Freshwater

Microbiological water quality

The suitability of water for recreational activities (such as swimming) is typically 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 27 sites in the water quality monitoring programme. These levels are compared with the red mode of the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (produced by the MfE and MOH in 2003 and shown in Table 8) and the frequency and magnitude of any exceedences are assessed.

TABLE 8 Recreational water quality thresholds based on the levels of *E. coli* bacteria. (Source: MfE and MOH).

Mode	Number of *E. coli* bacteria per 100ml water
Green mode (Acceptable)	Less than 260
Amber mode (Alert)	260 to 550
Red mode (Action)	More than 550

The suitability of water for stock drinking is assessed in a similar way. The ARC uses the same indicator bacteria but a different threshold (1000 *E. coli* per 100ml water) as described by ANZECC (1992). This measure is calculated only for the rivers with rural catchments within the monitoring programme, as these are the catchments that are likely to provide drinking water for stock. The observed levels of *E. coli* at these 13 sites are compared with the ANZECC guideline, and the frequency and magnitude of exceedences are assessed in the same way.

Indicator 4: Water quality for recreation

Site based

The Cascades and Mahurangi W.T.P sites had the best microbiological water quality of the monitored sites in 2007. Although all of the 27 monitoring sites had *E. coli* levels that exceeded the Green mode guideline at least once during 2007, the Cascades and Mahurangi W.T.P. sites exceeded the guideline on only one occasion.

All of the sites (except Cascades and Mahurangi W.T.P.) recorded at least one exceedence of the Red mode guideline during 2007 (Table 9).

In contrast, the Omaru, Otaki and Papakura sites failed to meet the Red mode guideline on every sampling occasion in 2007. The worst individual sample was from the Otara – East Tamaki site, when a level of 510,000 *E. coli* per 100ml was recorded in February 2007.

TABLE 9 Ordersites by frequency first and then magnitude, 2007. (Source: ARC).

Rank	Site name	Frequency	Magnitude
1	Cascades	0.0	0.0
2	Mahurangi W.T.P.	0.0	0.0
3	West Hoe	8.3	5.0
4	Mahurangi T. C.	8.3	5.3
5	Mahurangi Forest	8.3	65.2
6	Hoteo	25.0	17.4
7	Rangitopuni	25.0	48.4
8	Matakana	25.0	49.0
9	Pakuranga @ Guys Rd	33.3	43.4
10	Ngakaroa	41.7	65.8
11	Oteha	41.7	71.3
12	Okura	50.0	69.1
13	Kumeu	50.0	71.3
14	Pakuranga @ Greenmount	58.3	46.9
15	Waiwera	58.3	66.0
16	Lucas	58.3	69.6
17	Opanuku	66.7	65.7
18	Puhinui	75.0	60.0
19	Wairoa	75.0	63.5
20	Pakuranga @ Botany	75.0	85.1
21	Otara @ Kennel Hill	83.3	77.8
22	Oakley	83.3	79.3
23	Vaughans	83.3	86.2
24	Otara @ East Tamaki	83.3	99.3
25	Omaru	100.0	84.7
26	Papakura	100.0	96.4
27	Otaki	100.0	98.3

Land cover based

To assess the effect of the type of land cover on recreational water quality, the 27 sites in the monitoring programme were assigned to one of three land use types, based on the predominant land use type in their catchments (native and exotic forest sites were combined into the same class because of the low number of sites).

The average values for the frequency and magnitude of the exceedences of the recreational water quality guidelines were then calculated for each land use type (Table 10).

The forested sites clearly produced the best recreational water quality scores with a lower average frequency and magnitude of exceedences of the Red mode threshold. At the other end of the scale, the urban sites clearly had the greatest frequency and magnitude of exceedences while the rural sites were intermediate between the forested and urban land use categories.

TABLE 10 Frequency and magnitude of recreational water quality exceedences for all sites within a land use type. (Source: ARC).

Land cover type and number of sites	Frequency	Magnitude
Forested	5.6	23.4
Rural	46.8	54.2
Urban	72.0	74.2

Indicator 5: Drinking water quality for stock

The majority of the 13 rural sites failed to meet the ANZECC stock drinking guideline at least once during 2007. However, the two Mahurangi sites met the stock watering guideline throughout 2007 and the Hoteo site failed to meet the guideline only once.

In contrast, the Papakura site exceeded the guideline on every sampling occasion and the magnitude of the exceedences was very high (Table 11).

TABLE 11 Frequency and magnitude of exceedences of the ANZECC stock watering guideline. (Source: ARC).

Rank	Site name	Frequency	Magnitude
1	Mahurangi W.T.P	0.0	0.0
2	Mahurangi T.C.	0.0	0.0
3	Hoteo	8.3	4.8
4	Rangitopuni	16.7	30.4
5	Matakana	16.7	30.6
6	Waiwera	33.3	46.2
7	Ngakaroa	33.3	46.9
8	Kumeu	40.0	53.8
9	Wairoa	41.7	41.0
10	Okura	41.7	50.8
11	Opanuku	50.0	43.6
12	Vaughans	83.3	75.4
13	Papakura	100.0	93.5

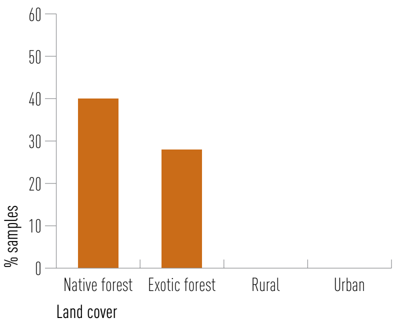
Freshwater

Ecological quality programme

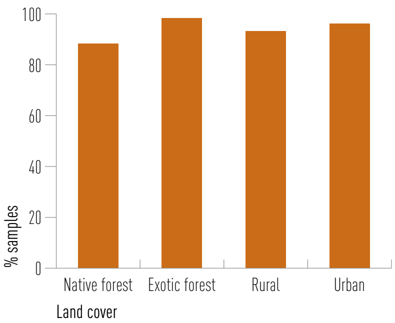
Invertebrate community monitoring programme

Many species of invertebrates (also known as macroinvertebrates), such as aquatic insects, crustaceans, snails and worms live in rivers and have been used to indicate the ecological quality of rivers since the early 1900s.

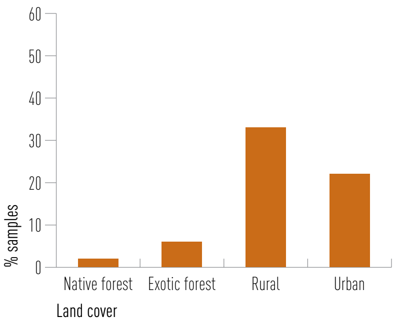
Invertebrates are suited to this role primarily because of their high abundance and diversity. Many different types of invertebrates live in the rivers and they react differently to various environmental pressures. For example, some species, such as the *Helicopsyche* caddisfly (Figure 5a) are extremely sensitive and are found only in high quality rivers while others, such as the *Potamopyrgus* snail (Figure 5b), are tolerant and can survive in a wide range of rivers. Some species, such as the *Glossiphonia* leech (Figure 5c), are found mainly in degraded rivers with rural or urban land cover.



5a
Helicopsyche caddisfly



5b
Potamopyrgus snail



5c
Glossiphonia leech

FIGURE 5 The different distribution patterns of three freshwater invertebrates, reflecting their environmental sensitivity. (Source: ARC).

This differing sensitivity means that the ARC can use the types and numbers of invertebrates found at a river as biological indicators to show the ecological quality of the river. The information generated from invertebrate sampling is often complex so it is typically summarised into an index. In New Zealand, the Macroinvertebrate Community Index (MCI) is used.

Essentially, the MCI assigns a score to each invertebrate found at a sampling site, based on its sensitivity to environmental conditions. Scores range between one (least sensitive) and 10 (most sensitive). The MCI score for a site is calculated based on the average score for all the invertebrates found at that site.

The MCI score is then interpreted into ecological quality classes using the following ranges:

→ Greater than 120 = Excellent quality

→ Between 100 and 120 = Good quality

→ Between 80 and 100 = Fair quality

→ Lower than 80 = Poor quality.

Although the ARC began an invertebrate community monitoring programme in 1999, there have been methodological developments and programme changes since then. More recently, the programme has been stable; consequently the ARC used data only from 2006, 2007 and 2008 and included only those sites that were sampled in each of these years.

This produced a dataset for 52 sites across the Auckland region (Figure 6).

Indicator 6: Ecological quality (MCI)

Site based

There was a wide range in average MCI scores (from 44.4 to 141) across the 52 sites, indicating a large variation in ecological quality at the monitoring sites (Table 12).

Sixteen sites (31 per cent) were classified as excellent on the basis of their average MCI score, 13 (25 per cent) sites as Good, 14 (27 per cent) as Fair and 9 (17 per cent) as Poor.

Most of the 16 Excellent sites were in rivers that drained from forested catchments (nine native forest and four exotic forest catchments) whereas only three were from catchments with more intensive land use types (two rural and one urban catchment).

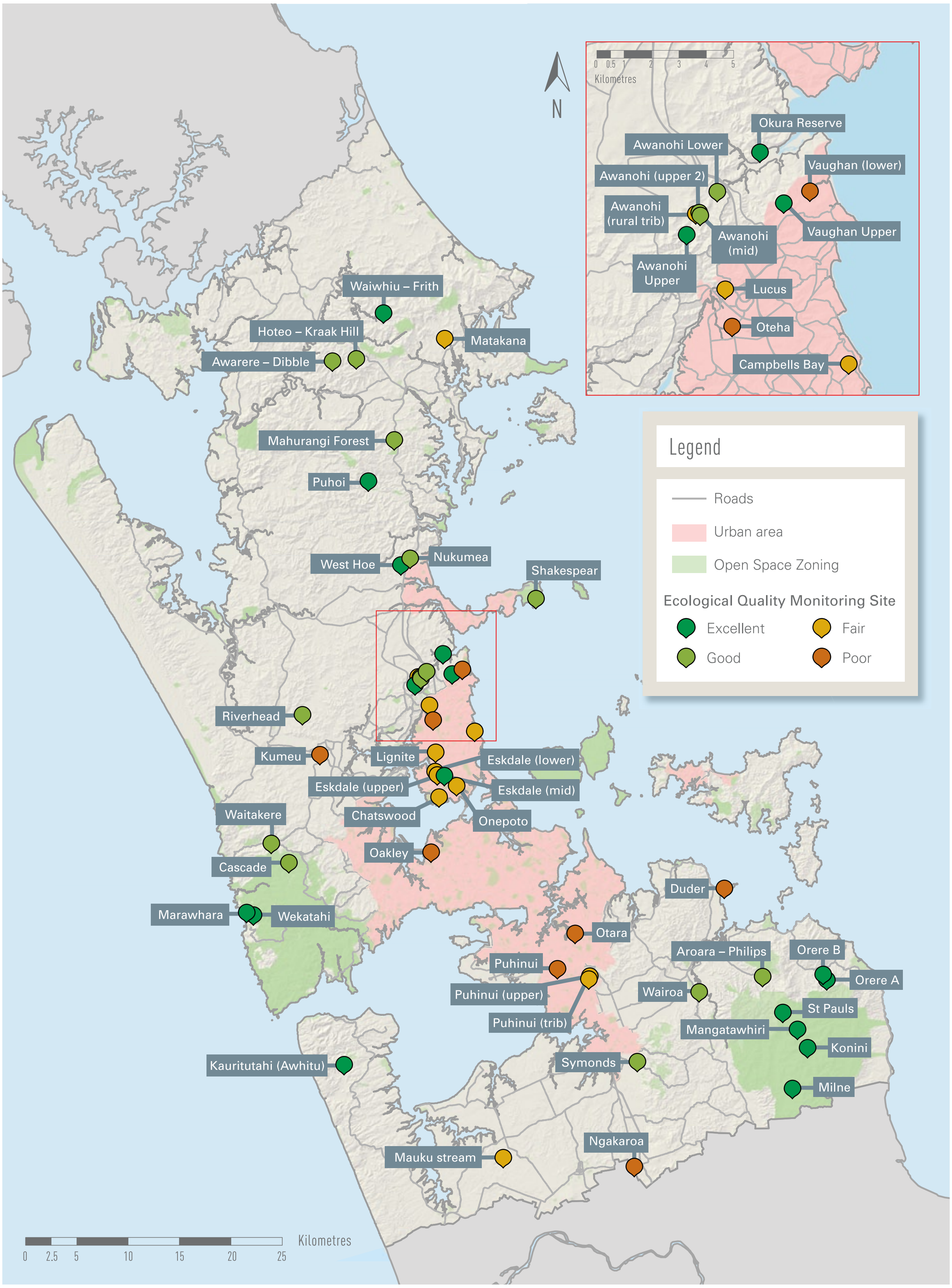


FIGURE 6 The ecological quality monitoring network and quality class. (Source: ARC).

Freshwater

TABLE 12 Individual and average MCI scores for each monitoring site sampled in 2006, 2007 and 2008 and ecological quality class based on the average MCI score. (Source: ARC).

Site	MCI score for year			Average MCI score	Ecological quality class
	2006	2007	2008		
Orere B	147.0	144.3	131.7	141.0	Excellent
Konini	137.9	140.0	132.3	136.7	Excellent
Milne	130.8	136.4	130.8	132.6	Excellent
Orere A	134.1	138.9	124.3	132.4	Excellent
Wekatahi	132.8	133.9	126.8	131.2	Excellent
Awanohi Upper	139.3	124.0	127.5	130.2	Excellent
St Pauls	133.0	132.8	123.4	129.7	Excellent
Puhoi	126.9	134.2	127.8	129.6	Excellent
Kauritutahi (Awhitu)	126.2	134.8	127.7	129.5	Excellent
Marawhara	127.3	136.8	121.0	128.4	Excellent
Mangatawhiri	130.4	121.2	127.6	126.4	Excellent
West Hoe	129.4	124.8	125.0	126.4	Excellent
Vaughan Upper	130.4	121.6	122.4	124.8	Excellent
Waiwhiu @ Frith	134.7	141.6	97.1	124.4	Excellent
Okura (reserve)	124.1	116.4	124.2	121.6	Excellent
Eskdale (upper)	132.0	119.1	109.1	120.1	Excellent
Awanohi (mid)	120.1	100.0	117.7	112.6	Good
Mahurangi Forest	117.0	114.7	105.5	112.4	Good
Riverhead	108.0	116.1	104.5	109.5	Good
Waitakere	122.1	103.1	101.8	109.0	Good
Awanohi (upper 2)	103.0	111.4	111.8	108.7	Good
Awarere @ Dibble	104.9	111.5	106.6	107.7	Good
Cascades	103.3	105.6	105.4	104.8	Good
Wairoa	107.5	106.2	98.2	104.0	Good
Aroara	92.7	112.8	104.1	103.2	Good

Contd...

TABLE 12 continued Individual and average MCI scores for each monitoring site sampled in 2006, 2007 and 2008 and ecological quality class based on the average MCI score. (Source: ARC).

Site	MCI score for year			Average MCI score	Ecological quality class
	2006	2007	2008		
Shakespear	86.6	115.5	103.9	102.0	Good
Symonds	95.2	100.7	108.4	101.4	Good
Hoteo @ Kraak Hill	106.3	92.5	104.1	101.0	Good
Awanohi Lower	94.3	112.5	95.5	100.7	Good
Puhinui (upper)	97.5	94.4	96.7	96.2	Fair
Matakana	95.5	94.3	92.6	94.1	Fair
Onepoto	92.7	95.3	89.3	92.4	Fair
Opanuku	83.3	104.8	84.0	90.7	Fair
Eskdale (mid)	89.8	90.0	85.6	88.5	Fair
Awanohi (rural tributary)	92.9	84.7	87.8	88.5	Fair
Lignite	84.6	91.3	86.4	87.4	Fair
Lucus	93.4	76.4	88.0	85.9	Fair
Mauku stream	71.2	97.1	86.0	84.8	Fair
Campbells Bay	71.3	84.0	89.5	81.6	Fair
Eskdale (lower)	82.9	73.6	87.6	81.4	Fair
Chatswood	78.0	86.2	78.6	80.9	Fair
Duder	75.2	74.5	84.4	78.0	Poor
Ngakaroa	83.8	53.3	67.9	68.3	Poor
Kumeu	70.8	64.7	62.4	65.9	Poor
Oakley	54.3	58.9	64.5	59.2	Poor
Oteha	54.4	63.9	55.9	58.1	Poor
Papakura	59.1	52.9	60.1	57.4	Poor
Vaughan (lower)	51.2	50.0	65.7	55.6	Poor
Otara	47.3	47.5	59.2	51.3	Poor
Puhinui	51.6	32.7	48.9	44.4	Poor

4.3

Freshwater

Land cover based

To assess the effect of land cover on the ecological quality of the river, each of the 52 sites in the invertebrate monitoring programme were assigned to one of the four catchment land cover types (native forest, exotic forest, rural and urban) on the basis of the predominant land cover in their catchments. The average MCI score was then calculated for all sites in each land cover type (Table 13).

The native forest sites clearly produced the best average MCI score indicating Excellent ecological quality, followed by the exotic forest sites which produced an average score indicating Good ecological quality. In contrast, the urban sites produced the lowest average MCI scores indicating Poor ecological quality at these sites. The rural sites were intermediate between the urban and exotic forest sites.

TABLE 13 Average MCI score for all sites within a land cover type with indicative MCI quality class. (Source: ARC).

Land cover type and number of sites	Average MCI	MCI quality class
Native forest (11)	124.5	Excellent
Exotic forest (8)	119.8	Good
Rural (19)	95.2	Fair
Urban (14)	77.6	Poor

This finding was reinforced when the percentage of sites in each MCI quality class were stratified by land cover type within the catchment (Table 14). All of the sites draining forested catchments (native and exotic forest) produced average MCI scores indicating excellent or good ecological quality while all but one of the urban sites produced average MCI scores indicating either fair or poor ecological quality.

However, the average MCI scores indicated a wide range of ecological quality at rural sites, with scores ranging from 55.6 to 130.2. The wide range of average MCI scores at rural sites, in comparison with the other land cover types, can be seen in Figure 7.

TABLE 14 Percentage of sites in each MCI quality class by land cover type. (Source: ARC).

Land cover type and number of sites	Excellent	Good	Fair	Poor
Native forest (11)	82	18	0	0
Exotic forest (8)	50	50	0	0
Rural (19)	11	42	26	21
Urban (14)	7	0	57	36

There was a strong relationship between the ecological quality of a river measured using invertebrates and the type of land cover in the surrounding catchment. Rivers with intensive (urban and rural) land cover were associated with lower ecological quality (as measured with MCI scores) than those with forested catchments. Overall, urban rivers had the lowest ecological quality.

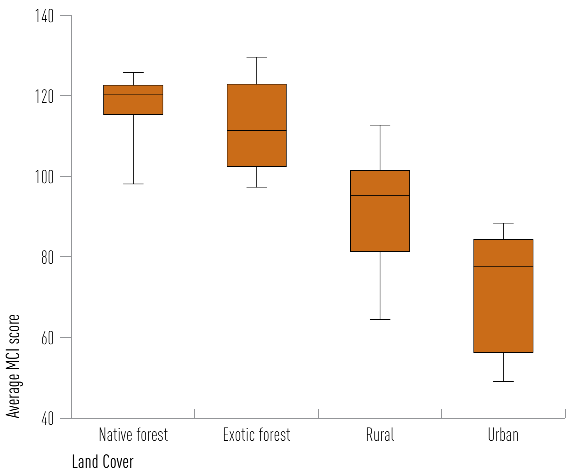


FIGURE 7 Box plots showing the variation of MCI scores for each land use type (line = average, box = 25th to 75th percentiles, whiskers = 5th and 95th percentiles). (Source: ARC).

Native fish programme

The rivers of the Auckland region are home to seventeen species of native fish (Table 15). These include common species that are familiar to many people, such as longfin and shortfin eels, as well as rare and threatened species such as the black mudfish and dwarf inanga. Most native fish are small, well camouflaged and nocturnal, with the result that they are seldom seen and therefore unfamiliar to many people.

TABLE 15 Native fish species in the Auckland region. (Source: NZFFD).

Common name	Scientific name	Frequency of occurrence (% of sites)	Distribution
Banded kokopu	*Galaxias fasciatus*	39	Widespread
Shortfin eel	*Anguilla australis*	37	Widespread
Longfin eel	*Anguilla dieffenbachii*	33	Widespread
Common bully	*Gobiomorphus cotidianus*	20	Frequent
Inanga	*Galaxias maculatus*	17	Frequent
Redfin bully	*Gobiomorphus huttoni*	13	Frequent
Cran's bully	*Gobiomorphus basalis*	10	Frequent
Giant bully	*Gobiomorphus gobioides*	3	Sparse
Common smelt	*Retropinna retropinna*	2	Sparse
Torrentfish	*Cheimarrichthys fosteri*	2	Sparse
Koaro	*Galaxias brevipinnis*	1	Rare
Giant kokopu	*Galaxias argenteus*	1	Rare
Dwarf inanga	*Galaxias gracilis*	<1	Rare
Black mudfish	*Neochanna diversus*	<1	Rare
Bluegill bully	*Gobiomorphus hubbsi*	<1	Rare
Shortjaw kokopu	*Galaxias postvectis*	<1	Rare
Lamprey	*Geotria australis*	<1	Rare

Five fish species collectively make up the whitebait fishery: these are the giant kokopu, banded kokopu, shortjaw kokopu, koaro and inanga. These all belong to the *Galaxiidae* family.

Most native fish species are diadromous, meaning that they need to migrate between freshwater systems and the sea to complete their life cycle. This requirement can increase their vulnerability to human-induced environmental pressures, particularly barriers to migration such as weirs, dams and culverts. If these are poorly designed, they can exclude native fish from large areas of freshwater habitat (Figure 8).

FIGURE 8 Example of a perched culvert, a common barrier to fish passage. Native fish are unable to leap the vertical distance required to enter the culvert and continue migrating upstream. (Source: ARC).

Freshwater

Although the ARC does not currently operate a comprehensive fish monitoring programme across the Auckland region, a large amount of information is available from the New Zealand Freshwater Fish Database (NZFFD). This national repository, administered by NIWA, contains more than 28,000 site records nationwide, with over 2000 individual records from the Auckland region. By analysing these records the ARC can gain an understanding of the frequency of occurrence and distribution of native fish species within the Auckland region.

Due to the need to migrate between the marine and freshwater environments, the two overriding natural environmental factors that influence the distribution of most native fish populations are elevation and the distance from the coast. This means that a greater number of native fish species are expected at sites close to the coast and at low elevations, when compared to sites that are found further inland and at higher altitudes.

The Quantile Index of Biotic Integrity (QIBI) is a tool that enables the ARC to assign a score to a site based upon the fish species found there. The QIBI predicts which fish species should be present at a site – based on its elevation and distance from the coast – and compares this prediction with the fish species actually found there. QIBI scores range from 0 (no native fish found) to 60 (the full range of species predicted for that site were present).

The QIBI score can be interpreted into ecological quality classes associated with the following ranges:

- 49 to 60 = Excellent quality
- 37 to 48 = Good quality
- 25 to 36 = Fair quality
- 1 to 24 = Poor quality
- 0 = No native fish present.

The QIBI is a powerful tool for comparing the effects of factors such as the type of land cover on fish populations. It allows comparisons to be made between sites and provides a basis for management decisions aimed at conserving and enhancing the native fish populations.

A limitation of the QIBI is its inability to specifically identify the influence of fish passage barriers (both natural and man-made) from other factors that may influence the distribution of fish species at some sites. For example, a site might have a low QIBI score due to a weir or large waterfall downstream, despite having high habitat and water quality values. Therefore, site-specific factors have to be taken into account when interpreting individual scores.

Indicator 7: Ecological quality for native fish

To investigate the effects of land cover on native fish populations within the Auckland region the QIBI model was used to analyse data from Auckland sites in the NZFFD. The sites were stratified into four land cover types (urban, pasture, exotic forest and native forest) using the REC scheme described in the Introduction to rivers. The average QIBI score was then calculated for all sites in each land cover type.

The native forest sites had the highest average QIBI score, indicating Good habitat quality, while the urban sites had the lowest, indicating Fair habitat quality (Table 16).

TABLE 16 Average QIBI score for all sites within a land cover type with indicative quality class. (Source: ARC).

Land cover type and number of sites	Average QIBI score	Quality class
Native (362)	39.1	Good
Exotic forest (78)	33.7	Fair
Pasture (955)	30.9	Fair
Urban (669)	28.6	Fair

Figure 9 shows that the urban sites had significantly lower QIBI scores than all other categories, while native sites scored significantly higher than the other types of land cover. There was no significant difference between the pasture and exotic forest land cover types, but their scores were significantly lower than native and higher than urban. This indicates that the native sites (which are subject to less human pressures) have fish communities that are less impacted than those at other types of site.

This finding is supported when the percentage of sites in each QIBI quality class are compared across the REC land cover categories (Table 17). Sites in catchments covered by native vegetation have a higher percentage of Excellent scores and a lower percentage of Poor and No native fish scores than sites in the other three categories. In contrast, urban sites have the lowest percentage of scores indicating Excellent habitat quality and the highest percentage of sites containing no native fish.

TABLE 17 Percentage of sites in each QIBI quality class, by land cover type. (Source: ARC).

Land cover type and number of sites	Excellent	Good	Fair	Poor	No native fish
Native (362)	23	36	27	6	7
Exotic forest (78)	8	38	32	8	14
Pasture (955)	7	28	34	18	13
Urban (669)	4	25	35	20	15

The low QIBI scores for the pasture and urban sites may be partially attributable to the higher numbers of man-made barriers to fish passage such as culverts, weirs and dams that are likely to be present in these catchments.

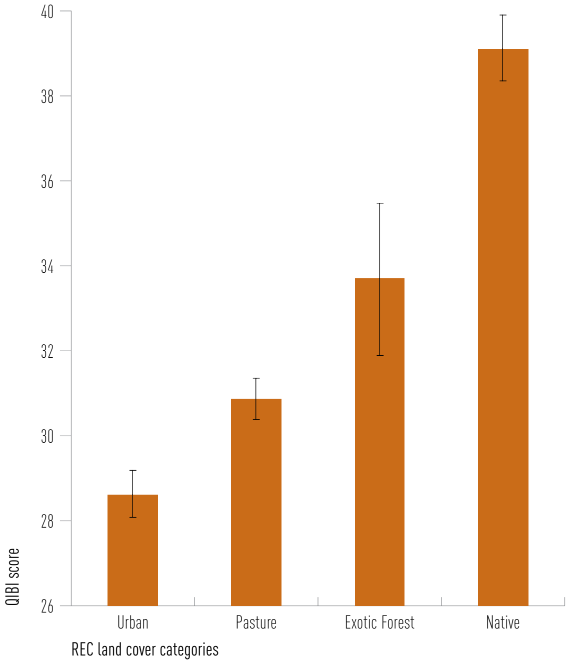


FIGURE 9 Average QIBI scores (± 1 standard error) for 2064 sites in the Auckland region, stratified by land cover type in the surrounding catchment. (Source: ARC).

Implications of river quality

The results from the ARC's freshwater monitoring programmes consistently emphasise the importance of the land cover type in the surrounding catchment on both the water quality and ecological quality of the river.

Rivers draining forested catchments (particularly native forest) have Excellent water quality and Excellent ecological quality. In contrast, rivers draining urban catchments typically have Poor water quality and Poor ecological quality. These findings indicate that the life supporting capacity of urban and rural rivers is impaired. These river systems are impacted by the type of land cover in their catchments and typically do not support diverse populations of native invertebrates and fish.

There was a statistically significant correlation between the ecological quality and the water quality at the 16 sites that were common to both monitoring programmes. This correlation shows that sites with poor water quality also have poor ecological quality, while good water quality is linked with good ecological quality (Figure 10). However, this does not necessarily demonstrate a causal relationship between water quality and ecological quality, since both could be responding to the same environmental pressure, such as land use type.

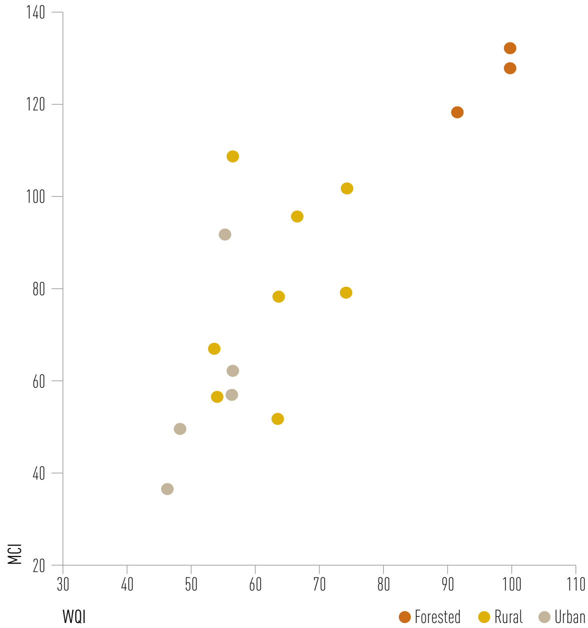


FIGURE 10 The relationship between ecological quality and water quality at the 16 sites common to both monitoring programmes. (Source: ARC).

Overall, the monitoring sites in urban catchments had the lowest water quality. This finding is similar to the results from the national river water quality monitoring network, which concluded that urban rivers had lower water quality than rivers with rural or forested catchments for almost all of the water quality parameters.

However, an analysis of trends for the Auckland region between 1995 and 2005 indicated that, for most parameters at most sites, the water quality was either stable or improving. These findings are a very positive development for the rivers in the Auckland region, which had some of the worst water quality in the country. It is clear that there has been a considerable improvement in water quality, particularly in the urban streams. The causes of these improving trends are difficult to identify, but it is likely that improvements in water management within the urban areas have helped.

Although only a few of the rivers within the Auckland region are used for recreation, our microbiological water quality monitoring programme showed elevated levels of *E. coli* bacteria in many of the rivers, indicating the presence of faecal pollution. Again, there was a strong relationship between the type of land cover in the surrounding catchment and the microbiological water quality. Intensive (urban and rural) land cover types were associated with higher levels of *E. coli* than forested catchments. Overall, sites in urban catchments exceeded the guidelines the most frequently, and by greater magnitudes. In addition, the assessment of rural rivers against the ANZECC stock drinking guideline showed that most rural rivers exceeded this guideline at least once during 2007. This means that some rural rivers may not be suitable sources of drinking water for stock because of elevated levels of faecal pollution.

4.3

Freshwater

Another notable finding was the large variation in the water quality and ecological quality at different rural sites. This raises questions around the land management of rural catchments. For example, rural sites in our monitoring programmes ranged from unfenced rivers with degraded riparian vegetation (the trees and shrubs that grow alongside a river) to rivers with riparian fencing and riparian buffers of native woody vegetation (Box 12, Chapter 4.6, pg 239).

Lakes

Key findings

- → The Auckland region has 72 lakes, most of which are small in a national context.
- → The water quality of the monitored lakes was generally degraded, due principally to nutrient enrichment, but the microbiological lake water quality was good when compared with national guidelines for recreation. There was no clear trend for changes in lake water quality (some lakes had improved, some had got worse and some had not changed).
- → The ARC's ecological monitoring programmes showed that the ecology of the lakes was impaired, with exotic species considered to be the main cause of environmental stressor.

Introduction

There are 72 natural and artificial lakes that are larger than one hectare in the Auckland region. These range in size from small farm ponds to the largest water supply reservoir behind the Mangatangi Dam in the Hunua Ranges. On a national scale, the lakes are small and shallow; there are no large deep lakes in the Auckland region.

Lakes can be classified according to how they were formed. Natural lakes in the Auckland region are usually dune lakes although one, Lake Pupuke, has a volcanic origin (Box 4). Dune lakes have one common feature – a barrier of sand that blocked the stream valleys to form a dammed valley lake, e.g. Lakes Ototoa and Wainamu. The water supply reservoirs are usually found in flooded valleys behind artificial dams in the Waitakere Ranges and the Hunua Ranges.

The ARC routinely monitor the water quality, ecological quality, and microbiological quality of seven natural lakes within the Auckland region. The surrounding catchments have different types of land cover and this can affect the water quality, habitat quality and the water level of the lake. Two of the lakes (Ototoa and Wainamu) have predominantly forested catchments, four of the lakes (Kereta, Kuwakatai, Spectacle and Tomorata) are in predominantly rural catchments and one lake (Pupuke) is in an urban catchment.

Note: The RMA defines a 'lake' as a body of freshwater which is entirely or nearly surrounded by land. The term 'lake' is used in this chapter consistent with this definition.

Box 4 Lake Pupuke – an explosive beginning

Lake Pupuke is located between Takapuna and Milford on the North Shore. It is Auckland's only freshwater volcanic lake.

It formed about 150,000 years ago after volcanic activity left a crater that later filled with freshwater. It covers 110 hectares and has a maximum depth of about 60 metres.

Lake was used as a source of drinking water for much of the North Shore between 1894 and 1944, until a new drinking water supply was sourced from the Waitakere Ranges.

Lake Pupuke is now used extensively for recreation, with a wide range of water sport activities occurring on the lake.

The water quality of the lake is usually good, although the ecology is affected by the numerous exotic fish and plant species found in the lake.