual parameters and lake TLI between 1992 and 2005. (Source: ARC).

Lake	Parameter				
	Chlorophyll *a*	Secchi depth	Total phosphorus	Total Nitrogen	Overall TLI
Ototoa	⇩	⇩	⇩	⇩	⇩
Pupuke	⇩	⇩	⇔	⇔	⇔
Tomorata	⇧	⇧	⇔	⇔	⇧
Wainamu	⇔	⇔	⇧	⇔	⇔
Kuwakatai	⇔	⇔	⇔	⇧	⇔
Kerata	⇧	⇔	⇧	⇔	⇧
Spectacle	⇧	⇩	⇩	⇩	⇩

*Trends are shown by ⇩ for declining, ⇧ for improving, and ⇔ for no detectable change.

Microbiological lake water quality

In lakes, the suitability of the water for recreational activities is typically assessed by the levels of two indicator organisms, blue-green algae and *E. coli*. The ARC monitors the levels of these indicator organisms at each of the seven sites in the lake water quality monitoring programme.

Indicator 9: Lake water quality for recreation (blue-green algae)

Blue-green algae (cyanobacteria) are commonly found in lakes all over the world. However, some species of blue-green algae, under certain conditions, produce chemicals that are highly toxic to mammals. Consequently, health authorities recommend avoiding contact with water containing high levels of blue-green algae because of potential adverse reactions to the toxins.

The ARC monitors the levels of blue-green algae in the seven lakes as part of the lake water quality monitoring programme, but it is important to note that the ARC's monitoring measures the levels of (potentially toxin producing) blue-green algae, not the presence or levels of any toxins.

Freshwater

The levels of blue-green algae at the lakes were compared with threshold derived from existing international guidelines (15,000 cells/ml). Levels above this threshold are indicative of an increased health risk. The frequency and magnitude of exceedences of this threshold were also measured (Table 20).

TABLE 20 Frequency and magnitude of exceedences of the blue-green algae threshold (2007 sampling year). (Source: ARC).

Lake	Frequency	Magnitude
Ototoa	0.0	0.0
Pupuke	0.0	0.0
Tomorata	0.0	0.0
Wainamu	14.3	1.7
Kuwakatai	14.3	7.1
Kereta	14.3	18.5
Spectacle	57.1	48.4

Lakes Ototoa, Pupuke and Wainamu had low levels of blue-green algae throughout the 2007 sampling year (July 2007 to June 2008) and, therefore, complied with the threshold. At the other end of the scale, Lake Spectacle exceeded the threshold frequently and by the biggest magnitude.

Lakes Kuwakatai, Kereta and Tomorata exceeded the threshold only once during the summer (in either December 2007 or January 2008). Lake Spectacle had the greatest magnitude of exceedences.

Indicator 10: Lake water quality for recreation (bacteria)

As with rivers, the suitability of lake water for recreation activities is also assessed by the level of *Escherichia coli* bacteria in a water sample. Although most *E. coli* are harmless, elevated levels are used to indicate the presence of faecal pollution, which may pose a threat to human health because it contains other pathogenic organisms.

The ARC monitors *E. coli* levels at each of the seven lakes in the lake water quality monitoring programme. These levels are compared with the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (produced by the MfE and MOH in 2003, see Table 8). The frequency and magnitude of any exceedences are also assessed.

All samples from all the lakes met all of the guidelines. The highest single sample (200 *E. coli* per 100ml from Lake Spectacle in May 2008) was within the Green mode guideline (260 *E. coli* per 100ml). Every other sample collected during 2007 produced results below 100 *E. coli* per 100ml.

Ecological quality programme

Rotifer monitoring programme

Rotifers are part of the natural zooplankton community of lakes and, as with invertebrates in rivers, they are useful biological indicators because of their high abundance and diversity, and their sensitivity to environmental impacts.

The rotifer community was sampled at the seven lakes in the water quality monitoring programme, at the same time as the water quality samples were collected. The information generated from these samples is often complex, so it is summarised into a rotifer index for ease of interpretation and communication.

The rotifer index can be used to infer the ecological quality of the lakes and allow comparison with the results from the lake water quality class. As with the TLI, the lower the rotifer index, the better the lake quality.

Indicator 11: Ecological quality (based on rotifer index)

Lake Ototoa had the lowest rotifer index and inferred quality class (Table 21), and was therefore considered to have the best ecological quality (based on rotifers) of the seven monitored lakes. At the other end of the scale, Lake Spectacle had the highest rotifer index and was considered to have the worst ecological quality of the monitored lakes.

Again, there are not enough lakes sampled in each type of catchment land cover to identify reliable relationships between catchment land cover and lake water quality. However, it is interesting to note that the two lakes in predominantly forested catchments had the best ecological quality, based on their rotifer index results.

TABLE 21 Rotifer index results for 2008. (Source: ARC).

Lake	Catchment	Rotifer index	Inferred quality class
Ototoa	Forested	3.0	Mesotrophic
Wainamu	Forested	3.7	Mesotrophic
Tomorata	Rural	4.0	Eutrophic
Pupuke	Urban	4.2	Eutrophic
Kuwakatai	Rural	4.2	Eutrophic
Kereta	Rural	4.9	Eutrophic
Spectacle	Rural	5.8	Supertrophic

Macrophyte monitoring programme

In a pristine state, lakes within the Auckland region would contain a diverse range of native macrophytes (submerged plant species) growing from the lake edge towards the centre of the lake. Their extent is determined by the water clarity or the maximum depth of the lake. In shallow lakes, the macrophytes would have probably grown across the entire lake. Today, relatively few lakes remain in a pristine condition because invasive species and reduced water clarity has limited the quality and extent of the macrophytes in most lakes.

To assess the ecological condition of lakes based on their macrophyte communities, surveys were undertaken at 29 lakes during 2008. Key features of the macrophyte community structure and composition were used to produce a series of indices using the LakeSPI (Submerged Plant Indicators) tool. Macrophytes are useful indicators of ecological condition because of their size, ease of identification and perennial nature.

Results from the macrophyte survey and subsequent LakeSPI analysis produced three indices:

- LakeSPI index. This is an overall index of the plant community (the higher this score, the better).
- Native condition index. This index is based on the diversity and quality of native submerged plants (the higher this score, the better).
- Invasive condition index. This index is based on the degree of impact by invasive weed species (the lower this score, the better).

The LakeSPI index enables the ARC to assign an overall quality class using the following ranges:

- Greater than 75 = Excellent quality
- Between 50 and 75 = Good quality
- Between 20 and 50 = Fair quality
- Between 1 and 20 = Poor quality
- 0 = Non-vegetated.

Indicator 12: Ecological quality (based on macrophytes)

A wide range in LakeSPI index scores (from 0 to 90) was observed from surveys of the 29 lakes, indicating a large variation in the ecological quality of these lakes. Of the 29 sites:

- four lakes (14 per cent) were classified as Excellent,
- three lakes (10 per cent) as Good,
- seven lakes (24 per cent) as Fair,
- seven lakes (24 per cent) as Poor,
- eight lakes (28 per cent) were non-vegetated.

The environmental pressure having the biggest effect on the LakeSPI index was identified for those lakes that produced scores lower than 50 (Table 22). As expected, water level changes had the biggest effect in the water supply reservoirs.

Of more interest were the many natural lakes that had lower than Good LakeSPI scores: the main limiting factor for these lakes was considered to be invasive weeds. The number of lakes within the Auckland region that have invasive weeds is high compared to the national average.

Implications of lake quality

The lake water quality programme indicated that all seven monitored lakes were enriched to some extent, although there was no clear relationship with land cover in the surrounding catchment. This may be due to the relatively small number of sites in the monitoring programme, although our ecological monitoring programme (using macrophytes) indicated that invasive weeds may be the most important stressor in the lakes.

The trend analysis of the lake water quality produced mixed results. The best and worst lakes (Ototoa and Spectacle) both showed signs of a decline in water quality between 1992 and 2005 but two others (Tomorata and Kereta) showed signs of an improvement in water quality. The ARC is researching the nature and impact of these trends.

As with the lake water quality monitoring, the rotifer index indicated that all of the seven routinely monitored lakes were enriched to some extent. As with most of the lake indicators, the relationship with land cover is not obvious, although the two lakes with forested catchments did produce the lowest rotifer index and hence best quality class.

The assessment of the submerged plant community, using the LakeSPI indices, indicated that the ecological quality of most of the lakes was degraded. The main impact on the natural degraded lakes was considered to be the presence of aquatic plant pests.

Unlike the rivers, several of the lakes are used for recreational activities. Our lake water quality programme showed that the recreational water quality of these seven lakes was generally good with little, if any, indication of faecal pollution. The low level of *E. coli* at all seven lakes was a welcome result and indicated an absence of faecal pollution. The levels observed were all below the most conservative (green mode) national recreational guidelines and, therefore, also met the stock watering guideline.

Lake Spectacle exceeded the blue-green algae threshold frequently. This lake is located within a catchment where intensive agriculture dominates land use. As a result nutrient levels were very high, water clarity was very low and algal blooms were common.

Whilst there was some agreement between the water quality and ecological monitoring, the correlation between the results of the two programmes was not statistically significant.

Freshwater

TABLE 22 LakeSPI results derived from the submerged plant surveys at 29 lakes. (Source: ARC).

Lake	LakeSPI index	Native condition index	Invasive condition index	LakeSPI class	Main limiting factor
Poutoa	90	82	5.6	Excellent	
Tomorata	78	56	0	Excellent	
Mangatawhiri*	76	61	0	Excellent	
Pokorua	76	82	23	Excellent	
Ototoa	72	60	8.1	Good	
Wairoa*	66	47	0	Good	
Waitakere*	51	46	39	Good	
Cossey's*	49	28	20	Fair	Water level change
Upper Huia*	36	22	53	Fair	Water level change
Whatihua	33	43	81	Fair	Invasive weeds
Lower Huia*	31	23	33	Fair	Water level change
Pupuke	30	35	79	Fair	Invasive weeds
Silver Hills*	30	22	59	Fair	Water quality
Pehiakura (small)	25	25	85	Fair	Invasive weeds
Okaihau	18	16	80	Poor	Invasive weeds
Wainamu	16	16	85	Poor	Invasive weeds
Pehiakura (large)	15	5	89	Poor	Invasive weeds
Kuwakatai	11	5	99	Poor	Invasive weeds
Te Kanae	10	4	96	Poor	Invasive weeds
Kawaupaku	10	3.3	89	Poor	Invasive weeds
Kereta	8	3	94	Poor	Invasive weeds
Mangatangi*	0	0	0	Non vegetated	Water level change
Hays Creek*	0	0	0	Non vegetated	Water quality
Karaka	0	0	0	Non vegetated	Water quality
Paekawau	0	0	0	Non vegetated	Water quality
Slipper	0	0	0	Non vegetated	Water quality
Spectacle	0	0	0	Non vegetated	Water quality
Nihotupu*	0	0	0	Non vegetated	Water level change
Western Springs	0	0	0	Non vegetated	Grass carp

* Water supply reservoirs

Groundwater

Key findings

- → The Auckland region has six major aquifer types, two are typically unconfined and four are typically confined.
- → Natural groundwater quality is controlled principally by the aquifer's geology, confinement and rate of groundwater flow.
- → The potential for groundwater contamination is primarily controlled by the aquifer confinement, depth and ground water age.
- → Deep, confined aquifers are not usually contaminated.
- → Contamination of unconfined aquifers is strongly related to the overlying and upgradient land use activities.

Introduction

The Auckland region has many aquifers, typically of sedimentary or volcanic origin (Figure 13). Stored in these aquifers is groundwater used for municipal water supply, irrigation, geothermal energy, domestic and stock water supplies; they also contribute to the water in the rivers and other surface water bodies such as lakes and wetlands.

Aquifers are defined as 'saturated rocks or sediments with sufficient permeability to yield economic quantities of water.'

The principal aquifer systems of the Auckland region are related to rock types (Figure 13):

- → volcanics (basalt and andesite lava flows, and pyroclastics)
- → alluvial sands and gravels
- → coastal dune sands
- → shelly marine sandstones
- → marine sandstones and mudstones
- → marine greywackes.

Each of these rock types contains many aquifer systems which, in turn, consist of numerous, individual aquifers that each store and transport quantities of groundwater.

The quality of the groundwater is related to the geology of the aquifer (through the water interacting with the rock), how long the water is in the aquifer and the degree of confinement and depth of the aquifer.

Figure 12 shows the different aquifer types. A confined aquifer occurs where the rocks above and below the aquifer are relatively impermeable. This restricts the vertical flow of groundwater and restricts the rise of the water table, pressurising the aquifer.

An unconfined aquifer is where the rocks above the aquifer are permeable. This allows the vertical flow of groundwater, movement of contaminants from the surface and permits the water table to rise and fall.

The impermeable layers that overlie a confined aquifer tend to protect the aquifer from contaminants migrating vertically downwards, particularly those from overlying land use activities (anthropogenic contamination). However, the groundwater quality can be affected by land-use activities within the groundwater recharge zone that can be located a large distance away. Generally, the deeper the aquifer the greater possibility of a confining layer existing between the aquifer and the surface.

Other important factors that control the effect of land use activities on groundwater quality are the rate of flow of groundwater through the aquifer and the volume of water stored within the aquifer. The length of time that the water has been in the ground is also important. When the groundwater is old, historic land uses that are no longer present can still have a significant impact today.

Groundwater quality monitoring programme

The quality of the High Use and Sensitive aquifers in the Auckland region is monitored routinely. The ARC's groundwater quality monitoring programme monitors the physical, chemical and microbiological properties of the groundwater at 24 boreholes. Bores are sampled quarterly, twice a year or annually, depending on the rate of groundwater flow and the rate of change in groundwater quality.

The physical parameters monitored include field measurements of the water temperature, pH, electrical conductivity, dissolved oxygen and redox potential. Laboratory measurements of pH, turbidity, suspended solids and total dissolved solids are also conducted.

The chemical parameters monitored include alkalinity, hardness, nutrients, pesticides, major and minor cations and anions, and silicate. Levels of faecal coliforms and *E-coli* bacteria are also monitored.

The groundwater quality monitoring enables the ARC to assess the:

- → natural physical and chemical characteristics of the groundwater within each aquifer type,
- → nature and degree of contamination within each aquifer system,
- → suitability of the groundwater for supporting plant and animal life upon discharge into the rivers (as baseflow) and the coastal environment,
- → suitability of the groundwater for drinking and irrigation.

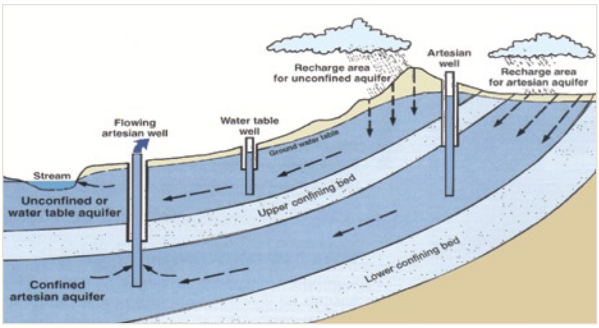


FIGURE 12 Groundwater Concepts (Source: ARC).

Freshwater

The groundwater quality of the aquifers in the Auckland region was summarised into three specific groundwater quality indicators based on the relevant environmental, recreational or drinking water guideline or standard. The indices is used to assess groundwater quality are described earlier in Box 3: Water Quality Index (page 146).

The WQI enables the ARC to assign an overall groundwater quality class. This can be used to evaluate the groundwater in each of the aquifer systems for its suitability for discharge to rivers and the coastal environment, and for use as drinking water (Table 23).

Groundwater data from 1998 to 2009 was used to calculate the drinking water quality indices and data from 2004 to 2009 was used for the river and coastal discharge indices.

TABLE 23 Threshold for assigning quality classes to rivers and coastal environments and for drinking water. (Source: ARC).

Class	Groundwater quality for discharge to rivers and coastal environments	Groundwater quality for use as drinking water
Excellent	Greater than 90	Greater than 90
Good	75-90	70-90
Fair	60-75	50-70
Poor	Less than 60	Less than 50

Groundwater quality for discharge to river and marine environments

Indicator 13: Groundwater quality for discharge to rivers

The suitability of the groundwater quality in each of the monitored aquifer systems to support plant and animal life when discharged as baseflow into rivers was calculated using 15 dissolved parameters. The parameters used comprised forms of nitrogen, aluminium, arsenic, boron, chromium, copper, iron, manganese, nickel, lead, zinc and *E. coli* bacteria. Table 24 shows the results.

Indicator 14: Groundwater quality for coastal discharge to marine environments

The suitability of the groundwater quality in each of the monitored aquifer systems to support plant and animal life when discharged into the coastal environment was calculated using the same parameters for Indicator 13, except for iron. Table 25 shows the results.

Sedimentary aquifers

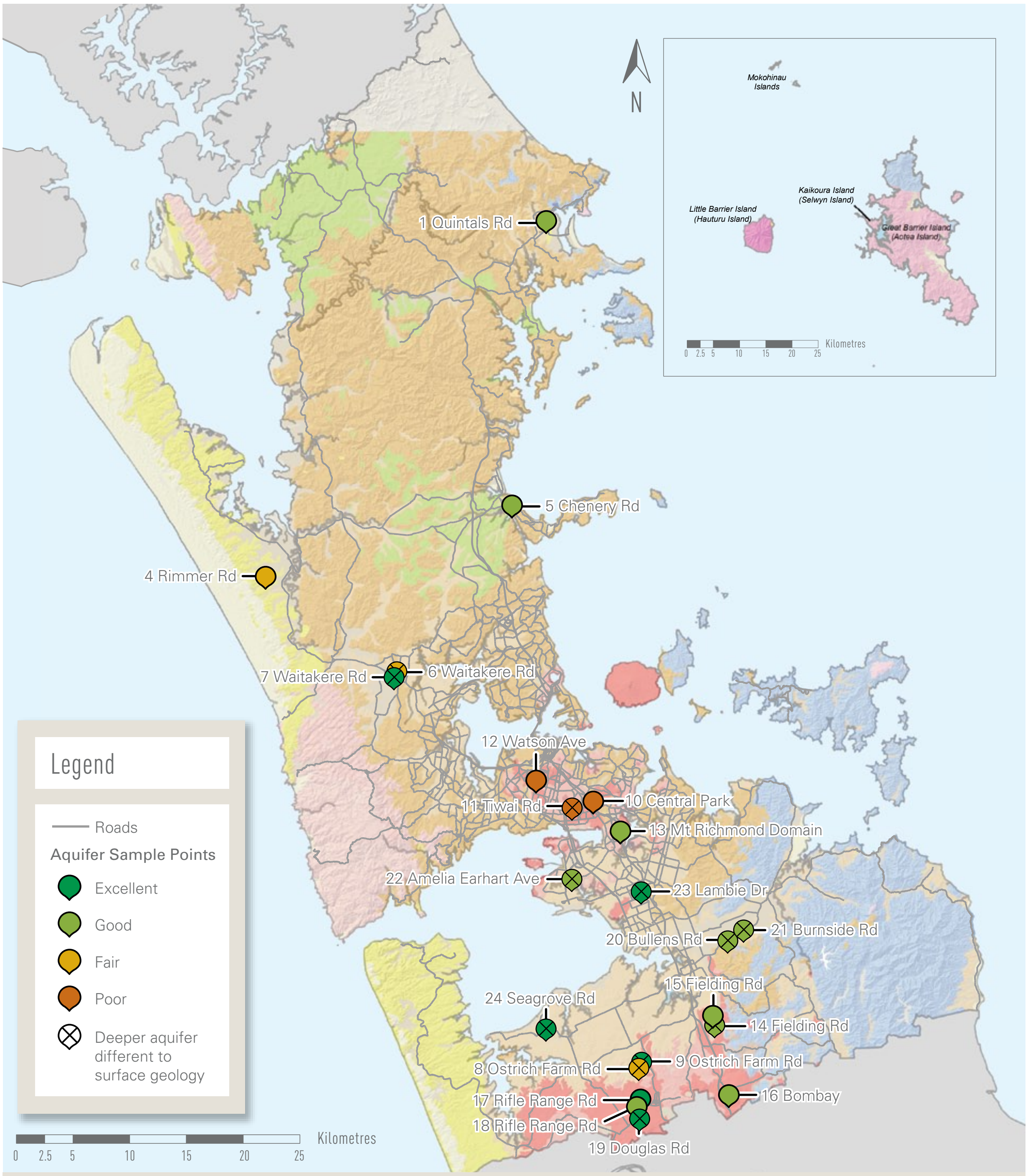
The groundwater quality for discharge to rivers from deep, confined sedimentary aquifer systems of the Waitemata Group and Pleistocene Alluvial Sediments was classed as Good or Excellent. This was primarily due to their relatively good flow rates, good protection from overlying land use activities and groundwater aged typically more than 100 years.

However, the groundwater in these confined sedimentary aquifers tends to have naturally elevated levels of ammoniacal nitrogen, iron, boron, manganese and zinc (depending on the geology and degree of confinement of the particular aquifer). When the iron levels are elevated, the groundwater quality often exceeds (up to 10 times) the environmental guideline for protection of freshwater ecosystems. Occasionally, zinc can marginally exceed the freshwater guidelines, (typically around 1-2 times). Boron, in the very deep (typically 100-200m) southern Waitemata Group aquifers can be at, or marginally exceed, the freshwater guidelines. Levels of ammoniacal nitrogen and manganese, although naturally elevated, remain below the freshwater guidelines.

Whether the groundwater quality for discharge to rivers for these confined aquifer systems is classified as Good or Excellent depends mainly on the amount of iron that has dissolved naturally within the groundwater, as a result of complex chemical reactions between the rocks and the groundwater. These reactions are controlled mainly by the redox potential, pH and temperature of the groundwater within the aquifer.

Most of the deep, confined sedimentary aquifer systems with low iron concentrations have excellent groundwater quality due to their strongly anoxic conditions.

The groundwater quality for discharge to rivers from the deep, confined Pliocene Dune Sands aquifer is classified as Fair due to naturally high iron concentration and anoxic conditions. The semi-confined shallow aquifer in the northern Waitemata Group at Waitakere Road is also classified as Fair due to the high iron concentrations from strong weathering on the top of this rock. The groundwater quality for discharge to the marine environment from all deep, confined sedimentary aquifers is classified as Excellent.



Geology

Holocene Sediments
- Alluvial Sediments
- Dune Sands

Pliocene and Pliocene Sediments
- Alluvial Sediments
- Dune Sands
- Kaawa – Shelly, Calcareous Sandstones

Waitemata Group
- Sandstones, Mudstones

Te Kuiti Group
- Sandstones, Mudstones, Coal measures

Northland Allochthon
- Mudstones, Limestones and Minor Volcanics

Jurassic Basement
- Greywackes

Great Barrier Island Volcanics
- Volcanics

Waiheke Island
- Volcanics

Little Barrier Island Volcanics
- Volcanics

South Auckland and Auckland Volcanics
- Basalt
- Scoria
- Tuff

Waitakere Group Volcanics
- Volcanics
- Volcaniclastic

FIGURE 13 Aquifers and quality scores. (Source: ARC).

TABLE 24 Groundwater quality class for discharges to rivers for monitored aquifers in the Auckland region. (Source: ARC).

Aquifer system and borehole name	Type of aquifer confinement	Aquifer depth (m)	Scope (%)	Freq. (%)	Mag. (%)	WQI (%)	Class
Central Auckland Volcanics							
10 – Central Park	Unconfined	13-22	40.0	10.4	18.5	73.8	Fair
12 – Watson Ave	Unconfined	32.5-38.5	40.0	3.5	19.0	74.4	Fair
11 – Tiwai Rd	Unconfined	46.5-58.5	40.0	2.9	1.5	76.8	Good
13 – Mt. Richmond Domain	Unconfined	29.0-36.5	26.7	5.2	15.5	82.0	Good
South Auckland Volcanics							
17 – Rifle Range Rd	Unconfined	30-42	20.0	7.0	2.3	87.7	Good
16 – Bombay	Unconfined	62-79.5	13.3	9.6	6.4	89.8	Good
15 – Fielding Rd	Semi-confined	16.3-46.7	6.7	0.6	0.9	96.1	Excellent
18 – Rifle Range Rd	Confined	78-90	6.7	0.3	0.0	96.1	Excellent
Pleistocene Alluvial Sediments							
14 – Fielding Rd	Confined	57-64	20.0	5.6	1.7	88.0	Good
Pliocene Dune Sands							
4 – Rimmer Rd	Confined	49.5-61.5	13.3	7.3	53.5	67.9	Fair
Waitemata Group							
6 – Waitakere Rd	Semiconfined	10-15.0	13.3	6.7	51.8	68.9	Fair
1 – Quintals Rd	Confined	94-129.6	3.7	6.1	23.0	85.7	Good
5 – Chenery Rd	Confined	151-500	13.3	5.0	12.2	89.2	Good
7 – Waitakere Rd	Confined	78-150	13.3	5.7	10.8	89.6	Good
20 – Bullens Rd	Confined	38.9-75	20.0	6.1	5.7	87.5	Good
21 – Burnside Rd	Confined	154.2-169	13.3	7.0	12.5	88.7	Good
23 – Lambie Dr, Puhinui	Confined	60-200	13.3	5.3	3.0	91.5	Excellent
24 – Seagrove Rd	Confined	97.8-201	0.0	0.0	0.0	100.0	Excellent

TABLE 25 Groundwater quality class for discharges to the coastal environment for monitored aquifers in the Auckland region (Source: ARC).

Aquifer system and borehole name	Type of aquifer confinement	Aquifer depth (m)	Scope (%)	Freq. (%)	Mag. (%)	WQI (%)	Class
Central Auckland Volcanics							
10 – Central Park	Unconfined	13-22	28.6	8.7	13.1	81.2	Good
12 – Watson Ave	Unconfined	32.5-38.5	28.6	2.5	14.6	81.4	Good
11 – Tiwai Rd	Unconfined	46.5-58.5	28.6	2.2	1	83.4	Good
13 – Mt. Richmond Domain	Unconfined	29.0-36.5	14.3	4.2	13.6	88.4	Good
South Auckland Volcanics							
17 – Rifle Range Rd	Unconfined	30-42	21.4	7.1	2.1	86.9	Good
16 – Bombay	Unconfined	62-79.5	14.3	9.6	3.5	89.8	Good
15 – Fielding Rd	Semi-confined	16.3-46.7	0	0	0	100	Excellent
18 – Rifle Range Rd	Confined	78-90	7.1	0.3	0.1	95.9	Excellent
Pleistocene Alluvial Sediments							
14 – Fielding Rd	Confined	57-64	7.1	0.6	0	95.9	Excellent
Pliocene Dune Sands							
4 – Rimmer Rd	Confined	49.5-61.5	0	0	0	100	Excellent
Kaawa Formation							
8 – Ostrich Farm Rd #1	Confined	68-84	7.1	1.6	0.6	95.8	Excellent
8 – Ostrich Farm Rd #2	Confined	46-47	7.1	0.6	1.7	95.7	Excellent
22 – Amelia Earhart Ave	Confined	42.6-48.6	0	0	0	100	Excellent
19 – Douglas Rd	Confined	254-268	0	0	0	100	Excellent
Waitemata Group							
6 – Waitakere Rd	Semiconfined	10-15.0	13.3	6.7	51.8	68.9	Fair
1 – Quintals Rd	Confined	94-129.6	3.7	6.1	23.0	85.7	Good
5 – Chenery Rd	Confined	151-500	13.3	5.0	12.2	89.2	Good
7 – Waitakere Rd	Confined	78-150	13.3	5.7	10.8	89.6	Good
20 – Bullens Rd	Confined	38.9-75	20.0	6.1	5.7	87.5	Good
21 – Burnside Rd	Confined	154.2-169	13.3	7.0	12.5	88.7	Good
23 – Lambie Dr, Puhinui	Confined	60-200	13.3	5.3	3.0	91.5	Excellent
24 – Seagrove Rd	Confined	97.8-201	0.0	0.0	0.0	100.0	Excellent

Volcanic aquifers

The groundwater quality for discharge from the confined and semi-confined aquifer systems in the South Auckland Volcanics is classified as Excellent. These aquifer systems have very high groundwater flow rates and some protection from vertical migration of contaminants from overlying land use activities by less permeable layers above. However, this groundwater tends to be over 100 years old, meaning that any contamination may not have yet reached this part of the aquifer.

The groundwater quality for discharge from the shallow unconfined aquifer systems of the South Auckland Volcanics is classified as Good. These are more vulnerable to contamination from the overlying intensive horticultural and market garden land use activities. Nitrates, principally from fertiliser application, consistently exceed guideline values. Pesticide and herbicide residues have also been occasionally detected, albeit at low levels.

Although the shallow, unconfined Central Auckland Volcanic aquifer system is classified Good or Fair it is highly vulnerable and at risk of pollution from overlying urban land use activities. At the volcanic cones, where the aquifer system is overlain by parkland, the groundwater quality is Good because contaminant levels in the surface water or stormwater that migrates into the groundwater are relatively low. However, where the overlying land use is residential or commercial, the groundwater quality is variable as contaminants migrate easily into these unconfined aquifers. Microbial contamination is often ten times above guideline values mostly due to sewerage overflows and leaky pipes. Zinc and copper are also elevated due to stormwater contamination. Fortunately, the very high groundwater flow and recharge rates in these unconfined aquifer systems dilutes the contamination and, as a result, the groundwater quality is not as bad as it would otherwise be.

Groundwater quality for drinking water

Indicator 15: Groundwater quality for drinking water

The suitability of the groundwater quality for drinking was also assessed using 23 different parameters.

The results were compared to both the maximum acceptable values for human health and the guideline values for aesthetics following the New Zealand Drinking Water Standard. This assessment does not take into account any water supply treatment process. The results are shown in Table 26 and illustrated in Figure 13.

Sedimentary aquifers

The groundwater quality for drinking from the deep confined sedimentary aquifer systems of the Waitemata Group, Kaawa Formation and Pleistocene Alluvial Sediments was generally classified as Good or Excellent. This was primarily due to their relatively good flow rates, good protection from overlying land use activities and groundwater more than 100 years old.

The aquifers with excellent groundwater quality for drinking tend to have naturally higher pH (more than pH 8.5) and low iron levels, whereas those with good groundwater quality for drinking tend to have naturally elevated levels of iron, ammoniacal nitrogen, turbidity, total hardness, boron and manganese (depending on the geology and degree of confinement of the aquifer). Iron typically exceeded the aesthetic drinking water standard up to 16 times.

Volcanic aquifers

The groundwater quality for drinking from the confined aquifer systems in the South Auckland Volcanics is classified as Excellent. The semi-confined aquifer system is classified as Good due to naturally elevated levels of iron and turbidity. However, the shallow, unconfined aquifer systems, although classified Good, are impacted by high nitrate levels due to overlying intensive horticultural and market garden land use activities. Pesticides and herbicides (including Bentazone, Alachlor and Metolachlor) have also been detected within these aquifer systems, although not above the guidelines for drinking water.

The groundwater quality for drinking from the shallow, unconfined Central Auckland Volcanic aquifer system covered by parkland is classified as Good. However, where the overlying land use is residential or commercial, the groundwater quality for drinking is Poor due to the impact of stormwater contamination, overflows from sewers and leaky pipes.

Overall groundwater quality

When the results of the indicators are considered together, they show that land use effects on groundwater quality are strongly affected by the degree of confinement of the aquifer and the age of the groundwater (Figure 13).

Little or no land-use impacts were found in the deep confined sedimentary or volcanic aquifers with groundwater in excess of 100 years. However, the impacts of land use activities were apparent in the vulnerable unconfined, younger volcanic aquifer systems and, to a lesser degree, in the semi-confined aquifers.

E-coli and nitrate contamination from sewerage overflows and leaking pipes is an important issue for the unconfined aquifer systems of the Central Auckland Volcanics. Similarly, nitrates are also cause for concern in the South Auckland Volcanics unconfined aquifer system.

TABLE 26 Groundwater quality class for drinking water for monitored aquifers in the Auckland region. (Source: ARC).

Aquifer system and borehole name	Type of aquifer confinement	Aquifer depth (m)	Scope (%)	Freq. (%)	Mag. (%)	WQI (%)	Class
Central Auckland Volcanics							
10 – Central Park	Unconfined	13-22	28.6	8.7	13.1	81.2	Good
12 – Watson Ave	Unconfined	32.5-38.5	28.6	2.5	14.6	81.4	Good
11 – Tiwai Rd	Unconfined	46.5-58.5	28.6	2.2	1.0	83.4	Good
13 – Mt. Richmond Domain	Unconfined	29.0-36.5	14.3	4.2	13.6	88.4	Good
South Auckland Volcanics							
17 – Rifle Range Rd	Unconfined	30-42	21.4	7.1	2.1	86.9	Good
16 – Bombay	Unconfined	62-79.5	14.3	9.6	3.5	89.8	Good
15 – Fielding Rd	Semi-confined	16.3-46.7	0.0	0.0	0.0	100.0	Excellent
18 – Rifle Range Rd	Confined	78-90	13	2.4	0.2	92.3	Excellent
Pleistocene Alluvial Sediments							
14 – Fielding Rd	Confined	57-64	7.1	0.6	0.0	95.9	Excellent
Pliocene Dune Sands							
4 – Rimmer Rd	Confined	49.5-61.5	0.0	0.0	0.0	100.0	Excellent
Kaawa Formation							
8 – Ostrich Farm Rd #1	Confined	68-84	7.1	1.6	0.6	95.8	Excellent
22 – Amelia Earhart Ave	Confined	42.6-48.6	0.0	0.0	0.0	100.0	Excellent
19 – Douglas Rd	Confined	254-268	0.0	0.0	0.0	100.0	Excellent
Waitemata Group							
6 – Waitakere Rd	Semi-confined	10-15.0	0.0	0.0	0.0	100.0	Excellent
1 – Quintals Rd	Confined	94-129.6	0.0	0.0	0.0	100.0	Excellent
5 – Chenery Rd	Confined	151-500	7.1	0.9	2.3	95.6	Excellent
7 – Waitakere Rd	Confined	78-150	0.0	0.0	0.0	100.0	Excellent
20 – Bullens Rd	Confined	38.9-75	7.1	0.6	1.0	95.8	Excellent
21 – Burnside Rd	Confined	154.2-169	0.0	0.0	0.0	100.0	Excellent
23 – Lambie Dr, Puhinui	Confined	60-200	14.3	1.4	1.3	91.7	Excellent
24 – Seagrove Rd	Confined	97.8-201	0.0	0.0	0.0	100.0	Excellent

Freshwater

Copper and zinc contamination from stormwater soakholes and leaky pipes occurs in the unconfined Central Auckland Volcanic aquifers and, to a lesser degree, in the unconfined South Auckland Volcanic aquifers. Zinc, and to a lesser degree, copper, may also originate from elevated natural background concentrations within these volcanic rocks. Occasionally, levels of nickel, iron, chromium and lead are of concern in the unconfined Central Auckland Volcanic aquifers, although natural background levels could account for these concentrations, particularly nickel and iron. However, the elevated levels of lead are indicative of anthropogenic contamination.

Groundwater quality is generally worse in the more vulnerable shallow, unconfined aquifers in both urban and rural areas where the groundwater is not older than any land use.

Implications of groundwater quality

Groundwater quality of the aquifers in the Auckland region was mostly Good or Excellent although some aquifers had Fair or Poor groundwater quality.

The level of groundwater contamination is predominantly controlled by the rate of groundwater flow and by the amount of protection from the overlying land uses determined by the overlying geology. Knowledge of the age of the groundwater is important when determining the potential for future impact or any ongoing impact on the groudwater quality of an aquifer.

The deeper confined aquifers (the Waitemata Group, Kaawa Formation and Pleistocene Alluvial Sediments) all had Good or Excellent groundwater quality. Any variations in water quality (particularly iron, ammonia, manganese and boron) tend to be natural and are related to the aquifer's geology, depth, confinement and the groundwater's pH, temperature and redox potential.

Natural variations in iron levels have the largest effect on the groundwater quality of the sedimentary aquifers. The higher the iron levels, the lower the groundwater quality. The Fair groundwater quality of the shallow semi-confined Waitemata Group aquifer and the Pliocene Dune Sands aquifers is due to their naturally high iron levels.

Unconfined aquifers are highly vulnerable to contamination from overlying land uses. The unconfined South Auckland Volcanic aquifers are affected by the overlying rural land uses with very high levels of nitrate from prolonged horticultural and market garden land use and the associated application of fertilizers. The unconfined Central Auckland Volcanic aquifers were also significantly affected by the overlying urban land uses, with very high *E. coli* levels and elevated levels of copper, zinc and nitrate from urban stormwater contamination, sewerage overflows and leaky pipes.

Our groundwater monitoring programme does not specifically monitor the groundwater quality from contaminated land. Consequently, there are areas of very poor groundwater quality within the Auckland region that are not included in this assessment.

Exotic freshwater species

Exotic freshwater plant pests

Many exotic freshwater plants are found in New Zealand but, fortunately, the two worst pest plant species (*Hydrilla verticulate* and *Phragmites australis*) are not found in the Auckland region. However, many other exotic freshwater plants are found in the Auckland region and Table 27 indicates their relative distribution and potential environmental risk.

If un-managed, exotic freshwater plants can form dense, unsightly and hazardous weed beds. These growths can displace native plant communities and degrade the habitat for freshwater animals; block stream channels, drains and irrigation systems; reduce oxygen levels in the water and create drowning hazards for people and animals.

The five exotic freshwater plants the ARC considers to be the worst in the Auckland region because of their environmental effects are *Egeria*, Hornwort, Alligator weed, Lagarosiphon and Manchurian wild rice. These five species can all produce dense growths that reduce biodiversity by excluding native species and can be associated with declines in water quality and ecological quality. Extremely dense growth can affect the water flow and interfere with irrigation and water supply, restrict water traffic and recreational activities, and pose a drowning risk because of entanglement.

Egeria (Egeria densa)

Originally from South America, *Egeria* was first discovered at Western Springs in Auckland in 1963 and is now widespread throughout the North Island. It is the most common of the high environmental risk exotic plants, and has been found in at least eight lakes in the Auckland region.

It is a submerged, bottom-rooted perennial freshwater plant that inhabits standing and slow flowing water bodies. It can form dense weed beds up to 8m deep in clear lakes, and displaces both native and other introduced species. *Egeria* can spread only by distribution of vegetative fragments because there are only male plants in New Zealand, meaning that it cannot set viable seed.

Hornwort *(Ceratophyllum demersum)*

Hornwort has a wide global distribution, ranging from North America to Australia. It was first recorded in Auckland at Glendowie in 1975 and is widespread throughout the North Island. Because of its environmental effects it is considered to be the worst submerged freshwater exotic plant in New Zealand and has been found in at least five lakes in the Auckland region.

It is a submerged, perennial freshwater plant that inhabits standing and slow flowing waterbodies. Unlike *Egeria*, it does not produce true roots and anchors only lightly to the substrate using buried stems and leaves. It forms dense weed beds up to 10m deep in clear lakes and displaces both native and other introduced species. Hornwort is a relatively brittle plant so fragments break off readily and form new growths elsewhere. Like *Egeria*, this is the only mechanism of spread. Although the plants produce both male and female flowers, this species has not yet been observed to produce viable seed in New Zealand.

Alligator weed *(Alternanthera philoxeroides)*

Originally from South America, Alligator weed was first recorded in Auckland at Piha in 1945 and it is widespread throughout the upper North Island. Temperature is thought to limit its distribution.

It is an emergent, perennial freshwater plant that inhabits a wide range of freshwater and terrestrial environments, and can even tolerate salt water. It is a rooted plant that can produce dense beds up to 1m deep. It is typically found in slow flowing rivers, drains and wetlands and can form marginal mats in lakes although it cannot set root in water deeper than 3m. It is a relatively brittle plant and fragments break off easily and form new growths elsewhere. This is the only mechanism of spread as this species has not yet been observed to produce viable seed in New Zealand.

Lagarosiphon *(Lagarosiphon major)*

Originally from South Africa, this species of oxygen weed was first recorded in Auckland at Western Springs in 1953 and is widespread throughout New Zealand.

It is a submerged, bottom-rooted perennial freshwater plant that inhabits standing and slow flowing waterbodies. It can form dense weed beds up to 7m deep in clear lakes and displaces both native and other introduced species. This species can only spread by distribution of vegetative fragments because there are only female plants in New Zealand and, therefore, it cannot set viable seed.

Manchurian wild rice *(Zizania latifolia)*

Originally from China, Manchurian wild rice was first recorded in Auckland at Lake Kereta in 1950. It is limited to a small number of sites in the Auckland region and nationally is restricted to the upper North Island (Northland, Auckland and Waikato) with the exception of one isolated site in Wellington.

It is a very tall perennial grass that inhabits the margins of waterbodies and can tolerate brackish water. It is a strongly rooted plant that can form dense stands up to 4m in height. It spreads aggressively through rhizomes up to 10m from the parent plant. It also produces viable seeds and can regenerate from fragments.

Freshwater

TABLE 27 Exotic freshwater plants known in the Auckland region. (Source: ARC).

Common name	Scientific name	Distribution	Environmental risk
Egeria	*Egeria densa*	Widespread	High
Hornwort	*Ceratophyllum demersum*	Widespread	High
Alligator weed	*Alternanthera philoxeroides*	Widespread	High
Lagarosiphon	*Lagarosiphon major*	Frequent	High
Manchurian wild rice	*Zizania latifolia*	Sparse	High
Bladderwort	*Utricularia gibba*	Frequent	Moderate
Sagittaria	*all Sagittaria p. except S. teres*	Sparse	Moderate
Senegal tea	*Gymnocoronis spilanthoides*	Sparse	Moderate
Water poppy	*Hydrocleys nymphoides*	Sparse	Moderate
Eelsgrass	*Valisneria* sp.	Sparse	Moderate
Water lily	*Nymphaea* sp.	Frequent	Moderate
Great reedmace	*Typha latifolia*	Sparse	Moderate
Marshwort	*Nymphoides* sp.	Sparse	Moderate
Curled pondweed	*Potamogeton crispus*	Frequent	Moderate
Water buttercup	*Ranunculus trichophyllus*	Sparse	Moderate
Canadian pondweed	*Elodea canadensis*	Frequent	Moderate
Cape pondweed	*Aponogeton distachyus*	Sparse	Moderate
Yellow flag iris	*Iris pseudocorus*	Sparse	Moderate
Purple duckweed	*Landoltia punctata*	Frequent	Moderate
Spearwort	*Ranunculus flammula*	Sparse	Low
Water celery	*Apium nodiflorum*	Sparse	Low
Water primrose	*Ludwigia peploides*	Frequent	Low
Water purslane	*Ludwigia palustris*	Widespread	Low
Ferny azolla	*Azolla pinnata*	Frequent	Low
Lotus	*Lotus pedunculatus*	Sparse	Low
Marsh bedstraw	*Galium paustre*	Frequent	Low
Nardoo	*Marsilea mutica*	Sparse	Low
Jointed rush	*Juncus articulatus*	Sparse	Low
Bulbous rush	*Juncus bulbosus*	Frequent	Low
Lizard's tail	*Saururus cernuus*	Sparse	Low
Watercress	*Nasturtium officianle*	Widespread	Low
Swamp lily	*Otellia ovalifolia*	Frequent	Low

TABLE 28 Exotic freshwater fauna known in the Auckland region. (Source: ARC).

Common name	Scientific name	Distribution	Environmental risk
Perch	*Perca fluviatilis*	Widespread	High
Mosquitofish	*Gambusia affinis*	Widespread	High
Rudd	*Scardinius erythrophthalmus*	Widespread	Moderate
Koi carp	*Cyprinus carpio*	Frequent	Moderate
Goldfish	*Carassius auratus*	Frequent	Moderate
Golden orfe	*Leuciscus idus*	Sparse	Moderate
Tench	*Tinca tinca*	Sparse	Low
Brown trout	*Salmo trutta*	Sparse	Low
Rainbow trout	*Oncorhynchus mykiss*	Sparse	Low
Brown bullhead catfish	*Ameiurus nebulosus*	Sparse	Low
Grass carp	*Ctenopharyngodon idella*	Sparse	Low
Silver carp	*Hypophthalmichthys molitrix*	Sparse	Low
Gudgeon	*Gobio gobio*	These species were present in the Auckland region but all populations are now believed to have been eradicated.	
Marron	*Cherax* sp.		

Exotic freshwater fauna

There are many freshwater ecosystems within the Auckland region that contain established populations of exotic freshwater fish; indeed, some have more than five species present. Some exotic freshwater fauna (Table 28) have been in the Auckland region for over a century (e.g. rainbow trout, brown trout and brown bullhead catfish) while others were introduced in the mid to late twentieth century (e.g. rudd and orfe).

Some exotic fish species have bought benefits to the Auckland region. For example, trout are an important sport fish, while grass carp are used as biological agents to control plant and algae growths. However, several of the exotic species have adverse environmental effects.

These can include:

- → competition or predation on native species, reducing native biodiversity
- → changes to the community structure of submerged aquatic plants
- → hybridisation
- → the introduction or transmission of parasites and diseases
- → food web impacts through changes to the composition of the plankton community
- → water quality impacts and habitat degradation from devegetation or bio-perturbation.

4.3

Freshwater

Conclusions on the state of freshwater

The majority of the trends for water quality showed no change between 1995 and 2005 for forested and rural rivers but a small percentage of trends did show some improvement; particularly the decreasing nitrogen levels at several rural sites. Urban streams also showed several improving trends, particularly for decreasing levels of ammoniacal nitrogen, nutrients and turbidity.

Our freshwater and lake monitoring programmes suggest that different environmental stressors are impacting the rivers and lakes within the Auckland region.

The freshwater monitoring programmes consistently reveal the importance of land cover in the surrounding catchment on both the water quality and the ecological quality of the river. The main stressor on the rivers therefore appears to be intensive land use in the surrounding catchment.

Rivers that drain forested catchments (particularly native forest) have excellent water quality and excellent ecological quality while rivers that drain urban catchments typically have poor water quality and poor ecological quality.

There is a large variation in the water quality and ecological quality of the rivers that drain catchments. More than 60 per cent of the rivers in the Auckland region flow through rural catchments so there is scope to make dramatic and lasting improvements in the rural rivers that currently have poor water quality and ecological quality.

Many rivers also had elevated levels of *E. coli* bacteria, indicating the presence of faecal pollution. This makes them unsuitable for recreational activities. There appears to be a strong relationship between the type of land cover in the surrounding catchment and the microbiological water quality, with intensive land uses (both urban and rural) associated with higher levels of *E. coli* than forested catchments. These elevated levels of faecal pollution mean that some rural rivers are not suitable for stock to drink from.

The lake water quality programme indicated that all seven monitored lakes are enriched by nutrients to some extent, although there was no clear relationship with land use in the surrounding catchment. Invasive weeds appear to be the main threat to the ecological qualiy of the lakes.

Management of pest species is a complicated and difficult issue; this suggests that the ecological quality of the lakes and rivers is likely to remain degraded for some time. Although the presence of pest fish can impact the native fish populations, physical modifications to the rivers (such as weirs, dams and culverts) can also have a significant effect on native fish populations, because these structures prevent fish from migrating between the sea and the rivers.

The deep, confined aquifers in the region generally contain old groundwater and are relatively well protected from surface contamination and generally had good or excellent water quality. However, the shallow, unconfined groundwater systems containing younger groundwater are vulnerable to impacts from the overlying land use activities and water quality was particularly degraded in the central and southern volcanic aquifer systems. Reducing the discharge of contaminants to the ground is likely to improve the groundwater quality of vulnerable aquifers in the long-term.

In summary, our freshwater monitoring programmes show that most of the rivers, lakes and shallow unconfined aquifers in the Auckland region are degraded to some extent although the recreational water quality in the lakes is generally good with no faecal pollution. There have been welcome improvements in some aspects of the water quality of the rivers (particularly the urban streams) and many of the rural streams have the potential for dramatic improvement and recovery with suitable management.

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